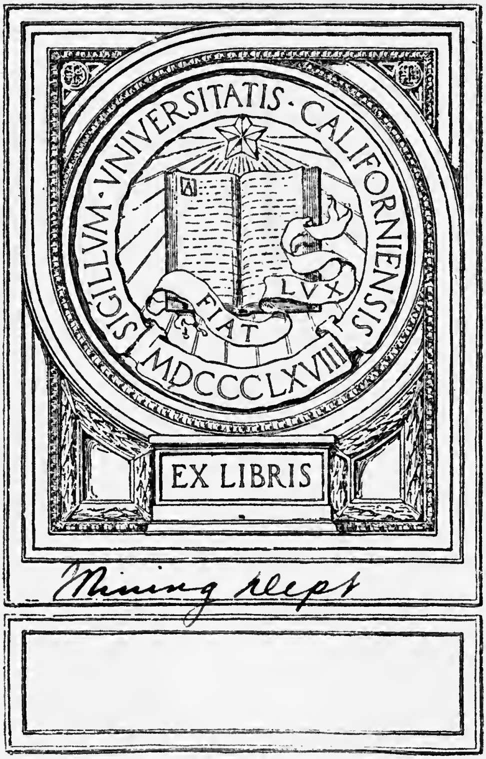
THE
BASIC OPEN-HEARTH
STEEL PROCESS



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BY

CARL DICHMANN

TRANSLATED BY

ALLEYNE REYNOLDS

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AUTHOR'S PREFACE

During more than twenty years' practical experience in open-hearth furnace management, I have frequently been faced with problems to which I was unable to find satisfactory solutions. A pause in such practical activity has enabled me to investigate these questions as a whole, and in this connection I have taken advantage of all available literature on the subject which was at my disposal. The gaps remaining I have endeavoured to fill in to the best of my ability.

This was the origin of my book, and in now giving it to the public, I do so on the plea that the literature relating to the open-hearth process is very meagre, in spite of the daily increasing importance of the process, and because I hope to enlist further workers in clearing up the abstruse problems involved.

My guiding principle has been to ascertain the conditions which admitted of the complete utilisation of all raw materials in the best possible way.

I have devoted special attention to the quantitative side of the subject, since procedure can only be completely known or controlled provided the effect of all determining factors can be quantitatively estimated.

Naturally, in consequence of this, the necessity arose of making numerous calculations, such as could be carried out by the most elementary means at my disposal.

In the course of my experience, I have felt the want of knowledge of the conditions governing the complete utilisation of fuel, and hence I devoted myself initially to the theory of gas producer working. The results arrived at appeared to me worthy of attention, although I was not so placed as to test all my conclusions by experiments of my own.

The details of the calculations may appear, many of them, too extended and elementary; nevertheless, I have given them in full in order to enable one to check one's position should one's recollection fail, as might easily occur owing to so many values coming into consideration.

All formulæ arrived at are, moreover (in so far as they have general validity), assembled in the Appendix, so that one is not obliged to seek them in the text.

My papers published in "Stahl und Eisen" in 1905, on working molten pig iron in basic lined open-hearth furnaces, have served as a basis, which I have elaborated.

In so doing, it appeared to me necessary to make certain allowances in the calculations of the amount of iron peroxide required for the removal of the reducing agents, and to take into consideration those amounts of ferrous oxide which remain in the slag, and which must be produced owing to the action of the individual reducing agents. As a consequence, the figures for the iron peroxide required for eliminating silicon have been increased, but for carbon decreased; whilst conversely the growth of charge due to silicon appears less, and that due to carbon appears larger than in the papers mentioned.

I am largely indebted to two instructive books, the first part of "Leitfadens zur Eisenhuttekunde," *i.e.*, "Feuerungskunde," by Th. Beckert, which by its references and its tables of the values of specific heats of gases at various temperatures rendered it possible for me to calculate the temperatures of reaction: and Campbell's "Manufacture of Iron and Steel," which suggested many new points of view.

To these gentlemen, as well as many others whose names are mentioned in the text, I tender my most grateful thanks.

(Signed) Carl Dichmann.

Riga,
November, 1909.

TRANSLATOR'S PREFACE

Soon after the publication of Mr. Dichmann's treatise in Germany, one of my most intimate and able friends, who is engaged in one of the largest Continental steel works, sent me a copy. At the outset, I recognised in it a book which filled many serious gaps in the literature of an important subject, viz.: the manufacture of steel by the basic process. Having myself found the book very valuable, I thought it desirable that it should be published in the English language.

After mature consideration, I resolved to confine myself in making my translation to the removal of any existing inaccuracies in the text, while otherwise rendering as literal a translation as the differences in the genius of the two languages would permit.

I beg to endorse the author's hope that this work will stimulate others into efforts to collect and co-ordinate the large amount of knowledge which actually exists in relation to the subject, but being distributed in many journals, published in various languages, is in a form which is not generally available, especially to busy works' managers and others engaged practically in the steel-making industry.

It is only by careful collation of the investigations of the various workers in the subject that a correct appreciation of the problems involved can be arrived at, and the way to further advances thereby prepared.

Alleyne Reynolds.

Birkbeck Bank Chambers,
Holborn, London, W.C.
November 28th, 1910.

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ABBREVIATIONS.

St. und E. for Stahl und Eisen.
I. & S. I. ,, Iron and Steel Institute.

THE BASIC OPEN-HEARTH STEEL PROCESS

CHAPTER I

INTRODUCTION

All metallurgical processes depend on chemical reactions, which are very simple in themselves. But the understanding of these is rendered difficult owing to their being reciprocal, and to conditions nearly always arising which permit these reactions to take place readily, first in one and then in the opposite direction. Only recently the grounds for this have begun to be traced out, and thereby yield explanations of many phenomena which formerly were obscure.

Steel and ingot iron generally contain 99 per cent. or more iron, and 1 per cent. or less of different admixtures, of which again the chief amount is formed from elements, the presence of which is necessary, in order to impart desired properties to the metal. The production of such high percentage iron direct from the ore has not hitherto been possible, the first product being more often a metal containing 4 per cent. or more of admixtures, such metal being termed pig iron.

In order to convert pig iron into steel the excess of foreign constituents must be removed, which is achieved by oxidising them, for which one may employ atmospheric oxygen or that of oxygen compounds.

The manufacture of steel in bulk nowadays is mainly by means of two methods: pneumatic refining, *i.e.*, Bessemer process; and open-hearth furnace refining, *i.e.*, in the open-hearth or Siemens furnace. By each method steel is obtained in the molten state, and is then cast into ingots, which are afterwards shaped by means of rolling or forging according to the desires of consumers.

The action of oxygen on the foreign constituents in the iron only takes place at high temperatures, and the degree of fluidity of the steel required to give a smooth casting involves it being heated to nearly 1,600°.[1] In steel manufacture it is therefore a paramount consideration to have considerable amounts of highly intense heat at disposal.

In both typical forms of pneumatic refinement the acid and the basic Bessemer processes, the vessel employed, *i.e.*, the converter, derives a great portion of the necessary heat from other apparatuses. The raw material, pig iron, which is supplied from the blast furnace, the cupola, or the reverberatory furnace in a molten state, is already at a temperature of at least 1,250°, which suffices for beginning of the reaction. After the introduction of the molten iron into the converter, air is blown through, the oxygen of which attacks the foreign constituents. By their elimination the melting point of the metal is raised, and thereby creates a heat requirement which must be supplied. This can be overcome by selecting for working such classes of pig iron as contain materials which, by their oxidation or burning out by means of cold air, evolve great amounts of heat. The latter proviso is only essentially fulfilled by two materials, namely, silicon and phosphorus; both are found in all pig irons, but in different amounts.

The oxidation of the silicon and phosphorus in pig iron proceeds under quite settled conditions, which involve that, in the acid converter only the silicon, in the basic, in the main, only the phosphorus are available as sources of heat. Therefore one is extremely limited in the selection of the materials which provide the heat. Over and above this one must employ so great an amount of the respective materials that their content of energy suffices to supply the total energy requirement, which, owing to the raising of the melting point of the metal on the one hand, and owing to the rapidly

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[1] Throughout temperatures are given in degrees centigrade and the metric system of weights and measures is employed in this book.

appearing heat losses on the other hand, is demanded. On these grounds, charges for pneumatic refinement require quite definite composition which permits only of variations within very narrow limits.

There are many qualities of pig iron which do not fulfil the conditions required in raw material for the pneumatic refining processes, and further, there are large amounts of so-called "old materials"—that is to say, scrap, of the most varied origin—the re-employment of which is desirable and the composition of which is not suitable for treatment in the converter. A process which will admit of the employment of such materials can only be conducted in an apparatus capable of supplying the necessary heat energy, without being dependent on the aid of the materials composing the charge. It requires a furnace which admits of the attainment of the highest temperatures, and thus the industry was dependent on the discovery of the regenerative gas-firing system.

As the name implies, the fuel must be supplied to such furnaces in the form of gas; thereby only is one able to completely control the firing—that is to say, at all moments able to regulate the supply of hot gas and air for combustion, and thereby generate exactly as much heat as is necessary for the purpose required.

In Nature combustible gases only occur in a few places. Natural combustible materials are found generally in the solid state, and must be artificially converted into the form of gas. This is performed in gas producers or generators, from which the gas is conducted through gas flues to the proper furnaces.

The temperatures which can be attained by the combustion of such gases with cold air are much under the height which is required for steel production. By means of preheating the air for combustion, in some cases also the gas, the temperature is able to be rapidly raised, and, therefore, as pointed out by H. H. Campbell in his treatise on "The Manufacture of Iron and Steel," "The problem in an open-hearth melting furnace is not to *reach* the desired temperature, but to *control* the temperature and prevent the roof and walls from melting down."

The preheating before mentioned is brought about expediently by means of utilising the waste heat of the issuing gases, a portion of which is in this way returned, and would have been otherwise irrecoverably lost.

The process of regeneration is divided into two portions. First of all, the issuing gases are deprived of their surplus heat by means of being passed through chambers or regenerators, built of refractory material, and fitted with a checker work of the same material, which forms small passages. This checker work is heated by the outgoing gases, which latter are correspondingly cooled down. Finally, an equilibrium is established between the temperature of the outlet gases and that of the checker work, for each portion of the chambers.

In order to return to the furnace the heat taken up by the checker work the second portion of the operation is carried out. The current of the outlet gases is stopped and diverted to the other (cold) chambers, whilst the gas and air currents are passed through the preheated chambers and are drawn into the furnace for combustion. In order that the operation described can proceed regularly the chambers must be arranged in corresponding numbers. The change of the current of gas is brought about by special reversing devices which are operated in the appointed intermediate space. Owing to this the whole furnace system is brought completely into a stable condition and is self-contained.

The gas and air are in a strongly-preheated condition as they enter the combustion chamber of the furnace and unite to form the flame. The latter plays against the surface of the charge, and thus the free energy of the flame is applied in the most direct manner for efficient melting. The transference of the heat to the charge in the open-hearth furnace is thus from the upper surface, and as the hotter portions of the bath are lighter, and therefore swim on the surface, so the heat is only transferable to the colder portions by conduction so long as the metal remains quiescent. Equal heating of the entire charge of metal is, therefore, the slower, the deeper the bath; but if a condition of the bath is established in which cold portions are brought to the upper surface, and therefore in

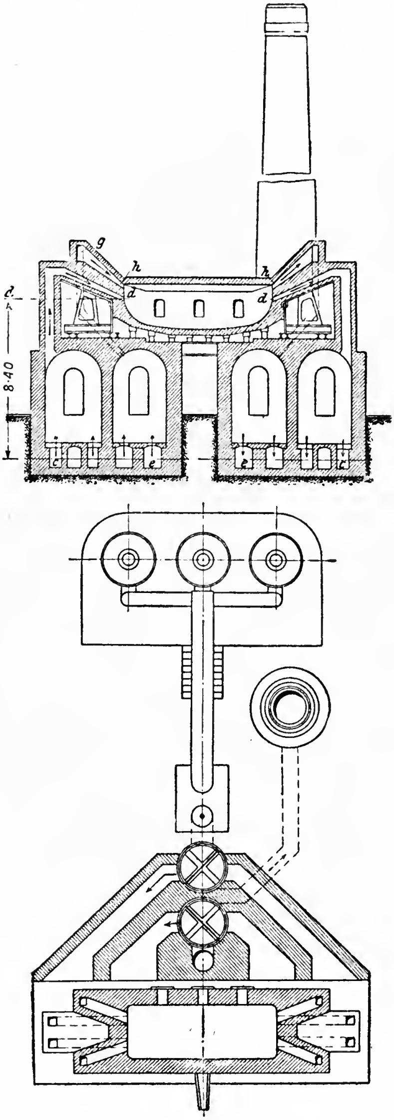

FIG. 1A.

direct contact with the flame, the transference of heat improves, and consequently economy of fuel ensues.

The products of combustion, the waste gases, are drawn from the combustion chamber into the before-mentioned regenerator chambers, and from these, still retaining a considerable amount of heat, through the chimney into the atmosphere.

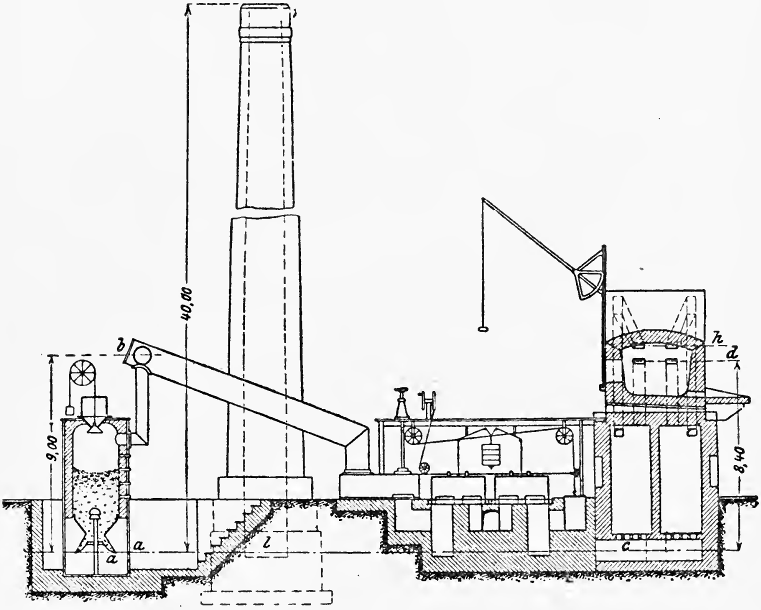

FIG. 1B.

The usual arrangement of the essential portions of an open-hearth furnace plant—namely the producers, the gas flues, the reversing valves, the regenerator chambers, combustion chamber, and the chimney—are indicated in the accompanying drawings (see Figs. 1A and 1B).

CHAPTER II

PHYSICAL CONDITIONS IN AN OPEN-HEARTH FURNACE SYSTEM—BUOYANCY

If one considers the entire system as filled with air of the usual temperature and connected with the atmosphere at the points *a* and *m* (*vide* Figs. 1A and 1B), so that atmospheric pressure will obtain throughout, the contents will be in quiescence; but if individual portions of the furnace system are filled with gases which are lighter than the air, so will the equilibrium be destroyed. A want of balance can be established owing to the different composition of the air and of the gas, through the heating of these, or from both causes. As, however, the gas in the furnace system will be lighter than that of the surrounding atmosphere, so must a buoyancy result, the amount of which can be calculated in the following manner:—

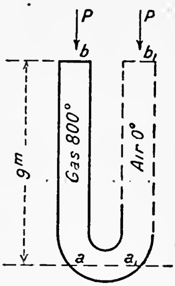

Fig. 2.

If one takes as an example that the producers and the gas flues are filled with gas at a mean temperature of 800°, one finds from the formula

$$V_t = V_o (1 + \alpha t)$$
$$V_t = 1 (1 + 0{\cdot}00367 \times 800)$$
$$V_t = 3{\cdot}936$$

that, by heating to the height given, the volume of 1 cubic metre of gas is increased to 3·936 cubic metres. Under normal conditions, the gas at a temperature of 0°, and under a pressure of 760 mm. of mercury, has a weight of 1·18 kilogramme per cubic metre, the weight of the same gas at 800° $= \frac{1{\cdot}18}{3{\cdot}936} =$ about 0·3 kilogramme.

One can compare the portion (*ab*) in Fig. 2—that is to say, the producer and gas conduit at its highest point (b)—to an arm of a U tube, which is filled with gas of 0·3 kilogramme per cubic metre, whilst the other equally tall arm contains air at the ordinary temperature. The arrangement is sketched in Fig. 2. The length of the arms of the U tube—that is to say, the height from the fire to the highest point b, the centre of the gas conduit—is 9 metres, and the arm (ab) which contains the gas, is closed at (b) by an elastic medium; whilst the arm (a_1b_1), filled with cold air, is open at the top, whilst at (b) and (b_1) the same pressure of air (p) is at work.

There is then the pressure which is exercised on an area of 1 square metre at (a_1) on the column of air (a_1b_1), equal to (p) + weight of 9 cubic metres of air; and as 1 cubic metre of air weighs 1·2937 kilogramme one obtains—

Kilogrammes
Pressure at $(a_1) = p + 9 \times 1{\cdot}2937 = p + 11{\cdot}64$
Pressure at $(a) = p +$ weight of
the gas column (ab)
$= p + 9{\cdot}0 \times 0{\cdot}3$ kg. $= p + 2{\cdot}7$
Difference of pressure 8·94

This difference of pressure is termed buoyancy. In the above case a value of 8·9 kilogrammes per square metre has been arrived at, which, as 1 cubic metre of water weighs 1,000 kilogrammes, is equivalent to the pressure of a column of water 8·9 millimetres in height. In consequence of the buoyancy of the gas in question, when a connection with the outer air is produced at (b), a movement of the gas results and air streams into the tube as fast as the gas contained in (ab) can stream out.

The gas is conducted to the open-hearth furnaces from the producers by means of conduits, by which it is passed downwards to the regenerator chambers, therein rising again to the ports, and during the entire way undergoing changes of temperature. One may regard the course of the gas as occurring in a system of communicating tubes, and if one knows the relative heights of the individual arms of the tubes and also the mean temperatures ruling therein, one can calculate the buoyancy of the gas at which it is forced upon its entrance into the furnace proper, *i.e.*, combustion chamber.

The following are the calculations for the relative heights given in the drawings :—

1. For the gas } in the ports at the entrance end.
2. For the air }
3. For the waste gases in the chimney.

1. Buoyancy of the Gas.

The vertical distance of the fire hearth of the producer below the middle of the highest portion of the gas conduit and the mean temperature of this portion are taken, as before, as being 9 metres and 800° respectively. The difference of height between the before-mentioned portion of the gas conduit and the inlet at the bottom of the regenerator chamber is also 9 metres, but the mean temperature at this portion is taken at 550°. The gas ports are arranged 8·4 metres above the inlet to the gas chamber, and the gas therein is assumed to be raised from 550° to 1,200°, its mean temperature being 900°.

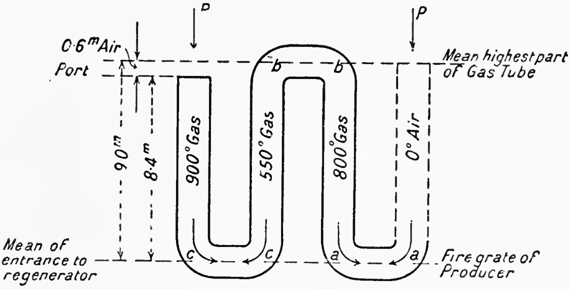

Fig. 3.

One can, therefore, regard the course of the gases as being as sketched in Fig. 3.

In this sketch (a_1) and (b_1) and (ab) as before, correspond to the producer and the gas conduit up to its highest point, (bc) to the gas conduit and flues to the regenerator chamber, and (cd) to the gas passage through the regenerator chamber up to the gas ports.

The volumes and the corresponding weight of a cubic metre of the gas are at mean temperatures :—

In column (ab) 800°=3·936 times volume, corresponding to 0·3 kilogramme per cubic metre.
" " (bc) 550°=3·01 times volume, corresponding to 0·388 kilogramme per cubic metre.
" " (cd) 900°=4·3 times volume, corresponding to 0·273 kilogramme per cubic metre.

The weights of the individual gas columns are :—

	Kg.	Kg.
In (a_1b_1) Air $p+9\times1{\cdot}2937=p+11{\cdot}64$ kilogrammes, operating in the sketch from right to left, attaining therefore a positive sign . .	$+p+11{\cdot}64$	
In (ab) Gas $9\times0{\cdot}3=2{\cdot}7$ kilogrammes, working in the sketch from left to right, as against the before-mentioned pressure, and therefore carries the negative sign .		$-2{\cdot}7$
In (bc) Gas $9\times0{\cdot}388=3{\cdot}49$ kilogrammes, working in the sketch from right to left, therefore . . .	$+$ 3·49	
In (cd) Gas $8{\cdot}4\times0{\cdot}273=2{\cdot}28$ Air $0{\cdot}6\times1{\cdot}2937=0{\cdot}78+p$		
Total weight $3{\cdot}06+p$ works in the sketch from left to right, therefore .		$-3{\cdot}06-p$
Total of the weights .	$+p+15{\cdot}13$	$-5{\cdot}76-p$

Or 15·13−5·76=9·37 kilogrammes for the square metre, or 9·37 millimetres height of water, buoyancy in the gas port.

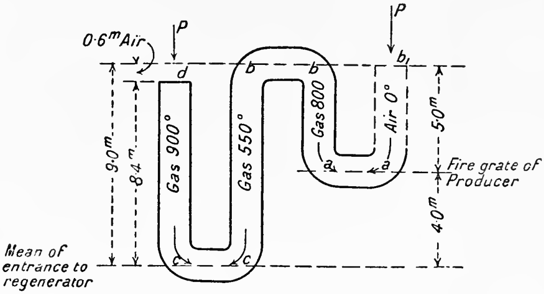

FIG. 4.

If one places the producers higher, as in many new plants —for example, 4 metres higher—whilst the other remaining conditions are as before, the natural buoyancy is altered as follows:—

The weights of the individual gas columns are as under:—

				Kg.	Kg.	Kg.
In a_1b_1	Air	$p+5$	$\times 1{\cdot}2937=$		$+p+6{\cdot}46$	
In ab	Gas	5	$\times 0{\cdot}3 =$			$-1{\cdot}5$
In bc	Gas	9	$\times 0{\cdot}388 =$		$+3{\cdot}49$	
In cd	Gas	$8{\cdot}4$	$\times 0{\cdot}273 =$	$2{\cdot}286$		
	Air	$0{\cdot}6$	$\times 1{\cdot}2937=$	$0{\cdot}776+p$		
			Total	$3{\cdot}061+p$		$-3{\cdot}061-p$
			Total		$+p+9{\cdot}95$	$-4{\cdot}561-p$

or 5·39 kilogrammes per square metre, or 5·39 millimetres height of water. The buoyancy is now, owing to the foregoing arrangement of the producer, lowered by 9·37 − 5·39 = 4 millimetres.

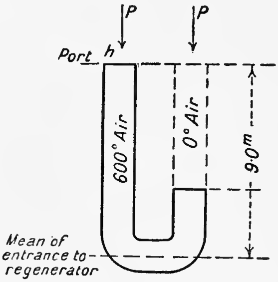

FIG. 5.

2. Buoyancy of Air.

As the air is led cold into the furnace and as the entrance opening is placed close to the air regenerator chamber, the calculations of the buoyancy can be taken as corresponding to a two-branched U tube system, of which the length of the branches are equal, whilst the difference of level between the air entrance to the chamber and the air port in the furnace in the previously given place amounts to 9 metres. The one branch of the U tube is filled with cold, the other is taken as being filled with air of a mean temperature of 600°. On both branches the same air pressure p operates.

At 0° a volume of air is 1 and the weight of 1 cubic metre is 1·29 kilogramme. At 600° the volume of air is 3·2 and its weight 0·404 kilogramme.

The weight of the air in the cold branch is $9 \times 1{\cdot}29 = 11{\cdot}61$ kilogrammes.

The weight of the air in the hot branch is $9 \times 0{\cdot}404 = 3{\cdot}64$ kilogrammes.

The buoyancy of the air amounts, therefore, to about 8 kilogrammes for the square metre, or 8 millimetres of water.

3. BUOYANCY OF WASTE GASES.

As a basis for the calculation of the buoyancy of the waste gases a **U** tube can be taken, the length of the branches of which are equal to the height of the chimney, in the foregoing case amounting to 40 metres.

At 0° and 760 millimetres barometer, the waste gases should have a weight of 1·36 kilogrammes per cubic metre; and be at *d* and *h* (*vide* Fig. 6) at 1,700°; at *l* at a mean of 700°; and thus in the portion *d h l* pass through the system at 1,200°, whilst the mean temperature in the chimney *lm* amounts to 600°. The weight of the gas column in the right branch is

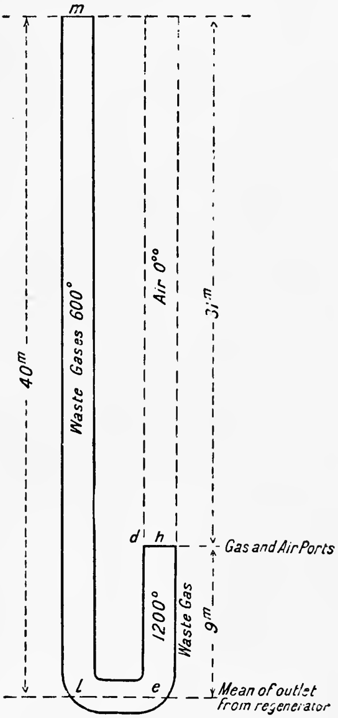

FIG. 6.

31 cubic metres of air $\times 1\cdot2937 =$ 40 kilogrammes.
9 cubic metres of gas at 1200° =
5·4 times volume $9\times\frac{1\cdot36}{5\cdot4}$ = 2·3 kilogrammes.
Total weight 42·3 kilogrammes.

In the right branch the waste gases are at 600°. Their volume amounts, therefore, to 3·2 times their volume at 0°, and their weight $\frac{1\cdot36}{3\cdot2} = 0\cdot43$ kilogramme per cubic metre. It therefore follows that the weight of the entire column of waste gases in the left branch per square metre section $= 40\times0\cdot43 = 17\cdot2$ kilogrammes.

The difference of weight between the gas columns, or the buoyancy in the chimney amounts, therefore, per 1 square metre section to 25·1 kilogrammes, or 25·1 millimetres of water.

The calculated driving forces—

(1) 9·37 and 5·39 millimetres of water in *d* for the gas,

(2) 8 millimetres of water in *h* for the air,

(3) 25·1 millimetres of water in *m* for the waste gases,

must appear in the furnace system, when this is filled with gases of the assumed composition and temperature, and one regards these gases as being, by the closure of the openings at *d*, *h*, and *m*, in some way brought to rest.

If these openings are free, these forces would be the cause of a continuous stream of gases passing through the entire furnace. The movements of these will be the livelier, and correspondingly the working of the furnace better, the greater the driving forces are; naturally up a certain limit.

The foregoing calculations demonstrate that, for equal temperature, and equal composition, of the gas, the buoyancy in a specified portion of the furnace rises and falls with difference of height of the entering and issuing portions, so that they can adapt their proportions to the required object. In the foregoing example forces were obtained from several components, the ascertained values of which were shown under the headings 1 to 3, and which were all operative in the same direction. One might therefrom be inclined to regard, as a result, all forces which the passage of the heated gas through the furnace occasioned as being the sum of 1 and 3, whilst for the air the sum of 2 and 3 came in question.

From the circumstance that in the open-hearth furnace all parts, but above all the regenerator chambers, are most practically arranged symmetrically, it follows that, for a specified height of chimney, the choice of lower chambers, as opposed to higher, must certainly have as a consequence a diminution of the buoyancy at the entrance ends, but that simultaneously the buoyancy in the adjacent outlet ends must be raised to the same amount, since the lower chambers now correspondingly must increase the usefulness of the height of the chimney. But the total power will still remain the same, independently of whether one chooses higher or lower chambers, and, therefore, the total amount of the buoyancy is determined only by the useful height of the chimney, whilst the arrangement of the individual portions of the passage of the gas in the interior of the furnace system must be without importance, and therefore can be chosen according to fancy. The easy passage of the gases admits of a pressure in the entire furnace system rapidly equalising, and as the share of the chimney draught on the total buoyancy is by far the greatest, the gases must be thereby drawn through the entire furnace system.

But in reality the conditions are otherwise. H. H. Campbell expresses himself on this question in his book as follows:—

"Both gas and air should enter the combustion chamber under a positive force, forcing them into contact with each other and throwing the resultant flame across the furnace in such a way that the draught of the stack on the outgoing end can pull it down through the ports without its impinging on the roof.

"A prevalent idea among furnace men is that the draught of the stack pulls the gases into the furnace; but this is entirely wrong. They are not pulled; they are pushed in by the upward force of the white-hot vertical port at the incoming end."

The correctness of the foregoing view is evident if one observes that, in addition to the buoyancy, a second condition influences the movement of the gases, and this is formed by the resistances which arise from the motion of the gases and are rendered sensible in that they obstruct these. These resistances, however, oppose themselves to an equalisation of pressure.

Now, in the open-hearth furnace, it is not possible to completely shut off the combustion chamber from the atmosphere, and if one were to be able to imagine that one could avoid leaky places by sealing the charging doors, there would still remain the necessity to frequently open these doors for the purpose of control and regulation of events in the combustion chamber. Therefore phenomena must appear, as would be the case if a current of any fluid were passed through a system of communicating tubes in which leaky places occurred, that is, as if they (the leaks) existed continuously, or suddenly broke out. Under pressure, this fluid would issue from the leaky places, whilst under partial vacuum, the stream of liquid would remain itself unbroken and air would be obliged to enter in at the leaky places.

On this ground, the path of the gases in an open-hearth furnace cannot be compared with a single closed system of communicating tubes, but one must suppose at least two such systems, the one for the inlet end and the other for the outlet end, as in the preceding calculations. The motion of the gas currents must be so directed that the inflowing current and the outflowing current are about the same weight, and the combustion chamber itself is the equivalent of a neutral portion—that is to say, completely filled by the products of combustion of the gas. Were one to regard it as possible for the chimney draught to have some important effect on the conveyance of gas to the combustion chamber, it would be impossible to avoid a disturbance of the path of the flame, or even at times its complete disappearance.

The condition for good working of a furnace is, that the driving forces are suitable for the before-mentioned resistances to the motion of the gas. Therefore, in the design and building of a furnace one must bear in mind that the resistances are confined to the smallest feasible proportions; and this one is able to attain by making the dimensions of all sections sufficiently large so that the gases do not acquire too great velocity, and that, as much as possible, changes of direction of the gas currents are avoided, and, lastly, that the chequers in the regenerator chambers are so disposed that the passage of the gas is obstructed as little as possible and to avoid flues which force the gases through zigzag lines.

The resistances at the entrance end are able to be overcome by the correspondingly chosen buoyancy, and apart from this also by admitting the gases under pressure. For the heated gas this condition is usually fulfilled in modern producers by means of introducing forced air draught at the bottom of the producer, which permits of the gas being put under any desired pressure. For the air supply, on the contrary, the impulse is furnished by the natural buoyancy in the great majority of furnaces, and this suffices whilst—though not in new furnaces, but in those which have been long in effective use—it frequently occurs that the chequer work of the regenerator chambers becomes obstructed during the run of the furnace, and thereby resistances are increased. Therefrom a shortage of air results, which involves the worst consequences. The working of the furnace becomes feeble and production falls off, and one is obliged to shut down the furnace. By means of supplying air under pressure—which is easily achieved by means of employing a fan, and whereby the amount of the same can be easily brought up to the required extent—this evil can be removed. These artificial increases of the gas and air supplies attain their natural limits, due to the suction power of the chimney; thus, if driven too hard, the flame blazes out of the doors and makes work at the furnace impossible.

The absolute and relative quantities of gas and air that must be supplied to the furnace can only be determined when the composition of gas, and air required for the heating gas are known, and therefore, firstly, the procedure for gasifying the fuel, and the properties of the resultant gas, must be known.

CHAPTER III

GENERAL REMARKS ON PRODUCER GAS

The gas producers or generators have as their function the conversion of fuel from the solid into the gaseous state. The practicability of this is offered by the intrinsic property of carbon (the principal constituent of all our solid fuels), that it will combine with oxygen to form a combustible gas, carbon monoxide, CO.

It is this CO gas, the manufacture of which in producers has been practised of old, which forms the chief, and again the most valuable portion of the constituents of producer gas.

Carbon forms with oxygen, besides CO, as is well known, a second compound, carbon dioxide, CO_2, in technical language most often called carbonic acid. This is the product of the complete combustion of the carbon which is capable of no further heat evolution, and which, therefore, is passed through the chimney into the atmosphere as worthless, after one has more or less utilised the serviceable portions of its heat.

The action of carbon with oxygen results, first, in the formation of CO_2, the product of complete combustion; but if this carbonic acid comes in contact with heated carbon, it takes up carbon and becomes changed into the combustible gas CO.

These observations indicate the way in which one must proceed to obtain a good gaseous fuel from carbon in the solid state. One must first burn the carbon, whereby a large amount of heat is evolved. If one then employs carbon in thick beds and forces the products of combustion through these layers, they must become incandescent and capable of changing the carbon dioxide formed at the beginning into carbon monoxide. It is, therefore, obvious that the layers should be of ample thickness in order to effect as completely as possible the conversion of the whole of the CO_2 formed.

Latterly, one has learnt that carbon is able to combine directly with oxygen to form CO, provided the temperature of reaction be sufficiently high. It must, therefore, also be possible to produce carbon monoxide if the carbon brought into use be in thin beds. But in such an arrangement it is very difficult to pass the oxygen through in such wise that it is completely absorbed by carbon, since in the layer of carbon formed out of individual small pieces spaces are left between these through which gaseous oxygen can easily pass unchanged. If this occurs, however, the free oxygen in the gas chamber immediately attacks the carbon monoxide, in addition to that formed by itself, and burns it, and thereby again produces CO_2, *i.e.*, the same substance which, according to old views, is the first product of the action of oxygen on carbon. This substance can, however, only be changed back into combustible CO through the agency of incandescent carbon.

Incandescent carbon proves itself in all cases a means for correcting the imperfections which are able to present themselves in the production of carbon monoxide, and in order to bring its action to the maximum, it appears to answer the purpose to charge it direct into the gas chamber, and in such wise that—

1. The incandescent carbon completely seals the gas chamber, and all gases forced through are only permitted access thereto through this itself.
2. It is also employed to an amount which safely suffices to compel all gas molecules to have their composition subjected to the test of contact with carbon, and completely saturate themselves therewith, before they are able to issue from the reaction zone and enter the gas chamber proper.

Thus the bed of incandescent carbon is equivalent to a safety device, which is a complete filter for the gas.

The apparatuses in which these reactions are brought about—the producers—must be able to be sealed gas-tight from the atmosphere, and their linings must possess the property of being able to withstand high heat. They must be provided with openings for the supply of the solid fuel, the gaseous oxygen, as well as for the gas produced, and the ashes. It is theoretically indifferent in which portion the gasification is effected and what course the gases take, and owing to this point of view the most varied constructions have been produced. For the production of gas for heating purposes one always selects the simplest pattern in which the gasification proceeds from below, and the gases, in conformity with their natural buoyancy, are impelled upwards. The supply of oxygen, therefore, takes place at the bottom, where also the ashes are removed, whilst the supply of fresh fuel and the discharge of the gases formed occurs at the top. The fuel sinks in the producer at all times and its movement is therefore in opposite direction to that of the gas.

Formerly the bed of fuel rested on grates, the spaces in which admitted the entrance of oxygen into the apparatus. The reaction zone then lay on or immediately above the grate bars, and when a given amount of ash had accumulated thereon, the working had to be interrupted in order to remove the ashes, and with them the sensible heat of the materials withdrawn, and often also a not inconsiderable portion of the converted fuel (coke) was lost. At the present time, frequently the grate is replaced by means of a column of ashes formed naturally in the producer, through which the requisite amount of oxygen for the production of the gas is driven. This removes the sensible heat from the column of ashes and returns it to the producer; it also burns the last minute particles of carbonaceous material in the ashes, and thereby the waste product is often free from carbon. Such an arrangement also permits of the employment of devices, enabling the cinders to be removed during working, so that the working of the producer becomes continuous.

The combination of oxygen and carbon evolves, as already remarked, a large quantity of available heat, the major portion of which is taken up by and carried away with the gases produced. As these gases play against the carbon they come in contact with, they part with heat thereto until an equilibrium between them is established. Correspondingly to the heat receptive power of the fuel, the temperature in the different zones of height will vary, and by sufficient massiveness the effective columns of the fuel will be preheated nearly to the temperature which rules in the reaction zone when it reaches it. The fuels employed in producers, however, never contain merely particles of carbon and ashes, but in particular water and hydrogen in chemical combination, and they possess the property of changing their composition under the influence of heat. At temperatures up to a little over 100° they liberate only hygroscopic water in the form of steam, but at higher temperatures chemical compounds also. With these, however, are developed steam and gas from the hydrogen compounds, the so-called bituminous substances, and at sufficiently high temperatures these latter are completely driven off. The removal of the bituminous substances by means of heat itself is termed "dry distillation," and is largely practised in kilns and in the retorts of gas plants, whereby, on the one hand, combustible gases are given off, and yield, on the other hand, practically pure carbon (charcoal or coke), which remains behind in the apparatus.

In the producer, the fuel undergoes the same changes, in so far as it attains, in the apparatus, exposure to heat treatment from the hot gases. It evolves all the before-mentioned substances, *i.e.*, water-vapour, and lighting or distillation gas, which admix themselves with the products of gasification rising up from the bottom. The fuel becomes more and more converted into practically pure carbon, until it reaches the gasification area as such, and here is itself converted into the form of gas, and only the particles of ash remain behind, which finally must be removed from the producer.

Thus the gas generated in the producer issues therefrom as a mixture of the products of the following processes :—

1. The gasification or incomplete combustion of the carbon.
2. The degasification or dry distillation of the raw fuel.
3. The drying of the raw fuel.

CHAPTER IV

THE RAW MATERIALS USED IN PRODUCER WORKING

(*a*) The Solid Fuels.

The solid fuels most abundantly employed are charcoal, coke, anthracite, coal, lignite, peat and wood, their carbon contents being in the order of the foregoing sequence. For the generation of producer gas, only coal and lignite for the most part come into consideration, and peat and wood only in exceptional cases—that is to say, in localities where other fuels cannot well be procured.

It is unnecessary at this juncture to give a more detailed description of these fuels, such as, say, by means of supplying their analyses into elements, since up to the present a relation has not been successfully found out between the elementary composition of fuels and the composition of the gas which is produced from these fuels. For the purposes of the present considerations general statements as to the properties of these fuels will suffice. They all contain ingredients which on combustion liberate gaseous compounds and such as which remain behind as solid substances and form the ashes. The first-named group embraces, in addition to water, which is simply derived from the atmosphere and named hygroscopic water, many mostly very complicated compounds of the elements carbon, hydrogen oxygen and nitrogen, and, at times, some sulphur. On these fuels becoming heated, the hygroscopic water volatilises in the form of steam. On stronger heating, however, dry distillation commences, *i.e.*, the transmutation of the complicated compounds of hydrogen and oxygen with carbon into simpler ones (which at the temperature employed are gaseous and escape) and into a solid residue.

If the temperature be sufficiently raised, and the fuel be long enough exposed to it, the elements oxygen and sulphur (in so far as they are not retained by the constituents of the cinders) and hydrogen are able to be as much as completely driven off, and there remains a residue which, in the main, is carbon, which only contains as an impurity the constituents of the ash.

The gases obtained from dry distillation are combustible and therefore serve for heating purposes. They consist principally of free hydrogen, and hydrocarbons, together with small amounts of carbonic acid and carbon monoxide, consequently containing carbon. But of the total amount of carbon which is contained in the fuel, only a small portion can be converted into the form of gas by means of dry distillation, the bulk remaining as the before-mentioned residue.

If one allows oxygen to act on this residue the carbon content of the same is able to be completely converted into the form of gas, so that of the fuel, finally, only the ingredients of the ash remain as a residue. If the gasification of the last-mentioned quantity of carbon, which in the main only gives rise to the formation of combustible carbon monoxide, were so performed that it succeeded in analysing the fuel into combustible gases, and the ingredients of the ash, one would be able often to make more convenient and better utilisation of the former than of the solid fuel itself.

(*b*) THE OXYGEN NECESSARY FOR GASIFICATION.

This is supplied to the producer in two forms: in the form of atmospheric air and of water-vapour.

The atmospheric air is well exposed to fluctuations in its composition, but these are very insignificant, especially if the air be regarded as being in the dry condition; thus one always assumes it for technical calculations as being made up of 21 volumes O and 79 volumes N.

Thus 1 volume O is accompanied by $\frac{79}{21}$ N or 3·762 volumes of nitrogen.

Of these two gases, only the oxygen takes part in the changes, as opposed to which the nitrogen must be carried as a superfluous and inert ballast.

If, therefore, in the production of a gas, the atmosphere, *i.e.*, air, is employed, so must nitrogen be present in the gas; further, it must prove oxygen in its free or combined form; and lastly, the quantity of nitrogen which is derived from the air, and the quantity of oxygen derived from the same source to be in a specified ratio, which is fixed according to the formula

$$N = 3{\cdot}762\ O \quad . \quad . \quad . \quad (1)$$

As the relative ratios of O and N in later calculations must meet with frequent consideration, a table of the nitrogen volumes for values of 1 to 1,000 O has been drawn up, which is annexed as a supplement, and from which one can derive for each desired value of O or N (within these limits) the value of N or O.

Now atmospheric air is almost never dry, but generally contains certain quantities of water-vapour, which depend on the temperature and degree of saturation of the air with water-vapour, and from this admit of calculation. In the tables to be used for this are usually given the quantities of vapour which are contained in the volume or weight unit of the moist air mixture at saturation point of moisture. But it is more convenient here for the performance of these calculations to know the figures which specify the quantities of vapour that 1 cubic metre of dry air at 0° and 760 millimetres pressure is able to take up, when this amount of air is warmed up to higher temperatures. F. H. Weiss gives the following figures in his book, "Condensation," p. 323:—

1 kilogramme air can take up moisture as follows at temperatures given:—

0°	10°	20°	30°	40°
0·0037	0·0073	0·0114	0·0268	0·0477 kilogramme.

Wherefrom considering that 1 cubic metre air at 0° and 760 millimetres pressure weighs 1·293 kilogrammes, and 1 cubic metre water-vapour at 0° and 760 millimetres must weigh 0·8051 kilogramme, it follows that 1 cubic measure dry air can take up at:—

	0°	10°	20°	30°	40°
Moisture at 0° and 760 millimetres .	0·0035	0·0070	0·0109	0·0257	0·0458 cubic metre.

These figures show that the moisture content of air saturated with humidity rapidly grows with increasing temperature, and at 40° amounts to thirteen times that at 0°. As one can have in summer a heat of 30° to 40° and air richly laden with moisture, thus it can also happen that each cubic metre of air which one has calculated as necessary for the fire (taken as air in its dry state and normal condition) may contain up to about 0·04 cubic metre of moisture. This sum total, it is true, is not very considerable, but it can nevertheless in some cases demand consideration.

The second source of gaseous oxygen for gasification is furnished by aqueous vapour, equally, if the same accompanies the air as natural humidity, or is purposely introduced. The mode of operating steam in the formation of gas, its decomposition, and the quality of the corresponding gas will be dealt with later.

CHAPTER V

THE REACTIONS ACCOMPANYING GASIFICATION IN THE PRODUCER —STOICHIOMETRIC RELATIONS

(*a*) Carbon Dioxide CO_2, Ratio of C to O, and Volume of Gas Obtained from 1 kilogramme C.

Carbon combines with oxygen, forming carbonic acid or carbon dioxide, according to the equation $C+2\ O=CO_2$ which involves, according to the rules of stoichiometry, that

12 kilogrammes C with 32 kilogrammes O form
44 kilogrammes CO_2.

This mode of calculation is employable for the estimation of the equivalent quantities of mutually reacting substances in all chemical reactions. It is, however, particularly so in order to work out determinations of weight of gases, and these are usually done by the method of measuring the volumes of the gases and multiplying the figures obtained by the weight of a unit volume of the gas. Since, however, the volumes of gases vary with change of pressure and temperature, the figures for the volumes measured in experiments are always first corrected to the normal basis of 0° and 760 millimetres, if one wishes to employ their absolute weight in the above-mentioned manner. It has been known for many years that one can considerably simplify the calculations for the mutual reactions of gases, and, therefore, also knowledge of the occurrences, if one calculates in volumes of inter-reacting substances in lieu of the weights. With this object in consequence molecular formulæ are employed, which furnish direct the ratios of amounts of the volumes of the reacting and resultant substances. In the critical examination of the occurrences in technical generation of producer gases, these formulæ have as yet found much too little entry.

On dividing the above-given equivalent weights $O=32$ kilogrammes, and $CO_2=44$ kilogrammes by the respective weights of 1 cubic metre of $O=1{\cdot}4304$ and 1 cubic metre of $CO_2=1{\cdot}9781$ (in both cases under normal conditions) we obtain

$$32 \div 1{\cdot}4304 = 22{\cdot}3 \text{ cubic metres } O^{1}$$
$$44 \div 1{\cdot}9781 = 22{\cdot}3 \text{ cubic metres } CO_2{}^{1}$$

These results show that 22·3 cubic metres O, on combining with carbon, furnish 22·3 cubic metres CO_2, or, in other words, that, from 1 cubic metre O, 1 cubic metre CO_2 is produced . . . (2).

Further, as within the temperatures under consideration O and CO_2 appear as permanent gases, entirely equally altered in volume with varying pressure and varying temperature, it follows that the above relations are not only valid for the normal conditions, but their validity remains for all cases in which O and CO_2 are under equal conditions. But the same is valid for all gases remaining to be considered, and hereby the advantage is clearly perceivable, that calculations are continued in volumes. As an instance, the application immediately following will serve.

In the combustion of carbon, pure oxygen is not employed, but atmospheric air, which in addition to 21 per cent. O, contains 79 per cent. N. If the oxidation of the C takes place with precisely the theoretically requisite quantity of oxygen, then from the 21 volumes of O there result 21 volumes of CO_2, whilst the 79 volumes of N remain unaltered. Consequently, the reaction results in a gas of the composition 21 per cent. CO_2, and 79 per cent. N or 100 per cent. products of combustion. In this gas the nitrogen is determined according to the formula

$$N=\frac{79}{21}\,CO_2=3{\cdot}762\,CO_2 \quad . \qquad (3).$$

In simple manner further the quantity of gas which is obtained from the unit of weight of carbon admits of determination. As 12 kilogrammes C develops 44 kilogrammes

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[1] One obtains herefrom exactly 22·37 cubic metres O and 22·24 cubic metres CO_2, which is inaccurate, as the atomic weights $O=16$ and $C=12$ are not precise, but only approximate.

or 22·3 cubic metres CO_2, so one obtains from 1 kilogramme C, $\frac{22{\cdot}3}{12} = 1{\cdot}86$ cubic metre CO_2 (under normal conditions 0° and 760 millimetres) . . . (4).

Also when combustion occurs by means of the theoretically requisite amount of air, that

$$N = 3{\cdot}762\ CO_2 = 3{\cdot}762 \times 1{\cdot}86 = 7{\cdot}00 \text{ cubic metres } N.$$

Thus the volume of the gases of combustion of 1 kilogramme C with air under normal conditions is

$$1{\cdot}86 \text{ cubic metre } CO_2 + 7{\cdot}00 \text{ cubic metres } N = 8{\cdot}86 \text{ cubic metres} \quad . \quad . \quad (5).$$

(*b*) CO FORMATION. AIR-GAS.[1]

If one considers the formation of CO according to the equation $C + O = CO$, then 12 kilogrammes C with 16 kilogrammes O yield 28 kilogrammes CO. On division by the respective weights of 1 cubic metre O and CO, one obtains $\frac{16}{1{\cdot}4304} = 11{\cdot}15$ cubic metres O and $\frac{28}{1{\cdot}2555} = 22{\cdot}3$ cubic metres CO. Thus 11·15 cubic metres O yields 22·3 cubic metres CO, and from this it follows that 1 cubic metre O yields 2 cubic metres CO, or that for producing 1 cubic metre CO, ½ cubic metre O is required. . . (6).

For the manufacture of the gas, air is again employed, thus there will be yielded from 21 cubic metres O, $2 \times 21 = 42$ cubic metres CO and 79 cubic metres N unchanged. Thus 100 cubic metres air will yield 121 cubic metres gas. This will have the composition $\frac{42 \times 100}{121} = 34{\cdot}7$ volumes CO, and $\frac{79 \times 100}{121} = 65{\cdot}3$ volumes N . . . (7).

In this gas, the nitrogen content is defined according to the formula $N = 3{\cdot}762 \frac{CO}{2}$ . . . (8), as in the production of 1 cubic metre CO only ½ cubic metre O is necessary.

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[1] Note by translator. The German expression is "Luft-gas," and the definition thereof, according to the formula numbered 7, is so useful that the translator has adopted the literal translation of, and definition of the German word.

For the determination of the volume of CO, which is obtained from 1 kilogramme C, the quantity of gas 22·3 cubic metres which contains 12 kilogrammes C is used, and thus there is yielded $\frac{22·3}{12}=1·86$ cubic metre CO . . . (9). To this there belongs $N=3·762\times\frac{CO}{2}=\frac{3·762\times1·86}{2}=3·5$ cubic metres N, and the total quantity of air gas at 0° and 760 millimetres per 1 kilogramme C amounts to 1·86 cubic metre $CO+3·50$ cubic metres $N=5·36$ cubic metres air-gas . . . (10).

(*c*) Simultaneous Formation of CO_2 and CO in the Combustion of C by Means of Air.

If the combustion of pure carbon by means of air happens in the manner that simultaneously CO_2 and CO are present, the N content will be determined by the formula

$$N=3·762\left(CO_2+\frac{CO}{2}\right) \quad . \; . \; . \quad (11),$$

as given by the simple addition of formulæ (3) and (8).

In similar manner, one derives the total volume V as being :—

$$V=CO_2+CO+3·762\left(CO_2+\frac{CO}{2}\right).$$

(*d*) Gasification of Pure C by Means of Steam.

Water-vapour is, in definite ratios (to be discussed in detail later on), able to attack carbon and gasify it. Water, as is well known, results from the union of hydrogen and oxygen according to the equation

$$2H+O=H_2O$$

whereby 2 kilogrammes H with 16 kilogrammes O forms 18 kilogrammes water.

The water appears on its formation at first in the form of steam, and in this form only can it be employed for the gasification of carbon. The calculable weight of a cubic metre of water-vapour referred to a basis of 0° and 760 millimetres has been estimated at 0·8051 kilogramme, whilst 1 cubic metre H under equal conditions weighs 0·0899 kilogramme.

By division of the equivalent weights by means of above-given figures one obtains

$$\frac{2}{0{\cdot}0899}=22{\cdot}3 \text{ cubic metres H}, \quad \frac{16}{1{\cdot}4304}=11{\cdot}15 \text{ cubic metres O},$$

$$\frac{18}{0{\cdot}8051}=22{\cdot}3 \text{ cubic metres water-vapour},$$

from which figures one derives that

1 cubic metre O+2 cubic metres H yield=2 cubic metres water-vapour . . . (12).

Inversely, if 1 cubic metre water-vapour is decomposed, 1 cubic metre H+½ cubic metre O must be obtained.

The oxygen from the water-vapour carries no nitrogen with it, but H, and the relationship between the gases is,

$$O=\frac{H}{2} \quad . \quad . \quad . \quad (13).$$

(*e*) Production of CO and H from C and Steam. Water-Gas I.

The action of steam on C is conceivable according to the following formula :—

$$C+H_2O=CO+2H$$

wherefrom

12 kilogrammes C+18 kilogrammes H_2O=28 kilogrammes CO+2 kilogrammes H.

By division of the weights of gas by their weights under normal conditions one finds $\frac{18}{0{\cdot}8051}=22{\cdot}3$ cubic metres H_2O (vapour) $\frac{28}{1{\cdot}2555}=22{\cdot}3$ cubic metres CO, and $\frac{2}{0{\cdot}0899}=22{\cdot}3$ cubic metres H, or carbon+1 cubic metre steam=1 cubic metre CO+1 cubic metre H.

By use of the formulæ (12) and (6), which are graphically shown in the Appendix, one can also more simply ascertain the result. If one considers, that is to say, that 1 cubic metre steam is resolved into its constituents, one obtains 0·5 cubic metre O and 1 cubic metre H. In the gas now 1 cubic metre H goes, whilst 0·5 cubic metre O is combined with C, and this by formula (6) forms $2 \times 0{\cdot}5$ cubic metre$=$1 cubic metre CO, so that a gas results which contains 1 cubic metre CO+1 cubic metre H.

The percentage by volume of the composition of this gas will be, therefore, 50 per cent. CO and 50 per cent. H, and is characterised by the formula

$$\text{Volume H} = \text{Volume CO} \quad . \quad . \quad . \quad (14).$$

Also one must here (as in gasification by air) obtain from 1 kilogramme C, 1·86 cubic metre CO at 0° and 760 millimetres, but in place of the absent nitrogen, hydrogen of the same volume as the CO must be present, and the quantity of gas which will be obtained from 1 kilogramme C must, under normal conditions, measure 1·86 cubic metre CO+1·86 cubic metre H=3·72 cubic metres.

(*f*) PRODUCTION OF CO_2 AND H FROM PURE CARBON AND STEAM.

WATER-GAS II.

The action of steam on carbon is also conceivable according to the following formula :—

$$C + 2H_2O = CO_2 + 4H.$$

If one conceives according to formula (12) that 2 volumes of steam are decomposed into their constituents, so one obtains 2 volumes of H and 1 volume of O, of which the former goes over as gas, but the latter must first re-combine with carbon. As CO_2 results, so there must, according to formula (2), result from 1 volume of O also 1 volume of CO_2, and the composition of the gas will be

1 Volume CO_2+2 Volumes H, or 33·3 per cent. CO_2, and 66·7 per cent H.

The characteristic of this gas will, therefore, be $CO_2 = \frac{H}{2}$ or $H = 2CO_2$ . . . (15). As 1 kilogramme C evolves 1·86 cubic metre of CO_2 (*vide* (4)), so from consideration of formula (15) we easily ascertain that the volume of gas from 1 kilogramme C will be 1·86 cubic metre $CO_2 + 3{\cdot}72$ cubic metres $H = 5{\cdot}58$ cubic metres. The gases reviewed under the headings (*e*) and (*f*) are called water-gas and are not produced in this purity in practice.

(*g*) Steam-Air Gas.[1]

A mixture of the gases reviewed under the headings (*a*), (*b*), (*e*) and (*f*) is termed steam-air gas. One can regard this as a mixture of gases produced individually in separate apparatuses, or also as by production in a single apparatus in which the carbon is, by the joint influence of air and steam, converted into gas. It follows, therefore, on reflection that for each volume of oxygen which is obtained from air that this must be accompanied in the gas by a corresponding volume of N, whilst in the oxygen which was derived from the decomposition of water, a corresponding amount of hydrogen must be present. The quantity of nitrogen in the gas will, therefore, be no longer according to formula (11), $N = 3{\cdot}762 \times \left(CO_2 + \frac{CO}{2}\right)$, but will be less to the extent of 3·762 times the quantity of O which is contained in the water. This is, according to the formula (13), $= \frac{H}{2}$, and herewith furnishes the characteristic as under:—

$$\text{Steam-air gas, } N = 3{\cdot}762 \left(CO_2 + \frac{CO}{2} - \frac{H}{2}\right) \quad . \quad . \quad . \quad (16).$$

Example.—A gas of the composition 8 per cent. CO_2, 24·9 per cent. CO, 11·0 per cent. H, and 56·1 per cent. N, as analysed, must contain $8 + 12{\cdot}45 - 5{\cdot}5 = 14{\cdot}95$ O which $\times$ $3{\cdot}762 = 56{\cdot}2$ per cent. N. This proves the gas to be pure steam-air gas.

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[1] The Germans use the expression "Mischgas," which has not, but should have, an English equivalent. Such a word avoids much verbose explanation being involved. The translator has adopted the expression "steam-air gas" for the purposes of this book, but begs to direct attention to the desirability of a suitable equivalent to the German word being coined and adopted generally. The formula for this gas then from (16) is

$$xCO_2 + yCO + zH + 3{\cdot}762 \left(x + \frac{y-z}{2}\right) N.$$

(Translator.)

(*h*) CARBON CONTENT OF THE GAS.

It has been established by formulæ (4) and (9) that 1 kilogramme C is contained in 1·86 cubic metre CO_2, or 1·86 cubic metre CO. In 1 cubic metre of these carbonaceous gases, measured under normal conditions, there is, therefore, contained $1 \div 1{\cdot}86 = 0{\cdot}538$ kilogramme C . . . . (17).

CHAPTER VI

THERMAL CONDITIONS IN THE GASIFICATION OF CARBON

The reactions reviewed in the foregoing do not always take place in the manner assumed, and not under all conditions, as their progress is frequently forcibly interrupted. The most substantial factor is the temperature produced during the process. By way of example, as the result of experimental research, the influence of the air on the carbon according to the reaction $C+20=CO_2$ commences at about 375°. At this temperature, however, oxygen present only to an amount of about 0·5 per cent. of the weight of air is utilised, whilst the

Table A.

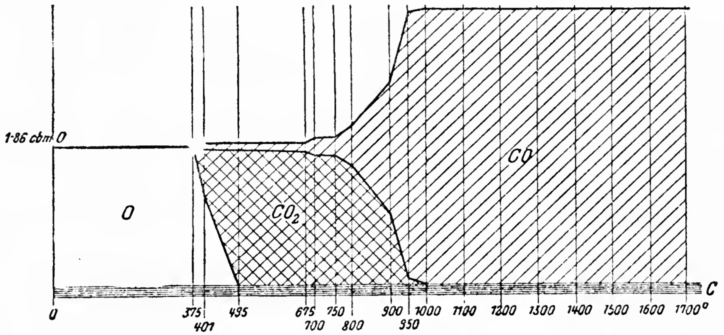
Length of bed of Coke. Centimetres.	Amounts of N collected in a minute.	Temperature.	Gas Analysis in Volumes per cent.		
			CO_2.	O.	CO.
17	19·9	375°	0·5	20	0
10	6·1	394°	1·1	20·1	0
17	32·2	395°	1·6	17·4	0·5
10	7·1	401°	6·2	12·3	0·8
10	6·1	495°	19	0	1·6
11	2·5	675°	19·8	0	1·1
10	22·3	677°	19	0	1·1
33	61	680°	18·9	0·2	1·7
33	17·9	700°	19·3	0·3	2·5
33	119·3	700°	17·3	1·4	3·3
17	10·7	700°	18	0	2·5
44	35·8	750°	19·4	0	2·7
10	8·9	800°	17·9	0	5·9
11	10·8	875°	11	0	14·7
11	24·5	900°	10·1	0	15·8
11	1·2	950°	0·6	0	31·5
11	2·2	1,000°	0	0	34·2

remaining 20·5 per cent. is unattacked. With increasing temperature the amount of oxygen utilised grows, and simultaneously therewith the amount of CO_2 produced. At about 495° the available oxygen present will be completely taken up by carbon, which forms a trace of CO in addition to CO_2. The formation of CO_2 attains its maximum at this temperature, from which forward there occurs more rapid simultaneous formation of CO. At 1,000° the formation of CO has become practically equal to that of the original O, and the O will be entirely taken up in the formation of CO, as will be seen from the accompanying table of the results of experiments by Naumann and Ernst, which are taken from Ferd. Fischer's "Techn. d. Brennst., p. 201 (Table A). The air was passed over hot coke in a porcelain tube. The temperatures were measured by a Chatelier pyrometer.

This table is graphically illustrated in Figs. 7 and 8, wherein the amount of air for the gasification of 1 kilogramme C to CO is taken. The first diagram on the larger scale gives only the active amounts of oxygen, at the different temperatures, the corresponding amounts of carbon monoxide, and carbon-dioxide, taken under normal conditions, whilst the second diagram at one-tenth of the scale of the first, gives also the nitrogen content of the gases and the changes of volume which occur owing to the higher temperatures. One obtains thus on a uniform scale a clear picture of the large increase of volume which air for gasification has to undergo in the producer, and of the large amounts of nitrogen with which the gas is laden.

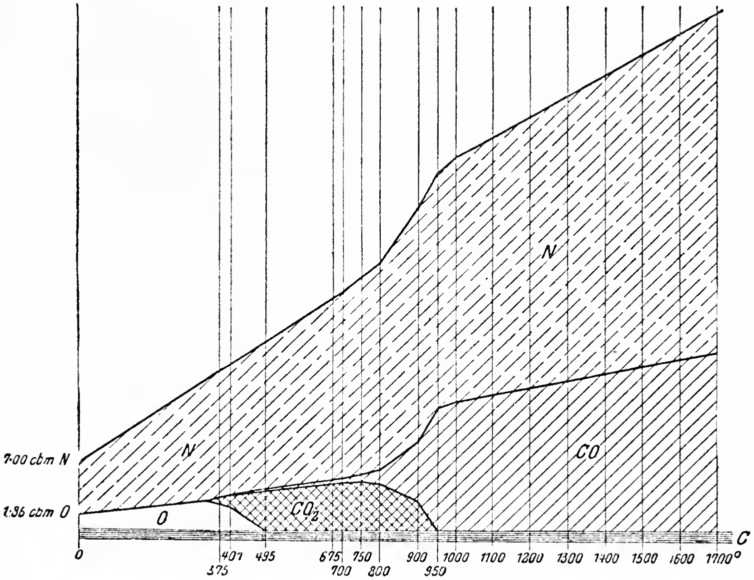
ACTION OF STEAM ON CARBON.

This action begins, according to Lang (*vide* Fischer, p. 202), at 530°, at which, however, only traces of the steam become active. With rising temperature decomposition becomes more complete until (as shown in Fig. 9 and Table B from the very instructive experiments of Harries) at about 1,125° it becomes practically ended, as then 99·4 per cent. of the steam has become decomposed when this is in large quantities and rapidly blown into the incandescent mass of carbon.



Scale 1 *millimetre*=0·1 *cubic metre.*

FIG. 7.—Action of oxygen of the air on carbon at various temperatures (gas at 0° and 760 millimetres barometer). Researches by Naumann and Ernst.



Scale 0·1 *millimetre*=0·1 *cubic metre.*

FIG. 8.—The same, taking into account increases of volumes due to heat.

D 2

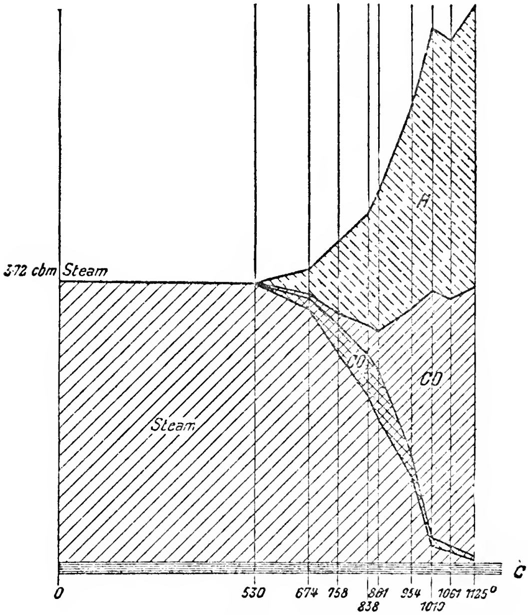


FIG. 9.—Action of 1·86 cubic metre O contained in 3·72 cubic metres steam, on carbon at various temperatures, from Harries' Researches. Gas volumes at 0° and 760 millimetres barometer.

TABLE B.—HARRIES' RESEARCHES.

Temperature °C.	CO content in per cent. of $CO + CO_2$.	Steam decomposed per cent. on Steam passed through.	Undecomposed Steam per cent. on Water-gas produced.	Velocity of Gas Stream. Litres per Second.
674	14	8·8	680	0·9
758	22·2	25·3	193	1·8
838	34·8	37·7	117	3·66
838	41·4	41·0	90	3·28
861	45	48·2	64	5·3
954	85·2	70·2	20·8	6·3
1,010	97·1	94·0	3·1	6·15
1,060	97·4	93·0	3·8	9·8
1,125	98·8	99·4	0·3	11·3

Table B has also been graphically set out, and one sees from the diagram (Fig. 9) that in gasification of carbon by means of steam, at a temperature of about 860°, the formation of CO_2 predominates, whilst from that point with increasing temperature the formation of carbon monoxide strongly gains the upper hand; and that at 1,125° only the latter gas is formed, and thereat the steam is completely decomposed. It should be very specially observed how much the quality of the gas is damaged by the passing through of undecomposed steam, if the temperatures in the reaction zone be too low.

The action of carbonic acid on carbon, which takes place according to the equation $CO_2+C=2CO$, has been investigated by Boubouard (Fischer's "Techn. d. Brennst," p. 206) at different temperatures; wherefrom the following conditions of equilibrium have been obtained:—

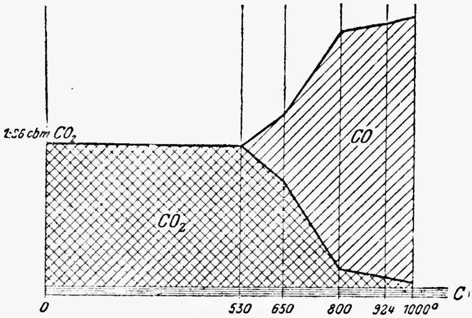


FIG. 10.—Gases at 0° and 760 millimetres barometer.

At a temperature of	The gas mixture contains	
650° . . .	61 per cent. CO_2 and	39 per cent. CO.
800° . . .	7 ,, CO_2 ,,	91 ,, CO.[1]
924° . . .	4 ,, CO_2 ,,	96 ,, CO.

These results are set out in the diagram (Fig. 10).

One perceives from all three cases considered that the gain in combustible gases is the greater, the higher temperatures employed. In the formation of air-gas and the reduction of carbonic acid by means of incandescent carbon, the maximum of formation of carbon monoxide is reached at a temperature of about 1,000°, whilst in the decomposition of water, only at

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[1] These figures do not tally (Translator).

1,125°. Thus one derives that the paramount condition of the production of the maximum of combustible gas in the gasification of carbon is *that the temperature in the reaction zone should never sink below* 1,125°.

The temperature can exercise yet another influence on the composition of the gas, in that it can cause inter-reaction between the different species of gases. Thus a mixture of carbon monoxide, hydrogen, nitrogen, and carbonic acid, *i.e.*, pure steam-air gas, only will not change its composition if it is very highly heated. If, however, this steam-air gas is mixed with water-vapour, derived from the hygroscopic water of the fuel, or which has passed through the reaction zone undecomposed, so it is possible for this to react with the carbon monoxide of the steam-air gas somewhat according to the formula $CO + H_2O = CO_2 + 2H$, so that combustible CO is capable of being converted into the worthless CO_2. Of course, thereby hydrogen will be formed, and in an amount which is equivalent to the carbon monoxide disappeared. The reaction before mentioned can, according to Engler and Grimm (*vide* Fischer, p. 204), commence between 250° and 300°, but at such low temperatures is of no importance; but at higher temperatures, as the following example, taken from the same source, illustrates, can become, under certain circumstances, quite marked. In the experiments carbon monoxide was passed with steam through a porcelain tube, heated up to about 954°, and gas of the following composition was obtained :—

TABLE C.

	Composition of Gas. Volumes per cent.		After passing through Tube.		After addition of excess of Steam.
	After half an hour's action.	After 2 hours' action.	Twice.	20 times.	
	I.	II.	III.	IV.	V.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
CO_2	15·2	22·8	16·0	18·8	39·7
CO	68·5	51·4	66·2	56·4	18·3
H	14·0	21·9	15·3	23·0	38·7
N	2·3	3·9	2·5	2·8	3·3

Transposed into the quantity of gas which contains 1 kilogramme C, the above numbers yield :—

Cubic metres.	Cubic metres.	Cubic metres.	Cubic metres.	Cubic metres.	Cubic metres.
CO_2	0·34	0·57	0·36	0·46	1·27
CO	1·52	1·29	1·50	1·40	0·59
H	0·31	0·55	0·35	0·56	1·24
N	0·05	0·10	0·06	0·07	0·07

It appears that the presence of great amounts of hydrogen favours the reaction, whilst minute amounts have little influence, and herein may lie the cause why these reactions have seldom received attention in practical management.

The hydrocarbons are more sensible to the influence of temperature than carbon monoxide and water-vapour. These constitute a not inconsiderable portion of the distillation gases, and are very valuable for heating purposes. The hydrocarbons split up on heating to more than 700°, giving off carbon which deposits itself as soot in the gas conduits and checkers of the regenerators, and the phenomenon is the more perceptible, the more concentrated the hydrocarbons in the gas are. Besides this, the hydrocarbons are also exposed to change by the action of other gases.

Thus, for example, methane and carbonic acid produce changes which the experiments of Lang (*q.v.*) demonstrate. The mixture of methane and carbonic acid exhibited, before and after heating, the following contents of CO_2 and CO :—

Before heating.		After heating.	
CO_2.	Temperature.	CO_2.	CO
Per cent.		Per cent.	Per cent.
41	703° to 814°	41	0·6
33·3	954° to 1,054°	26·8	6·4
29·4	954° to 1,054°	20·1	8·2

The exchange took place according to the formula, $CH_4 + 3CO_2 = 4CO + 2H_2O$—that is to say, it yielded carbon monoxide and steam, which again, according to the before-considered equation, are able to revert into CO_2 and H.

Methane and steam likewise react and (*vide* Fischer, p. 205) according to the equation $CH_4 + H_2O = CO + 6H$. The same author gives (p. 204) the following results of experiments:—

Methane with 2 volumes steam heated to 954° to 1054°, and the same with great excess of steam, gave from separation of carbon:—

	1.	2.
CO_2	1·2 per cent.	5·0 per cent.
O	0·5 ,,	—
CO	2·8 ,,	9·4 ,,
H	48·8 ,,	47·1 ,,
CH_4	43·5 ,,	37·3 ,,
N	3·2 ,,	1·2 ,,

One perceives in all examples that the changes only result partially, and that they show smaller values, the smaller the amounts of the hydrocarbons are. It therefore results that producer gases cannot be subjected to great changes in their composition from the influences which high temperatures in the producer or regenerator chambers can bring to bear if they contain little CO_2 and little steam, and likewise not too large quantities of hydrocarbons.

Lastly, steam can be split up into its constituents by means of heating alone. Nevertheless this only occurs at such high temperatures that this reaction is practically without importance in gas firing.

CHAPTER VII

INFLUENCE OF THE INDIVIDUAL REACTIONS ON THE REACTION TEMPERATURE

(*a*) Energy Content Corresponding to the Combustion Heat of Carbon.

On p. 27 it is shown that by the incomplete combustion of C by O from 1 kilogramme C, $\frac{28}{12}$ kilogrammes CO or, measured in normal conditions, 1·86 cubic metres CO can originate, for which by formula (6) $1{\cdot}86 \times 0{\cdot}5 = 0{\cdot}93$ cubic metre O is required. This CO is combustible, and can by means of oxygen be converted into carbonic acid according to the equation $CO+O=CO_2$, whereby 28 kilogrammes CO+16 kilogrammes O=44 kilogrammes CO_2 is furnished.

On division by the respective weights of the individual gases, one obtains $\frac{28}{1{\cdot}2555}=22{\cdot}3$ cubic metres CO, $\frac{16}{1{\cdot}4304}=$ 11·15 cubic metres O, $\frac{44}{1{\cdot}9781}=22{\cdot}3$ cubic metres CO_2. That is to say, 1 cubic metre CO + 1 cubic metre O yield 2 cubic metres CO_2 . . . (18). For the combustion of 1·86 cubic metres CO, therefore, 0·93 cubic metres O is required, and as a product of the reaction 1·86 cubic metres CO_2 must result.

There is necessary, therefore, for the combustion of 1 kilogramme C to 1·86 cubic metres CO (*vide* 6), an amount of 0·93 cubic metres O, and for 1·86 cubic metres CO to 1·86 CO_2 (*vide* 18) also 0·93 cubic metres O, or a total for the combustion of 1 kilogramme C to 1·86 cubic metres CO_2 of 1·86 cubic metres O, corresponding to the formulæ (2) and (4).

This knowledge teaches that the same causes bring about the same actions. Thus, the quantity of heat evolved by the direct combustion of 1 kilogramme C with 1·86 cubic metres O direct to CO_2 must be equal to the sum of the quantities of heat which will result if the same kilogramme C is first burnt into CO and the resultant CO subsequently is burnt into CO_2, for the amounts of the mutually reacting substances are the same at the conclusion. Since, further, in the second case the action ensues in two steps, wherein in each step the same amount of oxygen is employed, one might assume that in each of these separate operations the same quantity of heat would be set free, that is to say, that the combustion of 1 kilogramme C to CO would liberate as much heat as the combustion of the resultant carbon monoxide into carbonic acid.

Now the latter quantity of heat admits of comparatively easy experimental estimation, and has been established as being 3,063 calories per cubic metre CO at 0°) and 760 millimetres. From this, one obtains from—

	Calories.
1·86 cubic metre CO and 0·93 cubic metre O, 1·86×3,063	5,693
And one would obtain from the combustion of 1 kilogramme C with 0·93 cubic metre O to 1·86 cubic metre CO likewise	5,693
Which would give for the total energy derived from 1 kilogramme C	11,386
Practical determinations of the heat of combustion of carbon have, however, established an amount of	8,080
So that a deficit appears of	3,306

This difference in the estimation of the heat of combustion is explained in that the carbon is always employed in the solid phase, whilst in the products carbon monoxide and carbonic acid, it is present in the gaseous phase. An expenditure of energy is required for its transmutation into the gaseous condition, and therefore one assumes that the energy in question for 1 kilogramme carbon amounts to the beforementioned 3,306 calories. Consequently, an energy content of 11,386 calories represents the combustible value of theoretically imagined gaseous carbon, which, for practical purposes, does not enter into consideration. The practicably available energy for 1 kilogramme carbon amounts to only 8080 calories, and this must be completely disengaged and likewise must be rendered fully evidenced in the products of combustion in the form of disengaged, or heat proper, and of latent heat or combustible value; and of this amount of 8,080 calories, there will (in the face of a view which even at present appears not to have wholly vanished), be absolutely no deduction required, in the case of complete or incomplete combustion in all processes.

	Calories.
Taking the combustible value of 1 kilogramme C at	8,080
And the combustible value of 1·86 cubic metre CO containing 1 kilogramme C at	5,693
The difference is thus . . .	2,387

i.e., the amount of heat which would be liberated on the combustion of 1 kilogramme C to CO, or the heat of combustion of carbon to carbon monoxide.

(*b*) THE TEMPERATURE IN REACTION ZONE IN THE PRODUCTION OF AIR-GAS.

Previously (p. 37), on the basis of practical experiments, it has been established that the most favourable conditions for the production of CO from carbon are provided, if the temperature in the reaction zone amount from 1,000° to 1,125°, and it will be assumed in the following investigations that there shall be a pausing of temperature at 1,150°. The small surplus of 25° will be regarded as a reserve, which can thus serve to balance chance inaccuracies which must arise in the following calculations owing to the unreliability of the values employed for the specific heats of gases at high temperatures. These values are regarded by many as being to such an extent inexact that they hold as valueless calculations in which they have been employed. And though there remains no other way to approach the problem, one will be obliged to compare the results of such kinds of calculations with the results of practical observations as frequently as possible, and if these come near the calculated ones, one will not be able to deny a certain value to the latter.

	Calories.
Now the carbon present in the reaction zone at a temperature of 1,150° possesses a heat content the amount of which (according to Viole's formula for the specific heat of coke $C_0 = 0{\cdot}203 + 0{\cdot}00006t$) is ascertained at .	313
The heat of combustion of 1 kilogramme C to CO is (*vide* preceding section)	2,387
Thus the energy content which 1 kilogramme C at 1,150° can liberate in the production of CO is	2,700

This carbon is gasified by means of air at 0°, the air, therefore, introducing no free heat energy into the producer.

In the mass, as gasification takes place, solid carbon disappears, and becomes changed into the products of gasification, which must, therefore, in the moments of their origin, take up the whole quantity of energy produced, which they are of course able to give off later in greater or less scale to other substances capable of taking up energy.

Were theoretically pure air-gas produced, one would obtain from formula (10), p. 28, from 1 kilogramme C, 1·86 cubic metre $CO + 3{\cdot}50$ cubic metres $N = 5{\cdot}36$ cubic metres gas, which at the moment of origin would be endowed with the total available amount of energy. This, from the foregoing, amounts to 2,700 calories.

From the definition of specific heat, the amount of heat Q which is contained in a substance is equal to the temperature of the substance multiplied by its specific heat and weight, or corresponding volume thereof $Q = ctv$, and therefore Q must be equal to

$$2{,}700 = c\,(1{\cdot}86 \text{ cubic metre } CO + 3{\cdot}50 \text{ cubic metres } N)\ t.$$

From the preceding this equation can be transferred intc $t = \frac{Q}{cv}$ and,

$$\therefore\ t = \frac{2{,}700}{c(1{\cdot}86 \text{ cubic metre } CO + 3{\cdot}50 \text{ cubic metres } N)}$$

In this equation c is dependent on t, and one obtains both most conveniently by means of the method of approximation which is given by Th. Beckert in his treatise "Feuerungskunde." According to the tables of the "mean specific heats of 1 cubic metre gas" in the introduction, the specific heat of CO and N is equal, and amounts at 1,200° to 0·3534, and at 1,100° to 0·3496, the mean of which or 0·3515 is taken for the specific heat at 1,150°, whilst 1·86 cubic metre $CO + 3{\cdot}50$ cubic metres $N = 5{\cdot}36$ cubic metres. It is thus $5{\cdot}36 \times 0{\cdot}3515 = 1{\cdot}884$, whence $t = \frac{2{,}700}{1{\cdot}884} = 1{,}433°$.

Inasmuch as the temperature yielded was higher than that assumed, the specific heat was selected at too low a figure: on placing this at the value for 1,400° or 0·3610, one obtains $5{\cdot}36 \times 0{\cdot}3610 = 1{\cdot}395$, and hence

$$t = \frac{2{,}700}{1{\cdot}395} = 1{,}395^\circ \text{ C.}$$

This figure is also not correct, since the basis for the calculation was not correctly selected, owing to the carbon bringing into the reaction zone not 313 calories (corresponding to a temperature of 1,150°), but more, as the temperature of reaction will be higher. Further following up of the problem, however, is saved, as the calculations already made show that the requisite temperature of 1,150° is not only attainable, but is considerably exceeded. This is in accordance with observations made in practice, whereby a producer driven by means of air alone is not able to run cold. It more often heats itself considerably above 1,150°, and this circumstance is the cause why most fuels cannot be gasified by means of air alone. The temperature becomes so high that the constituents of the ashes melt, or sinter together, and form great lumps, which bring the producer to a stop, as their removal becomes impossible. The results obtained are obviously able to be made into a heat balance-sheet.

HEAT BALANCE-SHEET FOR PURE AIR-GAS PRODUCTION.

Heat Units generated in the Producer.	Calories.	Heat Units absorbed in the reaction zone of the Producer.	Calories.
1. Heat content of 1 kilogramme C= . .	313	Heat content of 5·36 cubic metres gas . . .	2,700
2. Combustion value of do.=	8,080	Combustible value of 1·86 cubic metre CO . . .	5,693
3. Heat content of air . .	Nil.		
Total supply of heat .	8,393	Total heat in reaction zone	8,393

(c) INFLUENCE OF THE PRODUCTS OF GAS PRODUCTION ON THE TEMPERATURE OF REACTION.

On p. 43 it has been shown that by the combustion of 1 kilogramme C to CO, 2,387 calories are evolved, whilst measured under normal conditions, 1·86 cubic metre CO is generated. One can thus also say that the generation of 1·86 cubic metre CO involves that in the reaction space 2,387 calories are produced, or that $\frac{2,387}{1 \cdot 86} = 1,283$ calories per cubic metre CO are liberated . . . (19).

If now, instead of CO, CO_2 were produced, 8,080 calories would be liberated by 1 kilogramme C, whilst 1·86 cubic metre, CO_2 would be formed.

Therefore, the production of 1 cubic metre CO_2 is a proof that in the reaction chamber, $\frac{8,080}{1 \cdot 86} = 4,344$ calories are liberated . . . (20).

From a comparison between these two numbers for CO and CO_2 it results that the temperature of reaction in the producer in the production of air-gas must undergo a considerable increase if, in addition to CO, CO_2 is also generated. From the researches of Naumann & Ernst (*vide* pp. 33 and 34), it however follows that the formation of CO_2 at temperatures above 1,000° generally is impossible; and as already in the formation of pure CO a temperature of reaction of far above 1,000° is insured, so in cases in which CO_2 appears in an air-gas must this have had a special cause. The cause thereof is only explainable by free oxygen having reached the gas chamber and having burnt CO already formed. It is thus due to either insufficient thickness of the bed of carbon, or there have been faults in the air supply.

In the dissertation on the reactions in the producer, the formation of water has been already referred to. Herein the oxygen required to gasify the C is derived from water, which is thereby decomposed into its constituents. Now, water consists of H and O, and by the union of both in the form of fluid water at 0°, there is developed from 1 kilogramme H, 34,600 calories,[1] and 9 kilogrammes water are formed.

Therefore, on the decomposition of 9 kilogrammes water, the same amount of energy, *i.e.* 34,600 calories, must be absorbed.

Now, the water is almost exclusively introduced into the producer in the form of steam, and in most producers this steam is taken from the main steam pipes of the works in which it is under a pressure of some atmospheres and possesses an energy content of some 650 calories per kilogramme;

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[1] For these calculations the so-called "higher heat value" is employed.

9 kilogrammes steam corresponds therefore to $9 \times 650 = 5{,}850$ calories, which must be taken as a deduction from the above 34,600 calories, so that the decomposition only requires $34{,}600 - 5{,}850 = 28{,}750$ calories.

In case the steam, in its introduction into the producer, performs mechanical work, thus, should it in some way drive the air supply into the producer, its energy content would be smaller and the requisite amount of heat for its decomposition be higher, which however will be aimed at here.

Thus the amount of heat, 28,750 calories which is expended in the decomposition of 9 kilogrammes steam, from which 1 kilogramme H is produced which under normal conditions occupies a volume of 11·1236 cubic metres; the production of 1 cubic metre H by decomposition of steam requires therefore an amount of heat of $\frac{28{,}750}{11{\cdot}1236} = 2{,}585$ calories . . . (21).

Thus the production of 1 cubic metre H, which is brought about by the decomposition of steam, involves in water-gas or steam-air gas an absorption of 2,585 calories from the reaction chamber and a corresponding diminution in the temperature of reaction.

Thus by the addition of steam to the air supply a means is found of bringing the temperature of reaction to a specified standard and to maintain it thereat.

As hereinbefore the most favourable reaction temperature has been taken at 1,150°, and since at this temperature all atmospheric oxygen is converted into CO, and (practically speaking) all water-vapour is decomposed, and as well all of any CO_2 by chance formed under the circumstances will be converted into CO, it should be investigated how much steam is required for assisting the atmospheric air in maintaining a reaction temperature of 1,150° and what composition of gas would result therefrom.

(*d*) STEAM-AIR GAS WITH PURE CO FORMATION.

Firstly, the case should be considered in which pure CO is produced, so that the product of the producer may consist of $x\text{CO} + y\text{H} + z\text{N}$.

For the development of the foregoing, the employment of pure carbon is required, dry pure air at 0° and steam with an energy content of 650° per kilogramme.

Taking into consideration an amount of 1 cubic metre gas, then will $x+y+z=1$, from which one derives $z=1-x-y$ . . . (*a*).

Further, according to formula (16), p. 31,

$N=z=3{\cdot}762\times\left(CO_2+\frac{CO}{2}-\frac{H}{2}\right)$, and as no CO_2 is present,

$$CO_2=O \text{ and } z=3{\cdot}762\times\left(\frac{CO}{2}-\frac{H}{2}\right) \quad . \quad . \quad . \quad (b).$$

By combination of (*a*) and (*b*) it follows:
(as $CO=x$ and $H=y$) that

$$3{\cdot}762\left(\frac{x}{2}-\frac{y}{2}\right)=1-x-y.$$

These transposed give

$$2{\cdot}881x-0{\cdot}881y=1$$

or

$$y=3{\cdot}27x-1{\cdot}135 \quad . \quad . \quad . \quad (c).$$

A further comparison between x and y furnishes the amount of heat which would be liberated on its production and taken up by the gas at the moment of its origin. This quantity of heat admits of being derived from the above according to the formula

$$Q = \text{heat content of the C gasified} + 1{,}283x - 2{,}585y$$

The heat content of 1 kilogramme C at 1,150° amounts as before given, to 313 calories. In estimating the quantity of C which is necessary for the production of 1 cubic metre of steam-air gas, it should be remembered that from 1 kilogramme C are yielded:

Air-gas . . .	5·36 cubic metres . . .	(*vide* 10).
Water-gas I. . .	3·72 ,, . . .	do. p. 29.
Water-gas II. . .	5·58 ,, . . .	do. p. 30.

As a mean thereof, about 5 cubic metres producer gas would result, and therefore for 1 cubic metre steam-air gas 0·2 C will be required, and a heat content of $313\times0{\cdot}2=63$ calories will be brought into the reaction zone. The expression for Q will consequently be:

$$Q=63+1{,}283x-2{,}585y \quad . \quad . \quad . \quad (d).$$

The quantity of heat Q would, however, at the moment of origin of the gases be completely taken up by these, and be represented by the expression $Q = ct$.

t is known to be 1,150° and the specific heats for CO, H and N are at 1,150° taken at 0·3515. Therefore, for the 1 cubic metre gas taken into consideration, $Q = ct = 1{,}150 \times 0{\cdot}3515 = 404{\cdot}2$ calories . . . (*e*).

Consequently, from (*e*) and (*d*)

$$404{\cdot}2 = 63 + 1{,}283x - 2{,}585y,$$

and in this from (*c*)

$$y = 3{\cdot}27x - 1{\cdot}135,$$

inserting this gives

$$404{\cdot}2 = 63 + 1{,}283x - 8{,}453x + 2{,}934$$

$$\therefore\ 7{,}170x = 2{,}592{\cdot}8 \text{ or}$$

	$x = 0{\cdot}361$	cubic metre	CO
as $y = 3{\cdot}27x - 1{,}135$	$y = 0{\cdot}047$	,,	H
as $z = 1 - x - y$	$z = 0{\cdot}592$	,,	N
Total	$= 1{\cdot}000$	cubic metre	gas.

100 cubic metres gas, therefore, contains in relation to composition in vols. per cent. of steam-air gas manufactured from cold air and carbon at a reaction temperature of 1,150°:—

CO = 36·1 per cent.
H = 4·7 ,,
N = 59·2 ,,

From gas of this composition, the quantity of gas which one would obtain from 1 kilogramme C may be estimated. In 100 cubic metres of the gas there are 36·1 cubic metres of C-containing gases (in the foregoing case only CO is present). According to formula (17), this corresponds to $0{\cdot}538 \times 36{\cdot}1 = 19{\cdot}4$ kilogrammes C, and 1 kilogramme C will furnish $\frac{100}{19{\cdot}4} = 5{\cdot}14$ cubic metres gas.

As the product of the figure 0·538 times the volume of C-containing gases, and the quotient which results from dividing 100 by this product, is frequently brought into use in gas calculations, a table is appended, from which the required amounts can be taken direct.

The composition of the gas from 1 kilogramme C will therefore be

$5{\cdot}14 \times 0{\cdot}361 = 1{\cdot}86$ cubic metres CO
$\times 0{\cdot}047 = 0{\cdot}24$,, H
$\times 0{\cdot}592 = 3{\cdot}04$,, N
Total 5·14 cubic metres steam-air gas,

in which 0·24 cubic metre H is contained, which from formula (12) produces 0·24 cubic metre H_2O vapour, or transposing this into kilogrammes, one obtains by multiplying the volume by the weight of 1 cubic metre $0{\cdot}24 \times 0{\cdot}8501 = 0{\cdot}193$ kilogramme steam.

The amounts of steam to be employed and also the hydrogen content of the steam-air gas are thus remarkably small, if one obtains in the production of this same, formation of pure CO, and the result is in accordance throughout with all observations which have been able to be made practically.

(c) THE COMBUSTIBLE VALUE OF THE GAS PRODUCED AND THE EFFICIENCY OF THE PRODUCER.

The calculation of the combustible value of the gas produced for a certain gas volume is easily performed by multiplication of the volume of each individual combustible gas by its combustible value, which can be taken from the tables given in the Appendix, and by addition of all the products. Usually, the combustible value for 1 cubic metre gas is given, and then one uses direct the figures in the gas analyses (whilst one naturally shifts the decimal point two places to the left). If one, however, wishes at the same time to know the efficiency of the producer, one must refer the volume of gas and its combustible value to the unit of weight of the combustible which will be employed, and the combustible value of which must likewise be known. The combustible value of the same kind of fuel varies, however, quite importantly, which is clearly perceivable owing to the ash content and the content of hygroscopic water in fuel being subject to great fluctuations. Therefore, the writer is more inclined to refer the amount of gas and the combustible value of the gas to the unit of weight of carbon in the gas instead of to the unit of weight of the raw fuel, a method which has already been employed by Bunte and Ledebur. One thereby obtains many lucid figures, which for the rest can be referred to the raw fuel with facility. In this connection, one only requires to bear in mind the percentage of C in the fuel.

In the production of air-gas, one obtains a gas of the composition 34·7 per cent. CO + 65·3 per cent. N, the combustible value of this gas being $0{\cdot}347 \times 3{,}063 = 1{,}062$ calories.

The combustible value of the gas from 1 kilogramme C (inasmuch as 1 kilogramme C furnishes 1·86 cubic metre CO) is $1{\cdot}86 \times 3{,}063 = 5{,}693$ calories. In manufacture of the gas, 1 kilogramme C with a combustible value of 8,080 calories will be employed, hence the efficiency of the producer amounts to $\frac{569.300}{8{,}080} = 70{\cdot}4$ per cent.

The gases had at their origin (*vide* heat balance-sheet, p. 45) a heat content of 2,700 calories, of which 313 calories (heat content of the C) originated in the producer, which again must be given off. There have been, therefore, 2,387 calories or 29·6 per cent. of the combustible value of the C converted into heat content of the gas produced. On production of the steam air-gas previously considered, there is, on the other hand, a combustible gas which contains per cubic metre 0·361 cubic metre CO and 0·047 H. The combustible value of this gas per cubic metre is thus

$$\begin{array}{rl} 0{\cdot}361 \times 3{,}063 = & 1{,}105 \text{ calories} \\ 0{\cdot}047 \times 2{,}620 = & \underline{123 \quad\;\; ,,} \\ & \underline{\underline{1{,}228 \text{ calories}}} \end{array}$$

that is to say, 166 calories or 15 per cent. higher than the pure air-gas.

The combustible value of the gas from 1 kilogramme C thus, is

$$\begin{array}{rl} 1{\cdot}86 \text{ cubic metre CO} \times 3{,}063 = & 5{,}693 \text{ calories} \\ 0{\cdot}24 \text{ cubic metre H } \times 2{,}620 = & \underline{629 \quad\;\; ,,} \\ \text{Total} & \underline{\underline{6{,}322 \text{ calories.}}} \end{array}$$

There is thus derived from pure C an efficiency of

$$\frac{632{,}200}{8{,}080} = 78{\cdot}2 \text{ per cent.}$$

The efficiency of the producer has thereby been increased almost 8 per cent. above that due to the production of pure air-gas. The fact is easily explained, in that just as the reaction temperature is lower, and the heat content of the gas is lower, the amount of heat which remains owing to its transmutation into latent heat is the greater.

This kind of calculation of the efficiency of the producer is not quite correct, and really on the ground that other sources of heat are introduced into the producer than the combustible value and heat content of the C. These amounts are furnished by the steam which gets decomposed. In respect of these values, one obtains the following heat balance-sheet :—

Heat generated in the Producer.	Calories.	Received by the Gas at Moment of Origin.	Calories.
1 kilogramme C heat content	313	5·14 cubic metres gas heat content at 1,150°=1,150×5·14×0·3575= . . .	2,078
1 kilogramme C combustible value (total) . . .	8,080	Combustible value of gas .	6,322
0·193 kilogramme steam× 650 calories . . .	125	In the water-vapour of the products of combustion there will remain latent 0·193 x 600 which belong to the combustible value .	116
		Error of calculation . .	2
	8.518		8,518

Of these 8,518 calories, 313 calories are furnished by and returned to the producer, so that only 8,205 calories remain These can be allocated as

$$\text{Combustible value } \frac{632,200}{8,205} = 77 \text{ per cent.}$$

$$\text{Heat content (sensible heat)} = 23 \text{ per cent.}$$

(*f*) The Production of Producer Gas with High Hydrogen Content.

The favourable results which are able to be produced by means of the introduction of small proportions of steam into the producer must create a desire to produce gases of higher combustible value, and, if possible, to ensure a better utilisation of the fuel. At the first glance it appears as if this were to be attained by means of an increased decomposition of steam, as by such means the hydrogen content of the gas would be correspondingly increased. Simultaneously, also the nitrogen content must be lowered and a gas be obtained which would be lower in non-combustible substances. Hydrogen has hitherto been regarded as a very valuable heating gas, since, as will be remembered by everyone, until recently it has been practicable to obtain the highest temperatures only by means of the oxy-hydrogen jet; and further, one always remembers that hydrogen possesses the enormous combustible value of 34,600 calories per kilogramme. In connection with this figure, it should be borne in mind that hydrogen is very light, and therefore 1 kilogramme H occupies a very large volume. If one calculates the combustible value on the volume content, its halo diminishes, and it turns out to be 2,629 calories per cubic metre, and is considerably inferior to carbon monoxide (3,063 calories per cubic metre), and even more importantly inferior to the hydrocarbons (CH_4 8,600 and C_2H_4 14,186 calories per cubic metre).

Well and good, the gas before considered proves that a high hydrogen content admits of superiorities and advantages, and it is worth while to investigate when these attain their limit.

One thing is already clear, namely, that the production of hydrogen from water-vapour involves absorption of heat from the zone in which reaction occurs and lowering of the reaction temperature. This temperature of reaction must, however, have a minimum amount if the process is to be free from defects. If it is desired to decompose more water than calculated above, there must be more heat available in the producer.

This can be provided for in two ways:—

1. By allowing more relative production of CO_2 to CO.
2. By introducing additional heat into the producer by means such as superheating the steam or preheating the air supplied thereto.

From the aspects presented by the first-named method, one can at once see one's way superficially from consideration of the two classes of so-called water-gases dealt with on pp. 29 and 30.

The combustible value of these gases amounts per cubic metre of gas to

Water-gas I.	Calories.	Water-gas II.	Calories.
0·5 cubic metre CO × 3,063=	1,531	0·33 cubic metre CO_2 × 0 =	0
0·5 cubic metre H × 2,620=	1,310	0·67 cubic metre H × 2,620=	1,755
Combustible value per cubic metre	2,841	Combustible value per cubic metre	1,755

For the total gas from 1 kilogramme C, however,

	Calories.		Calories.
1·86 cubic metre CO × 3,063=	5,693	1·86 cubic metre CO_2 . .	0
1·86 cubic metre H × 2,620=	4,868	3·72 cubic metres H . .	9,736
3·72 cubic metres.		5·58 cubic metres.	
Combustile value of gas from 1 kilogramme C .	10,561	Combustible value of gas from 1 kilogramme C .	9,736

These numbers prove that the combustible value of the gas with formation of pure CO is decidedly superior to that of the gas, overburdened with formation of pure CO_2. The fuel is present in the first gas in a concentrated form, since it produces from 1 kilogramme C only 3·72 cubic metres gas, against 5·58 cubic metres in the second case.

As to the efficiency of the producer, one cannot of course form a judgment, since one obtains from 1 kilogramme C with a combustible value of 8,080 calories gas with a combustible value of 10,561, or alternatively 9,736 calories. Thus there has been more heat at disposal in the producer, than the carbon itself could evolve, but this excess-heat cannot be estimated in the absence of data as to the sensible heat possessed by the gases.

From the foregoing, it can be maintained that these sensible heats must be different—at least the temperature of CO_2-containing gas must be lower than that of the gas with formation of CO, because CO_2 can only be produced in considerable quantities at reaction temperatures under 1,000°.

One can most simply solve the question if one calculates the theoretical composition of the steam-air gas, which would result if carbon were wholly converted into the form of CO_2. That this is not practically attainable need not further deter one, as the result will only serve to point out the influence of the formation of CO_2 in complete purity. It is also not practicable to manufacture gas with formation of pure CO. However, the values obtained represent the extremest limits between which the results must lie, which arise from the simultaneous formation of CO_2 and CO.

From Table A (Naumann and Ernst) the maximum formation of CO_2 with air occurs at about 700° C., and let it be assumed that at this temperature steam is decomposed into H and O, and that the O set free combines with carbon, forming CO_2. According to the method of continual approximation, it will be found that 6·66 cubic metres of gas will be furnished from 1 kilogramme C, and that thus the quantity of heat that the requisite C brings into the reaction zone amounts to 28 calories according to the assumption as to the production of 1 cubic metre gas.

The amount of heat which this gas must take up at the moment of its origin will be given by the expression

$$Q = ct, \text{ wherein } t = 700°.$$

For C^t_o the specific heat of the so-called "fixed" gases CO, H, N, O can no longer be taken, as CO_2 is present in larger measure. By the method of approximation one ascertains that about 28 per cent. CO_2 would be present, and thereby one obtains 0·3983 for the mean specific heat of the gas at 700°.

Thus

$$Q = 0{\cdot}3983 \times 700 = 279 \text{ calories per cubic metre gas.}$$

Representing then the content of CO_2 in this by x, of H by y, and of N by z, whence $x+y+z=1$, then, as 1 cubic metre gas will be taken into consideration, one can ascertain Q in like manner to that given on p. 49, it is, viz., equal to the sensible heat of the C (as above found, *i.e.*, 28 calories) + the heat resulting from the formation of $x CO_2$, consequently from formula (20), 4,344x; *minus* the heat which would be associated with the production of x cubic metre H, which from (21) amounts to − 2,585 y.

Therefore

$$Q = 28 + 4{,}344x - 2{,}585y = 279 \text{ calories.}$$

It admits of being approached further from the formula for steam-air gas, from which

$$N = z = 3{\cdot}762 \left(CO_2 + \frac{CO}{2} - \frac{H}{2}\right).$$

In this

$$CO_2 = x,\ CO = \text{zero},\ H = y,$$
$$z = 3{\cdot}762x - 1{,}881y;$$

and from

$$x + y + z = 1,\ z = 1 - x - y,$$

wherefrom

$$1 - x - y = 3{\cdot}762x - 1{,}881y,$$
$$\therefore\ 0{\cdot}881y = 4{\cdot}762x - 1,$$
$$y = 5{\cdot}405x - 1{\cdot}135.$$

Placing these values in the equation for Q one obtains

$$279 = Q = 28 + 4{,}344x - 2{,}585(5{\cdot}405x - 1{\cdot}135),$$
$$\therefore\ 279 = 2{,}962 - 9{,}628x,$$

whence		$x = 0{\cdot}279$ cubic metre	CO_2
from	$y = 5{\cdot}405x - 1{\cdot}135$,	$y = 0{\cdot}373$,,	H
from	$z = 1 - x - y$	$z = 0{\cdot}348$,,	N
		1·000 cubic metre gas.	

The combustible value of this gas calculates out thus:—

0·373 cubic metre H × 2,620 = 977 calories.

It results herefrom that the combustible value of the gas is extraordinarily low, even being inferior to the combustible value of pure air-gas. Thus on this ground steam-air gas with CO_2 formation appears as of minor value.

Nevertheless, possibly the utilisation of the fuel could be achieved better, and in order to investigate this, the amounts of gas which can be obtained from 1 kilogramme must be determined.

The gas contained per cubic metre, 0·279 cubic metre CO_2, which corresponds to a C content of $0·279 \times 0·538 = 0·15$ kilogramme (*vide* Tables); and from 1 kilogramme C, therefore, $\frac{1}{0·15} = 6·66$ cubic metres gas will be obtained. The combustible value of the gas from 1 kilogramme C is thus $6·66 \times 977 = 6{,}507$ calories. The efficiency of the producer would therefore be roughly reckoned at $\frac{650{,}700}{8{,}080} = 80·5$ per cent., and therefore actually higher than with pure air-gas production, and even somewhat better than with production of CO_2 free producer gas. Herein, however, the amount of heat which has been introduced into the producer owing to the steam has not been taken into account.

In order to be able to do this, the amount of steam must be fixed which 1 kilogramme C will decompose. From 1 kilogramme C is produced 6·86 cubic metres gas containing 37·3 per cent. H, or 2·48 cubic metres H, which must be produced from 2·48 cubic metres steam. This, however, weighs $2·48 \times 0·8051 = 2$ kilogrammes.

Herefrom one derives the

HEAT BALANCE-SHEET FOR STEAM-AIR GAS (WITH FORMATION OF PURE CO_2).

Introduced into Producer.		Taken from the Producer at Moment of Origin of Gas.	
	Calories.		Calories.
Sensible heat of C . . .	185	Combustible value of gas .	6,507
Combustible value . .	8,080	Sensible heat of gas 279 × 6·66	1,858
Introduced with steam 2 × 650	1.300	In outlet gas 2 × 600 . .	1,200
Total . . .	9,565	Total . . .	9,565

From this there are, as set free by the producer and returned thereto, to be deducted 185 calories, thus leaving 9,380 calories, and the efficiency becomes $\frac{650{,}700}{9{,}380} = 69·4$ per cent. For comparison the results found are set out together in Table D.

TABLE D.

From 1 kilogramme pure C there will be obtained

	Theoretical pure Air-gas.	Theoretical Steam-air Gas with pure CO.	Theoretical Steam-air Gas with pure CO_2.
Quantity of gas obtained .	5·36 cubic metres	5·14 cubic metres	6·66 cubic metres
Steam decomposed by 1 kilogramme C.	—	0·193 kilogramme	2·0 kilogrammes
Temperature of origin of gas.	Above 1,400° C.	1·150° C.	700° C.
Combustible value of gas per cubic metre.	1,063 calories	1,228 calories	977 calories
Sensible heat of gas . .	2,700 ,,	2,078 ,,	1,858 ,,
Combustible value of gas .	5,693 ,,	6,322 ,,	6,507 ,,
Latent heat in the steam of products of combustion after combustion and condensation of the steam appearing . . .	—	116 ,,	1,266 ,,
Efficiency of the producer taken on the total heat introduced . . .	70·4 per cent.	77 per cent.	69·4 per cent.

The statement shows that by means of steam-air gas production, the gas volume which one can produce from a known quantity of fuel is able, on the contrary to air-gas production, to be well diminished, and the gaseous fuel thus be able to be made with more concentrated heat energy. Simultaneously the temperature of production will be reduced, and therefore it follows also the amount of sensible heat which the gas carries away from the producer, and thus the efficiency be increased. One easily perceives, however, also the limit up to which it is possible, since, in the production of steam-air gas, the steam addition will become so much increased, that formation of CO_2 must result; thus the gas volume increases, and moreover there appears (at least according to the kind of calculation employed) a new considerable source of loss thereby, in that water results from the combustion of H, which appears in the form of steam, and therefore carries with itself 600 calories per kilogramme in latent form. Hence the degree of efficiency of the producer will be reduced, finally, in the theoretical limits of pure CO_2 formation, to sink under the value which is obtained in pure air-gas production. The combustible value of the gas per unit of volume will, owing to the presence of CO_2, be considerably diminished, and hereby it results *that it is abortive to drive the addition of steam beyond the limit of the cessation of the minimum reaction temperature necessary for the formation of pure* CO.

This conclusion has been on all sides confirmed by experience in practice, and thus, amongst others, Lehrmann (" Stahl und Eisen," 1903, p. 435) maintains "that the introduction of H_2O vapour into the producer, can only be advantageous if one, nevertheless, is in a position to produce CO_2 free gas." Further, it has been demonstrated by practical experiments, as also follows from researches of Harries (p. 36), that by the introduction of large amounts of steam into the producer large quantities pass through the producer undecomposed. But thereby the quantity of heat which was expended on its production is lost, the steam is more highly heated in the producer, and carries off this heat, and imparts it finally to the properties of the producer gas, which is prejudicial to working of the furnace, and will be discussed later.

(*g*) Steam-Air Gas Production with Preheated Air Supply.

The second way of producing a steam-air gas with high hydrogen content, consists in the employment of superheated steam, or preheated air supply, and aims, owing to the sensible heat of the gasifying medium introduced, at compensating for the heat losses, which must result from increased decomposition of water. The steam and air should be just so much preheated, that in spite of the increased addition of steam, the reaction temperature is maintained at 1,150°, and thus also the conditions for pure CO formation are maintained.

One easily perceives that by means of superheating the steam which (as is apparent from Table E, given on p. 60) may only be achieved in practice in small measure, only a quite small calorific figure can be obtained, which may be summed up by the formula (*d*), p. 48:

$$Q=63+1{,}283x-2{,}585y,$$

since in the above calculation the steam has already been loaded with an amount of energy of 650 calories per kilogramme. Preheating the air will at all times furnish considerably higher values, and it is therefore, for establishing the values in the following table, only taken into account, whilst the steam is taken as before with 650 calories per kilogramme. Also the amounts of air are taken by approximation, and the writer believes himself to be allowed this liberty, since the calculations (themselves) owing to the unsafety of the values for the specific heat, can make no claim to accuracy, and only comparative values be obtained.

Table E.—Composition of the Steam-Air Gas, which is able to be produced by means of Preheated Air. Reaction Temperature 1,150° formation of Pure CO.

Degree of preheating of the Air.	Composition of Gas. Volumes per cent.			Gas from 1 kilogramme C in cubic metres.	Combustible Value.		Steam decomposed by 1 kilogramme C.	
	CO per cent.	H per cent.	N per cent.		1 cubic metre gas. Calories.	Gas from 1 kilogrammeC. Calories.	Cubic metre.	Kilogramme.
0°	36·1	4·7	59·2	5·14	1,228	6,322	0·24	0·193
50°	36·3	5·2	58·5	5·12	1,248	6,390	0·27	0·21
100°	36·5	5·8	57·7	5·09	1,270	6,464	0·29	0·23
200°	36·8	6·8	56·4	5·05	1,305	6,590	0·33	0·27
300°	37·1	7·8	55·1	5·00	1,340	6,700	0·38	0·31
400°	37·4	8·7	53·9	4·97	1,373	6,824	0·42	0·34
500°	37·7	9·7	52·6	4·93	1,408	6,941	0·47	0·38

The calculation has been only carried out up to preheating of the air to 500°, as the employment of more highly heated air supply for gas producers can scarcely come practically into the question. The figures show that one is able to obtain about 5 per cent. more H in the gas, and derive about 600 calories more per kilogramme C.

In case the preheating were performed by means of the waste heat of the producer itself, it would mean that a higher efficiency resulted. As the added steam amounts to 0·38 kilogrammes per kilogramme C, there has been brought into the producer $0{\cdot}38 \times 650 = 247$ calories, *plus* combustible value of C, *i.e.*, 8,080 calories, or a total of 8,327 calories, from which gas with a combustible value of 6,941 calories originates. The efficiency therefore will be $\frac{694,100}{8,327} = 83$ per cent., as against 77 per cent. by the employment of cold air.

But the improvement in quality of the gas, as the combustible value has been increased from 1,228 to 1,408 calories per cubic metre, is not inconsiderable.

CHAPTER VIII

INFLUENCE OF INCOMPLETENESS OF THE REACTIONS

It is theoretically impossible to obtain formation of pure CO or CO_2 from the influence of O or water-vapour on an excess of carbon, since it always results in the production of both gases. By the observance of the correct and most favourable reaction conditions, one is enabled, however, to reduce the CO_2 content to a certain minimum, and thus, for example, Naumann and Ernst (*vide* F. Fischer, p. 201) obtained by passing CO_2 over coke heated in a porcelain tube to 1,060° a gas mixture which contained 2·1 per cent. CO_2 and 97·9 per cent. CO.

Harries (*vide* p. 36) obtained by the passage of steam over incandescent coke at a temperature of 1,125° C.

$$1{\cdot}24 \text{ per cent. } CO_2 + 98{\cdot}76 \text{ per cent. } CO.$$

One can thereupon assume that it is possible to produce a gas in which in 100 parts of CO and CO_2 there exist 2 parts CO_2 and 98 parts CO, and can further make use of these figures as a means of remodelling the calculated theoretical composition of the steam-air gas manufactured from cold air, as they represent the limit which should be striven after in practice, having in view that it is actually able to be achieved.

The composition of the theoretical steam-air gas was

$$36{\cdot}1 \text{ per cent. } CO + 4{\cdot}7 \text{ per cent. } H + 59{\cdot}2 \text{ per cent. } N,$$

of which 36·1 per cent. C-containing gas, whereof 2 per cent. is able to be CO_2 and 98 per cent. CO.

There must thus be 0·722 per cent. CO_2 and $36{\cdot}1 - 0{\cdot}722$ per cent. CO, or in round figures 0·8 cubic metre CO_2 and 35·3 cubic metres CO, present in 100 cubic metres of gas, in conjunction with 4·7 cubic metres H and x cubic metres N.

As the gas is steam-air gas, the N content must correspond to the formula $N=3{\cdot}762\left(CO_2+\frac{CO}{2}-\frac{H}{2}\right)$, and thus

$$N=3{\cdot}762\left(0{\cdot}8+\frac{35{\cdot}3-4{\cdot}7}{2}\right)=60{\cdot}5.$$

Herefrom one derives the composition of technically produced steam-air gas as

CO_2 . . .	0·8 cubic metre	or	0·8 per cent.	CO_2
CO	35·3 ,,	,,	34·8 ,,	CO
H	4·7 ,,	,,	4·6 ,,	H
N	60·5 ,,	,,	59·8 ,,	N
	101·3 cubic metres.		100 per cent.	

with a combustible value of 1,186 calories per cubic metre with a gas volume of 5·23 cubic metres per kilogramme C, and a combustible value of the gas from 1 kilogramme C of, roundly, 6,200 calories. The composition for 1 kilogramme C calculates out at

CO_2 . .	0·04 cubic metre	1·86 cubic metre C-containing gas
CO . .	1·82 ,,	
H . .	0·24 ,,	
N . .	3·13 ,,	
	5·23 cubic metres gas . . . (22).	

Owing to the inconsiderable CO_2 formation, there will occur an increase of the reaction temperature, which will admit of slightly increased formation of H. This circumstance is negligible owing to its small utility.

CHAPTER IX

THE DISTILLATION GAS

UP to the present, the gaseous products which admit of manufacture from pure carbon in the producer have been dealt with. However, in Nature, absolutely pure carbon is not at disposal for the purposes of producers, but fuels contain generally not inconsiderable amounts of bituminous ingredients, which, on heating in the producer, escape in the form of gas, and mingle with the steam-air gas. The solid fuel, however, is purified by means of this "degasification process" (*i.e.*, coking), and is able finally, in conjunction with the ingredients of the ash, to reach the gasification zone in the form of pure carbon. If one desires to form from the gas analysis an idea of the degree of completeness of the production of the steam-air gas in practice, this can only happen if one knows the composition and amount of the products of distillation of the fuel employed at the time. Herein, however, lies the most difficult point in the investigation of heating gas, since there are innumerable kinds of fuel, the actual composition of which, as a basis for each case, it is difficult to ascertain, because this composition is not constant, coals from the same stratum showing considerable differences. But if the overcoming of this difficulty were achieved it would not help much, since the composition of the products of distillation depends essentially on the temperature of the degasification, and on the rapidity with which this takes place. One is able therefore to obtain from one and the same fuel considerably divergent products of distillation. Experiments have not failed to establish a connection between the composition of the distillates and the composition of the fuel, though they all, on the ground mentioned, remain somewhat futile. There is nevertheless another way to be found, which furnishes at least an approximate solution of the question.

If one considers the raw fuel, then its products of gasification, and lastly the products of complete combustion, one finds that the materials to be treated in this series always become of simpler kinds, and finally are narrowed down to the three simple substances, CO_2, H_2O, and N.

From the products of complete combustion of the fuel, one can already draw some conclusions of importance.

The products of combustion of pure C with pure dry air are CO_2 and N, and so one obtains from 1 kilogramme by direct combustion of the C according to formula (5)

1·86 cubic metre CO_2+7·00 cubic metres N,

whilst the production of air-gas from (10)

1·86 cubic metre CO+3·50 cubic metres H, is furnished.

If the gas be completely burnt with air, one would obtain, since according to (18) 1·86 cubic metre CO requires $1{\cdot}86 \times 0{\cdot}5 = 0{\cdot}93$ O, a yield of 1·86 cubic metre CO_2. The 0·93 cubic metre O brought, however, with it 3·5 cubic metres N; the products of combustion are therefore 1·86 cubic metre CO_2+7·00 cubic metres N—that is to say, they are the same as that due to direct combustion of pure C. If the pure C is gasified by the means of water-vapour, then the gas shows a content of hydrogen. For example :—

Composition of Gas from 1 kilogramme C.	Best Steam-air Gas. Formula (22).	Water-gas I. (p. 29).	Water-gas II. (p. 30).
CO_2	0·04 cubic metre	—	1·86 cubic metre
CO	1·82 ,,	1·86 cubic metre	—
H	0·24 ,,	1·86 ,,	3·72 cubic metres
N	3·13 ,,	—	—

Should these gases be completely burnt by air, the air requirement and composition of the products of combustion are easily ascertained from observation of the formulæ (18), (12), and (1).

Best Steam-Air Gas.	Water-Gas I.	Water-Gas II.
Cubic metre. Cubic metre.	Cubic metre.	Cubic metre.
(18) O required for 1·82 CO × 0·5 = 0·91 O . .	0·93 O	—
(12) ,, ,, ,, 0·24 H × 0·5 = 0·12 O . .	0·93 O	1·86 O
Total O required 1·03 O . .	1·86 O	1·86 O
This O carries with it N (1) . . 3·87 N . .	7·00 N	7·00 N
Products of Combustion produced from		
Cubic metre. Cubic metre.		
CO_2 0·04 CO (18) 1·82 } 1·86 CO_2	1·86 CO_2	1·86 CO_2
N 3·13+3·87=7·00 N	7·00 N	7·00 N
H 0·24=0·24 H_2O vapour	1·86 H_2O vapour	3·72 H_2O vapour.

The products of combustion are in all cases 1·86 cubic metre CO_2+7·00 cubic metres N, *plus* changing amounts of water-vapour, and those, by the way, exactly as much as were used in the production of the gases. By the ordinary methods of gas analysis, the water condenses, and there will only be found 1·86 cubic metre CO_2+7·00 cubic metres N.

If, therefore, on combustion, products of combustion appear in which the ratio of CO_2 to N corresponds to 1·86 cubic metre to 7·00 cubic metres, one arrives at the conclusion that it has been produced from pure C.

In case it be known that not solid carbon, but a gaseous fuel has, on combustion with air, resulted in these products of combustion, so the composition of the same shows that pure C has served in the production of the gas, which has been gasified by means of pure air or water, or both. But knowledge will be required whether, and, in that event, how much, water took part in the gasification; thus, further, either the water-vapour content of products of combustion should be estimated, or the hydrogen content of the gas itself should be tested. From these estimates the *rôle* which devolved upon the water-vapour in the gasification is clearly shown.

Conversely it appears possible that a different composition of the products of combustion indicates that the original fuel was not pure carbon, but that it contained impurities. If one should to some extent succeed in estimating these quantitatively, it does not appear hopeless to succeed in estimating, from the composition of the gas itself, some explanation as to the occurrences which yield other substances in addition to C.

If in addition to C the fuel also contained so-called free H, and incidentally assumed a quantity corresponding to 0·5 cubic metre H per kilogramme C, it is clear that more O, and thus more air, is necessary for the combustion of an amount of fuel containing 1 kilogramme C. There will be required—

For 1 kilogramme	C	1·86 cubic metre	O+7·00	cubic metres	N
,, 0·5 ,,	H	0·25 ,,	O+0·94	,,	N
Or a total of . .		2·11 ,,	O+7·94	,,	N

and in the products of combustion of 1 kilogramme C there will be found 1·86 cubic metre CO_2 and 7·94 cubic metres N.

The ratio of CO_2 to N has now become altered ; the amount of nitrogen has increased. It has increased by 3·762 times the amount of oxygen which was necessary for the combustion of the free hydrogen. Thus the ratio of CO_2 to N is a criterion for the event of the presence of so-called free hydrogen in the fuel, and if the products of combustion are produced from a gaseous fuel, a proof therefore *that free H also has been present in the combustible gas* and in an amount which can be estimated from the ratio of CO_2 to N in the products of complete combustion.

It must hence be shown from this that the content of free H found by this method is throughout not identical with the content of free H, which will be found from an analysis of the gas into its elements, but almost never identical with it. Nevertheless, the estimation of the same by the method given from the products of complete combustion is able to have some value for examination of the fuel, since it enables one to ascertain by experiment the quantity of hydrogen which is enabled to be given off from the fuel actually in combustible form.

Now, however, the hydrogen which constitutes the principal basis of the bituminous ingredients does not go off in the free state during the degasification process, but a large portion of the same forms compounds, and these with C. In producer gas, one finds, in addition to H, generally CH_4 and more highly carbonised hydrocarbons. The latter, however, only appear in quite small quantities, and are generally regarded as C_2H_4.

In CH_4 there are for 12 kilogrammes C, 4 kilogrammes H, which, together, thus furnish 16 kilogrammes CH_4. 16 kilogrammes CH_4 occupies, however, under normal conditions (as 1 cubic metre CH_4 then weighs 0·7178 kilogramme) a volume of $\frac{16}{0{\cdot}7178}=22{\cdot}3$ cubic metres, whilst 4 kilogrammes H, occupies $\frac{4}{0{\cdot}0899}=44{\cdot}6$ cubic metres, which yields that there is able to be produced from

$$C+2 \text{ cubic metres } H=1 \text{ cubic metre } CH_4 \quad . \quad . \quad . \quad (23).$$

In other words, one is able to regard 1 cubic metre CH_4 as resulting from C and 2 cubic metres H.

In C_2H_4 per 24 kilogrammes C there are 4 kilogrammes H, which give 28 kilogrammes C_2H_4. 28 kilogrammes C_2H_4 occupy under normal conditions

$$\frac{28}{1{\cdot}2503}=22{\cdot}3 \text{ cubic metres.}$$

4 kilogrammes H on the contrary $\frac{4}{0{\cdot}0899}=44{\cdot}6$ cubic metres, thus there results from

$$C+2 \text{ cubic metres } H=1 \text{ cubic metre } C_2H_4 \quad . \quad . \quad . \quad (24).$$

Thus each volume of CH_4 or C_2H_4 corresponds to 2 volumes of free hydrogen, and one can easily estimate the total amount of hydrogen, taken as in the free state, if one multiplies by 2 the amounts of CH_4 and C_2H_4 present and adds them to the content of free H.

If, for example, a gas contains

$$C_2H_4 \ 3{\cdot}1 \text{ cubic metres} + CH_4 \ 23{\cdot}7 \text{ cubic metres} + H \ 56 \text{ cubic metres,}$$

this will correspond to an amount of hydrogen taken in the free state of

C_2H_4 3·1×2= 6·2 H
CH_4 23·7×2=47·4 H
H . =56·0 H

Total . 109·6 cubic metres free hydrogen.

Thus one has a means of drawing up a comparison between the total amount of a gas and the free hydrogen.

In Table F use has been made of this means.

TABLE F.—GASES PRODUCED BY DISTILLATION FROM COAL (FERD. FISCHER).

Origin.	Composition in Volumes (cubic metres).							H taken as free Hydrogen = cubic metres.
	C_mH_n.	CH_4.	H.	CO.	CO_2.	O.	N.	
1. Otto Hofmann, first 14 hours.	5·2	38·7	38·4	6·1	3·6	0·3	7·7	126·2
2. Otto Hofmann, last 19 hours.	2·4	29·2	50·5	6·3	2·2	0·3	9·1	113·7
3. Hussener Ofen .	2·3	27·5	58·6	4·5	0·9	0·5	5·7	118·2
4. ,, ,, .	2·0	24·8	61·7	4·6	0·9	0·4	5·6	115·3
5. Otto Hofmann .	2·2	36·3	53·6	6·5	1·4	—	—	130·6
6. Solway (Belgium) .	2·6	31·2	52·8	7·9	3·3	2·3	2·0	120·4
7. ,, (England) .	3·1	23·7	56·0	8·8	3·0	—	—	109·6
8. Wright . . .	7·5	42·7	38·0	18·7	—	—	2·9	138·2
9. ,, strongly heated.	5·8	34·5	43·8	12·5	—	—	3·4	124·4
10. Wright, strongly heated.	4·5	30·7	48·0	14·0	—	—	2·8	118·4
11. Wright, first 10 minutes.	10·8	58·2	20·4	6·2	2·2	—	2·2	158·4
12. Wright, after 1 hour 30 minutes.	6·1	44·7	38·9	5·7	2·1	—	2·5	140·5
13. Wright, after 3 hours 25 minutes.	3·0	33·7	52·9	6·3	1·5	—	2·6	126·3
14. Wright, after 3 hours 35 minutes.	1·8	22·6	67·2	6·1	1·5	—	2·5	116·0
15. Mixed test from Westphalian coal.	3·2	35·8	48·9	7·2	1·2	—	3·7	126·9
16. Mixed test from Saar coal.	4·4	35·5	45·2	8·6	2·0	—	4·8	125·0
17. Mixed test from Bohemian coal.	4·4	33·0	45·2	10·0	3·0	—	4·4	120·0
18. Mixed test from Saxon coal.	4·0	35·9	45·3	9·5	2·2	—	3·1	125·1
19. Mixed test from Bohemian coal shale coal.	9·9	37·1	39·6	8·3	3·2	—	1·9	133·6
Mean	4·5	34·0	47·6	8·3	1·8	0·2	3·5	124·6

In the last column the volumes of free hydrogen are set out, which would result from the decomposition of the gases in question into their constituents.

As already mentioned, the composition of the distillation gases according to the species of fuel employed, as also the conditions by which the dry distillation is governed, can be very different. The composition of the distillation gases as they take place in the producer has moreover as yet never been ascertained, and will perhaps never admit of being ascertained. Explanation of the question can only at the present time be obtained by means of observation of the gases which are produced under other, but similar circumstances, and as such, gases from coke ovens, are at disposal. A series of such is taken from the work of Ferdinand Fischer, in which H_2S has been left out, and the remainder calculated in percentages.

All the foregoing gases are produced from mineral coal, and therefore the conclusions which are able to be drawn from the composition are only good for gases from producers which have been worked with similar fuels. This is, however, for the overwhelming majority the case; for review of the gases, which will be won from peat or wood, and in certain events, lignite, the distillation gases must naturally be based on these substances.

The table shows the following important peculiarities of distillation gases :—

That, of the volume, the overwhelming ingredient of the gases is hydrogen, either in its free form or combined with carbon.

(2) That hydrogen carries off in the gas not inconsiderable quantities of carbon from the solid fuel.

(3) In the gases there are minute quantities of N.

(4) Similarly small amounts of oxygen combined with carbon go over into the gases. This points also to the so-called chemically-combined water taking an active part in the actions during gasification.

The composition of the gases fluctuates within wide limits, and it is apparent from the researches of Wright quoted that one and the same fuel is able to give off gases of quite different composition, as, for instance, in the first example the CH_4 content of 42·7 per cent. gradually goes down to 30·7 per cent., and in the second even from 58·2 per cent. to 22·6 per cent. There are, that is to say, gases at the commencement of dry distillation richer in C, whilst at the conclusion of the same more free hydrogen is present. Such phenomena will, however, be manifested likewise in producer working, since the smallest producers are similarly worked; and were a large amount of fuel at a time charged into the producer, gases must similarly result, which are very rich in hydrocarbons, whilst later more free hydrogen would be given rise to, and then finally periods make their appearance when only little distillation gas can be given off.

Distillation gases may, therefore, be expected in practical producer working, which are similar to the most richly and most poorly carbonaceous of those in these tables.

As, however, the giving off of distillation gases proceeds more rapidly and thoroughly in producers than in coke ovens, in which a small proportion of H is always retained in the coke, one may thus properly expect in the distillation gases of producer working, a poorer average in carbon than in coke oven gases. In the selection of gases from the above table, which might be regarded as a basis value for the distillation gases occurring in producer working, it is readily apparent that not the C-richest gas, but the mean of all analyses should be taken as the C-richest gas; whilst as the lowest basis value, the C-poorest gas in the table—*i.e.*, No. 7, Solway (England)—may well be taken. The composition of the respective gases will then be as under:—

C-poorest Gas.[1]

C_mH_n, 3·1 per cent.; CH_4, 23·7 per cent.; H, 56·0 per cent.;
CO, 8·8 per cent.; CO_2, 3·0 per cent.; N, *nil*;
total, 91·6 per cent.

C-richest Gas.

C_mH_n, 4·5 per cent.; CH_4, 34·0 per cent.; H, 47·6 per cent.;
CO, 8·3 per cent.; CO_2, 1·8 per cent.; N, 3·5 per cent.;
total, 99·9 per cent.;

[1] This composition is given in the original.

and all distillation gases practically obtained must lie between the values, which are bounded by the above two analyses.

Let us now determine some characteristic properties of both these gases.

The combustible value is seen to be an important property, and this is:—

C-poorest Gas.			C-richest Gas.		
Cubic metre.		Calories.	Cubic metre.		Calories.
3·1	$C_mH_n \times 14{,}185=$	43,973	4·5	$C_mH_n \times 14{,}185=$	63,832
23·7	$CH_4 \times 8{,}600=$	203,820	34·0	$CH_4 \times 8{,}600=$	292,400
56·0	$H \times 2{,}620=$	146,720	47·6	$H \times 2{,}620=$	124,712
8·8	$CO \times 3{,}063=$	26,954	8·3	$CO \times 3{,}063=$	25,423
0·0	O		0·2	O	
3·0	CO_2		1·8	CO_2	
0·0	N		3·5	N	
94·6	gas.	421,467	99·9	gas.	506,367

A further characteristic is the carbon content of the gas. In the ascertainment of this, one must bear in mind that from p. 68 16 kilogrammes CH_4, which contains 12 kilogrammes C, occupies a volume of 22·3 cubic metres at 716 millimetres. 28 kilogrammes C_2H_4, which contains 24 kilogrammes C, occupies a volume of 22·3 cubic metres at 716 millimetres. Thus there is obtained from 1 kilogramme C

$\frac{22{\cdot}3}{12}=1{\cdot}86$ cubic metre CH_4, as is the case with CO and CO_2,

or

$$\frac{22{\cdot}3}{24}=0{\cdot}93 \text{ cubic metre } C_2H_4.$$

Thus

1 cubic metre CH_4 contains 0·538 kilogramme C.
1 cubic metre C_2H_4 contains 1·176 kilogrammes C . . . (25).

By use of the formulæ (17) and (25), one can easily estimate the carbon content of the gas in 94·6 and 99·9 cubic metres.

C-poorest Gas.	C-richest Gas.
3·1 C_mH_n ×2= 6·2 cubic metre C	4·5 C_mH_n ×2= 9·0 cubic metre C
23·7 CH_4 ×1=23·7 ,, C	34·0 CH_4 ×1=34·0 ,, C
8·8 CO ×1= 8·8 ,, C	8·3 CO ×1= 8·3 ,, C
3·0 CO ×1= 3·0 ,, C	1·8 CO ×1= 1·8 ,, C
Total 41·7 cubic metre C	Total 53·1 cubic metre C
× 0·538	× 0·538
22·43 kg. C	28·57 kg. C

Further, the gases contain hydrocarbons, and of the carbon-containing gases if one changed the C_mH_n into CH_4[1] the result would be :—

C-poorest Gas.	C-richest Gas.
C_mH_n 3·1×2= 6·2 cubic metre	C_mH_n 4·5×2= 9·0 cubic metre
CH_4 23·7×1=23·7 ,, ,,	CH_4 34·0×1=34·0 ,, ,,
Marsh gas 22·9 cubic metre	Marsh gas 43·0 cubic metre.

In order now to be able to bring these values, and some others (to be ascertained later) into simple relation to the H, one can conceive both the gases considered in the given

RESOLUTION OF THE GASES INTO THEIR ELEMENTS.

C-poorest Gas consists of:					C-richest Gas consists of:				
	Cubic metre G.	Cubic metre O.	Cubic metre H.	Cubic metre N.		Cubic metre G.	Cubic metre O.	Cubic metre H.	Cubic metre N.
C_mH_n	3·1×2	—	6·2	—	C_mH_n	4·5×2	—	9·0	—
CH_4	23·7×2	—	47·4	—	CH_4	34·0×2	—	68·0	—
H	56·0×1	—	56·0	—	H	47·6×1	—	47·6	—
CO_2	3·0×1	3·0	—	—	CO_2	1·8×1	1·8	—	—
CO	8·8×0·5	4·4	—	—	CO	8·3×0·5	4·15	—	—
O	—	—	—	—	O	0·2	0·2	—	—
N	—	—	—	—	N	3·5	—	—	3·5
Total	94·6	7·4 +	109·6 +	C	Total	99·9	6·15+	124·6+	3·5+C

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[1] This apparently entirely arbitrary operation has the object only of making the comparison between the H taken in the free state and hydrocarbons simpler and thereby to avoid the amount of the latter being made out too low, viz., one almost never finds C_mH_n in the analysis of producer gas. Should this nevertheless by way of exception occur, then one must further proceed as is given in the remarks on p. 85.

amounts of volumes as being resolved into their constituents. For the hydrogen it has been already shown, and for the O one adopts the same methods as brought into use in the expressions (2) and (6).

The composition of the gases now appears in much simpler form and consists as follows:—

C-poorest Gas.	C-richest Gas.
94·6 cubic metres gas from 7·4 cubic metres O + *nil* N + 109·6 cubic metres H, and C.	9·99 cubic metres gas from 6·15 cubic metres O+3·5 cubic metres N+124 cubic metres H, and C.
These would have :—	
Combustible value 421,467 calories	506,637 calories
Carbon . . . 22·43 kg.	28·57 kilogrammes
Marsh gas . . 29·9 cbm.	43 cubic metres

Per 1 cubic metre H in the distillation gas (taken in the free state) combustible value would be :—

$\frac{421,467}{109·6}$=3,850 calories	$\frac{506,367}{124·6}$=4,060 calories
Carbon :—	
$\frac{23·43}{109·6}$=0·20 kilogramme	$\frac{28·57}{124·6}$=0·23 kilogramme
Marsh gas :—	
$\frac{22·9}{109·6}$=0·27 cubic metre CH_4	$\frac{43·0}{124·6}$=0·35 cubic metre CH_4

And, lastly, if one takes into consideration O, N, CO_2 and CO.

O=$\frac{7·4}{109·6}$=0·07 cubic metre O	$\frac{6·15}{124·6}$=0·05 cubic metre O
N=*nil*	$\frac{3·5}{124·6}$=0·03 ,, N
CO_2 0·03 cubic metre CO_2	0·015 ,, CO_2
CO 0·07 ,, CO	0·07 ,, CO

In the analysis selected for the C-poorest gas, unfortunately, the N content is not given. Nevertheless, in practically all classes of coal N is contained, and goes over into the gas. As the amount is not considerable, let the mean amount of N be taken as good for the C-poorest gas, and therefore N be taken=0·03 cubic metre H_d[1].

All the figures given in formulæ No. 26 in the Appendix are

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[1] The hydrogen, owing its origin to the distillation gases, is distinguished by a suffix, thus, H_d.

drawn up with this alteration. Before, however, use can be made of the values found, one should investigate whether the hydrogen of both these gases admits of completely accurate determination by the previously-given method of combustion also.

With this object, one must know the quantities of oxygen which are required for the combustion of 1 cubic metre C_2H_4 and 1 cubic metre CH_4, and equally one must know what products of combustion result.

From $C_2H_4+6O=2CO_2+2H_2O$ and the equivalent molecular and atomic weights, as well as the weights of 1 cubic metre of the gas, it follows that 22·3 cubic metres C_2H_4+66·9 cubic metres O=44·6 cubic metres CO_2+44·6 cubic metres H_2O vapour, or 1 cubic metre C_2H_4+3 cubic metres O=2 cubic metres CO_2+2 cubic metres H_2O vapour results. For CH_4 one ascertains in the same way, 1 cubic metre CH_4+2 cubic metres O=1 cubic metre CO_2+2 cubic metres H_2O vapour . . . (27).

From these and formulæ (12) and (18), the products of combustion are calculated as follows:—

C-poorest Gas (cubic metre).		O required.	CO_2 produced.
C_mH_n	3·1×3	= 9·3,	×2= 6·2
CH_4	23·7×2	=47·4,	×1=23·7
H	56·0×0·5	=28·0,	
CO	8·8×0·5	= 4·4,	×1= 8·8
CO_2	3·0		3·0
N			
	O required	89·1	CO_2 41·7

This O is burdened with N=352·2.

The products of combustion therefore contain . . CO_2 41·7+N 352·2

From table, 41·7 CO_2 should only be burdened with 156·8 N.

Thus N excess= 178·4

C-richest Gas (cubic metre).		O required.	CO_2 produced.
C_mH_n	4·5× 3	= 13·5,	×2= 9·0
CH_4	34·0× 2	= 68·0,	×1=34·0
H	47·6×0·5	= 23·8,	
CO	8·3×0·5	= 4·15,	×1= 8·3
CO_2	1·8		1·8
N	3·5		
O required .		109·45	CO_2 53·1
Less free O .		0·20	
Nett O required		109·25	

This O is burdened with N=411·0
To which add that in gas = 3·5
Gross N 414·5

The products of combustion therefore contain . . CO_2 53·1+N 414·5

From table, 53·1 CO_2 should only be burdened with . 199·8 N

Thus N excess= 214·7

C-poorest Gas (cubic metre).	O required.	CO_2 produced.	C-richest Gas (cubic metre).	O required.	CO_2 produced.
This corresponds to 47·4 O, which from formula (12) could burn	2×47·4=94·8 H		This corresponds to 57·1 O, which from formula (12) could burn	2×57·1=114·2 H	
Actual H (if freed) contained in this gas =		109·6	Acutual H (if freed) contained in this gas =		124·6
Deficit in amount arrived at 14·8 =	15·6 per cent. (26)		Deficit in amount arrived at 10·4 =	9·1 per cent. (26)	

These respective amounts should be added to the amounts of H_d, respectively found by means of combustion, in order to obtain approximately correct values.

These latter inaccuracies might strongly discredit the method, were not the causes thereof so openly obvious. One sees at once that in addition to H and C, O and N also go over in the distillation gas, and that is the foundation of the trouble in the result.

If one takes into account, viz., that in C-poorest gas 7·4 cubic metres O are obtained from the fuel, which could burn 7·4×2=14·8 cubic metres H, the deficiency of 14·8 cubic metres H which was found by combustion, is cleared up. But the data always depend on so many arbitrary assumptions, that for quantitative calculations, they cannot come into great demand.

But in consequence of the advantageous circumstance that the amounts of O and N (especially that of O) in the gases from mineral coals, are quite small in ratio to the amounts of H (assumed as in the free state) these data, in default of better, are nevertheless able to render good service for quantitative purposes. Possibly in the future it will be possible to ascertain accurate values for specified fuels, and thus data which approximate more nearly; until then one must be satisfied with this.

CHAPTER X

PRODUCER GAS

Producer gas is constituted, as already frequently remarked, of a mixture of steam-air gas and distillation gas. Now, as the distillation gases are of very different composition, and also can be developed in different periods of working in very varying amounts, it appears really useless to want to find out a mean composition of producer gas. But, of course, thereby there is attained what relative ratio the distillation gas mainly has to the steam-air gas, since if relatively only very little distillation gas, as opposed to steam-air gas, is formed, so the influence of the distillation gas would come very little into play. Further, it would admit of one conceiving it possible to enable one to find out a construction of producer which will fulfil the task of producing a gas of the greatest possible uniformity of composition, and one in which devices ensure that fuel is brought continuously and in small, always uniform, amounts into the producer, as, for example, already takes place in the Morgan producer. For this case, then, the theoretically best uniform gas quality can well be discussed, and this also ascertained for a specified fuel. In most cases, a special class of fuel, usually designated gas coal, is employed in producers for open-hearth furnaces. They always contain a large amount (27 to 36 per cent.) of volatile constituents, and yield a gas rich in hydrocarbons and tarry vapours, which, on combustion, make the flame luminous. This is regarded as advantageous by many practical men (whether rightly remains undecided) in that such luminous flame may develop considerably more heating power than the pure carbonic acid flame.

Such like coal is employed in the manufacture of illuminating gas, and here the amount of distillation gas which can be obtained from a stated quantity of coal has been ascertained.

Therefrom there is obtained from 100 kilogrammes gas coal from 24 to 41 cubic metres, and on an average 28 cubic metres lighting gas. As on the grounds before quoted more gas must be developed in the producer, it may be taken that one obtains 30 cubic metres gas; 1 kilogramme yields, therefore, 0·3 cubic metre gas, and as the coal contains approximately 75 per cent. C, there results 0·4 cubic metre distillation gas from 1 kilogramme C of the coal. The mean composition of this is already given on p. 69, and on p. 73 it was found that 28·57 kilogrammes C. are contained in 100 cubic metres gas. Thus one obtains in 0·4 cubic metre gas, which is yielded from 1 kilogramme C in the gas coal, 0·4×0·2857=0·115 kilogramme C, *i.e.*, about 0·12 kilogramme C, or in other words, 12 per cent. of the carbon contained in the fuel is carried off in the form of gas, and consequently 0·88 kilogramme C, or 88 per cent. of the C, remain over for gasification into steam-air gas.

On this assumption, and the composition of distillation gas assumed on p. 69, as well as that of the best steam-air gas (in this case taken as being produced from cold air, *vide* formula 22, p. 63), one can easily calculate the composition of the best producer gas in good gas coal per kilogramme C at:—

0·12 kilogramme C. yields cubic metre distillation gas.	CO_2 0·01+CO 0·04+C_mH_n 0·02+CH_4 0·14+H 0·20+N 0·01=0·42 cubic metre.
0·88 kilogramme C. yields cubic metre steam-air gas.	CO_2 0·04+CO 1·59+C_mH_n *nil*+CH_4 *nil*+H 0·21+N 2·75=4·75 cubic metre.
1 kilogramme C. yields cubic metre producer gas.	CO_2 0·05+CO 1·63+C_mH_n 0·02+CH_4 0·14+H 0·41+N 2·76=5·01 cubic metre gas.

The combustible value of this gas is 7,554 calories.

Since the combustible value of steam-air gas from pure C only amounts to 6,200 calories, the combustible value taken on 1 kilogramme C is thus increased by the content of bitumen in the raw fuel, by 1,350 calories, or more than 20 per cent.

The volumetric composition of the producer gas is thus CO_2 1·0 per cent.+CO 32·5 per cent.+C_mH_n 0·4 per cent.+

CH_4 2·8 per cent.+H 8·2 per cent.+N 55·1 per cent., and the combustible value of 1 cubic metre of this gas is 1,507 calories.

As is apparent, distillation gas, viz., 0·42 cubic metre, only forms about 8 per cent. of the quantum of gas, and the quantity of steam-air gas amounts to about ten or eleven times that of the distillation gas. Producer gas, therefore, consists in the main of steam-air gas, and this points, therefore, to devoting quite special attention to its production. There is, therefore, no compulsory ground for production of bad steam-air gas, since all conditions for properly carrying out the process of its production are clear, and no serious difficulties are in the way of their exact observance. Also, it is on the steam-air gas portion of the gas alone on which the exercise of thought is capable of favourable influence, since the amounts and compositions of the distillation gases are fixed in the fuel by Nature, and therefore cannot be improved. We are, however, in a position by sudden introduction of a large quantity of coal into the producer, when it is quite hot, momentarily to produce a large quantity of distillation gas, and thereby an improvement in the quality of the gas, as is frequently wished for by practical people; but it can only be of short duration, and naturally have as a consequence the production of a producer gas poor in distillation gas for a longer period. But besides, it involves as a consequence of retrogression and periodical improvement of the quality of the gas no economical use of the fuel throughout, since under the attack of high heat, the highly carbonaceous bituminous substances, by setting free C, decompose into lighter hydrocarbons, and liberated C appears in the form of dust or soot, which is carried away from the producer, and can no longer be brought into use. They deposit themselves for the most part in the conduits, obstructing them, and finally interrupting the working.

Further, as shown in what follows, faults in the production of the steam-air gas unfavourably influence the composition of the distillation gas, and finally are able partly, or completely, to annul the advantages which it is possible to obtain from the employment of bituminous (often costly) fuels.

CHAPTER XI

JUDGMENT OF THE WORKING OF THE PRODUCER FROM THE ANALYSIS OF THE GAS

In producer management, as in all other technical-chemical management, control analyses of the products are carried out, and one might be of the opinion that it is perchance easy, by comparison of the same with the above-ascertained composition of a faultless producer gas, to find out possible faults in gases, produced in practice, whereby one would recognise the causes themselves, and be placed in the position to provide for their removal. In reality, however, the thing is not so simple, as follows from Table G (p. 81), in which are drawn up nineteen analyses of producer gases, taken from recent literature and the author's own notes. The table shows a varied assortment, which also will not reveal much to a well-practised eye. Also the ascertained combustible value per cent. by volume of the composition only indicates that the gas is relatively good or bad, but gives no more detailed information as to the cause.

For the performance of closer investigations, it should be remembered first to ascertain the quantity of gas which contains a total of 1 kilogramme C, and with this to operate further. One then, by copiously performed calculations, obtains directly comparable figures, and avoids errors through mistakes in figures which otherwise readily creep in.

From the gas volume ascertained for 1 kilogramme C, one obtains already a halting point in the examination, if the gas is properly manufactured, since the quantity of gas will approximate to 5 cubic metres per 1 kilogramme C. But one can (by reference to the statements on gases, in the section on "Distillation Gas," which are made from mineral coal) still further approximately estimate the amount of hydrogen which originates from the distillation gases ; from this one is enabled to determine the limit value for the amounts of carbon which,

TABLE G.—ANALYSES OF PRODUCER GASES IN PRACTICE.

No.	Composition, Volumes per cent.							Combustible Value, 1 cubic metre Gas. Calories.	Amounts of Gas obtained from 1 kilogramme C.									No.
									Cubic metre Gas given off by 1 kilogramme C.							Total Gas from 1 kilogramme C. cbm.	Combustible Value Gas from 1 Kg. C Calories.	
	CO_2.	CO.	C_mH_n.	CH_4.	H.	O.	N.		CO_2.	CO.	C_mH_n.	CH_4.	H.	O.	N.			
1 Theoretical Producer Gas	1·0	32·5	0·4	2·8	8·2	—	55·1	1,507	0·05	1·63	0·02	0·14	0·41	—	2·76	5·01	7,554	1
2	2·4	29·4	—	3·6	12·8	0·2	51·6	1,545	0·13	1·54	—	0·19	0·67	0·01	2·71	5·25	8,113	2
3	5·2	27·3	—	3·4	16·6	—	47·5	1,538	0·27	1·41	—	0·17	0·86	—	2·46	5·17	8,151	3
4	6·9	25·4	—	3·4	18·3	—	45·9	1,548	0·36	1·32	—	0·18	0·95	—	2·40	5·21	8,049	4
5	3·3	31·5	—	1·7	14·5	0·2	48·8	1,490	0·17	1·61	—	0·08	0·74	0·01	2·49	5·10	7,600	5
6	9·1	21·7	—	3·4	19·7	—	46·1	1,470	0·50	1·18	—	0·18	1·07	—	2·50	5·43	7,982	6
7	11·6	18·4	—	3·4	21·8	—	44·8	1,420	0·65	1·03	—	0·18	1·21	—	2·49	5·57	7,909	7
8	13·2	16·1	—	3·5	22·7	—	44·5	1,380	0·75	0·91	—	0·20	1·28	—	2·52	5·67	7,811	8
9	5·0	25·0	—	2·8	15·0	—	51·2	1,374	0·28	1·41	—	0·16	0·85	—	2·90	5·66	7,777	9
10	2·5	28·0	—	1·3	12·5	0·4	55·3	1,323	0·15	1·65	—	0·07	0·73	0·02	3·23	5·84	7,726	10
11	6·3	22·7	0·3	2·6	13·4	0·2	54·5	1,313	0·36	1·31	0·02	0·15	0·77	0·01	3·15	5·77	7,590	11
12	1·0	31·3	—	2·4	6·3	—	59·3	1,313	0·05	1·68	—	0·13	0·34	—	3·18	5·38	7,037	12
13	3·7	26·2	—	2·0	11·5	0·3	56·3	1,275	0·22	1·52	—	0·12	0·67	0·02	3·28	5·83	7,433	13
14	4·5	27·0	—	1·0	12·0	—	55·0	1,241	0·26	1·54	—	0·06	0·69	—	3·15	5·70	7,098	14
15	6·4	25·7	—	0·3	13·3	—	54·3	1,161	0·37	1·47	—	0·02	0·76	—	3·12	5·74	6,666	15
16	6·0	20·0	—	2·8	10·3	Tr.	60·9	1,122	0·39	1·29	—	0·18	0·66	—	3·92	6·45	7,237	16
17	2·0	29·4	—	1·0	4·7	—	62·9	1,092	0·11	1·69	—	0·06	0·27	—	3·61	5·74	6,269	17
18	7·0	18·0	—	1·2	15·0	0·3	58·5	1,042	0·50	1·28	—	0·08	1·06	0·02	4·15	7·09	7,398	18
19	7·0	19·5	—	1·2	13·0	0·2	59·3	1,040	0·47	1·31	—	0·08	0·87	0·01	3·97	6·71	6,968	19
20	15·0	9·0	—	1·0	21·0	—	59·0	893	1·11	0·67	—	0·08	1·56	—	4·01	7·13	6,635	20

in the form of distillation gas, have gone over into the gas, and thus, finally, also the quantity of carbon which appertained to the gasification into steam-air gas. From all these determinations one can obtain the combustible value which the gas must intrinsically possess from the fuel employed.

An example may serve the purpose of elucidating the train of thought. Example: Gas No. 2 in Table G evolved in a producer of the most modern construction had the composition

CO_2, 2·4 per cent.; CO, 29·4 per cent.; CH_4, 3·6 per cent.; H, 12·8 per cent.; O, 0·20 per cent.;. N, 51·1 per cent.= 100 per cent.

(*a*) GAS VOLUME FOR 1 KILOGRAMME C.

In the gas carbonaceous gases are as under—

CO_2 2·4
CO 29·4
CH_4 3·6
Total carbonaceous gas: 35·4 (If C_mH_n were present, it should be doubled in this (*vide* Formula 25).
×0·538 cubic metre (*vide* Table).
=19·04 kilogrammes C.

These give 100 cubic metres gas; therefore from 1 kilogramme C one obtains $\frac{100}{19·04}=5·25$ cubic metres gas. The gas, therefore, appears to have been very well manufactured.

The composition of the amounts of gas which would be obtained from 1 kilogramme C is ascertained by multiplying the results of the gas analysis by $\frac{5·25}{100}$; thus—

CO_2, 0·13 cubic metre+CO, 1·54 cubic metre+CH_4, 0·19 cubic metre+H, 0·67 cubic metre+O, 0·01 cubic metre+N, 2·71 cubic metres=5·25 cubic metres.[1]

Now the amount of hydrogen derived from the distillation gases is to be estimated, for which the combustion method

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[1] If the calculation is correctly set out, the sum of the C-containing gases must give 1·86 cubic metre:

(0·13 CO_2+1·54, CO+0·19, CH_4=1·86).

described in the chapter on "Distillation Gas" can be utilised.

Gas.	O required. Cubic metre:		Cubic metre CO_2.	Cubic metre N.
0·13 cubic metre CO_2	—	forming	0·13	—
1·54 ,, CO	× 0·5 = 0·77	,,	1·54	—
0·19 ,, CH_4	× 2 = 0·38	,,	0·19	—
0·67 ,, H	× 0·5 = 0·335	,,		
	O required 1·485			
0·01 ,,	O deduct 0·01			
	O required 1·475 which involves			5·55
2.71 ,,	N			2·71
	Products of combustion		1·86 +	8·26
	But 1·86 cubic metre carries with it only			7·00
	Surplus		N	1·26

This corresponds to 0·335 cubic metre O, or

2 × 0·335 = 0·670 cubic metre Hd from distillation gas.

One can arrive at the same result in another simpler and clearer manner by means of resolving the gas into its elements, which method has also been employed in the chapter on "Distillation Gas," and then considering these elements.

There exists in		Cubic metre O.	Cubic metre H.	Cubic metre N.
CO_2 0·13 cubic metre	× 1	0·13	—	—
CO 1·54 ,,	× ·05	0·77	—	—
CH_4 0·19 ,,	× 2	—	0·38	—
H 0·67 ,,	× 1	—	0·67	—
O 0·01 ,,	× 1	0·01	—	—
N 2·71 ,,	× 1	—	—	2·71
5·26 cubic metre gas consisting of . .		0·91	+ 1·05 +	2·71 + 1 kilogramme C.
If now only 2·71 cubic metres N alone originates from the air, it corresponds to . .		0·72		
Hence there is a surplus of		0·19		
If this proceeds from the decomposition of steam, there must have been originated 2 × 0·19 . .			= 0·38	
Leaving			0·67 Hd	

which could only have originated from the distillation gas. It is the same figure which was obtained by the combustion method.

The method last employed is in principle the same as the combustion method; merely, here, the products of incomplete combustion of the fuel have been considered direct. One obtains, however, simultaneously, approximately a value for the H originating from decomposition of steam, and can in the foregoing case come to the conclusion that the steam-air gas production has been very well conducted, as the hydrogen content is found to be approximately right. The latter should contain 0·21 cubic metre H according to the composition of the theoretical producer gas, whilst 0·38 cubic metre was found here. However, one cannot always regard the figure thus obtained as correct, as will be shown later.

As to the properties of the distillation gas, the figure 0·67 cubic metre Hd must be corrected, since N as well as O does not entirely originate from air and water, but small amounts thereof are furnished by the fuel. But these amounts are unknown, and therefore their further calculation can only be approximately undertaken, and this only by two ways—by utilisation of the values for the C-poorest and C-richest distillation gas which are taken as limiting values. The greater or lesser agreement of the same will then furnish a measure whether the mean value merits confidence, and if it is worth while to follow the calculation further.

Thus, first, there is the value of H_d to be corrected.

The correction amounts to:—

For the C-poorest distillation gas	For the C-richest distillation gas
+15·6 per cent.	+9 per cent.
H_d corr.=1·156×0·67=0·77 cubic metre H_d.	H_d corr.=1·09×0·67=0·73 cubic metre H_d.

Therewith will be gasified, as distillation gas from (26),

C=0·20×0·77 cubic metre H_d = 0·154 kilogramme C	0·23×0·73=0·168 kilogramme C,

and there will belong to the gasification into steam-air gas,

1−0·154=0·846 kilogramme C	0·832 kilogramme C.

The combustible value of the gas would be

	Calories.		Calories.
Distillation gas 0·77 H× 3,850 . . . . . =	2,964	Distillation gas 0·73 H× 4,060 . . . . . =	2,963
Steam-air gas from 0·846 kilogramme C×6,200 =	5,245	Steam-air gas from 0·832 kilogramme C×6,200 =	5,158
Total theoretical combustible value	8,209	Total theoretical combustible value	8,121

These two values differ by 88 calories, or only a little more than 1 per cent.

In reality the gas possessed a combustible value of 8,113 calories, attaining, thus one might say, almost that theoretically necessary, and therefore one may regard it as properly made. Nevertheless let the example be still further calculated out.

It is of interest first to ascertain the composition of the distillation gas. The content of hydrocarbon is determinable as

C-poorest Gas.	C-richest Gas.
From 0·77 cubic metre H comes	From 0·73 cubic metre H comes
$0{\cdot}77 \times 0{\cdot}27 = 0{\cdot}21$ cubic metre CH_4	$0{\cdot}73 \times 0{\cdot}35 = 0{\cdot}25$ cubic metre CH_4.

(Actually, however, only 0·19 cubic metre CH_4[1] was present.)

Now let it be assumed in this case that not more were present. The distillation gas is thus at all events more similar to the C-poorest than the C-richest and therefore it is only required to be found from the former assumption.

There is in the distillation gas H_d . .	=	0·77 cubic metre
Present as CH_4 0·19 corresponding to free H	=	0·38 ,,
Thus free H in distillation gas . .	=	0·39 cubic metre

Further, from formula (26), there must be present approximately

CO_2 $0{\cdot}03 \times 0{\cdot}77 = 0{\cdot}02$ cubic metre CO_2
CO $0{\cdot}07 \times 0{\cdot}77 = 0{\cdot}05$,, CO
N $0{\cdot}03 \times 0{\cdot}77 = 0{\cdot}02$,, N

so that the total distillation gas is CO_2 0·03 cubic metre + CO 0·05 cubic metre + CH_4 0·19 cubic metre + H 0·39 cubic metre + N 0·03 cubic metre.

If one deducts that gas from the total gas, "steam-air" gas must remain.

	CO_2.	CO.	CH_4.	H.	N.
Total gas . . .	0·13	1·54	0·19	0·67	2·67
Less distillation gas .	0·03	0·05	0·19	0·39	0·03
Balance steam-air gas	0·10	1·49	—	0·28	2·64

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[1] Were actually C_mH_n present also, so for $xC_mH_n + yCH_4$, in the gas analysis the following calculation of the content of hydrocarbons in the gases must be taken as $2x + y$ cubic metres, and the content of free H in the distillation gas be taken as $0{\cdot}77 - 2\,(x + y)$.

and this "steam-air" gas must, if all assumptions were correct, correspond to the formula

$$N=3{\cdot}762\left(CO_2+\frac{CO}{2}-\frac{H}{2}\right).$$

This furnishes $N=3{\cdot}762\left(0{\cdot}1+\frac{1{\cdot}49}{2}-\frac{0{\cdot}28}{2}\right)=3{\cdot}762\times 0{\cdot}705$ $=2{\cdot}65$, which agrees remarkably with 2·64.

0·846 kilogramme C belonged to gasification into steam-air gas, and according to formula (22) there could be obtained from this quantity of carbon in steam-air gas

0·846 kilogramme C × 0·24 cubic metre hydrogen = 0·20 cubic metre H;

and correspondingly 0·20 cubic metre water-vapour have been decomposed.

But in the foregoing case 0·28 cubic metre had been employed, and hence the addition of steam to the air supply must be accordingly reduced a little.

Example II.—It is a rarity for so good an agreement between theory and practice to be met with, and if such be not the case, the mode of calculation becomes somewhat more complicated.

As an example of such a case, gas No. 18 given in Table G will serve, this gas also having been made in a producer of the most modern construction.

The composition is CO_2 7·0 per cent., CO 18·0 per cent., CH_4 1·2 per cent., H 15·0 per cent., O 0·3 per cent., N 58·5 per cent. Combustible value per cubic metre, 1,042 calories.

In this gas are CO_2 7·0 cubic metres, CO 18 cubic metres, CH_4 1·2 cubic metre, total C-gases 26·2 cubic metres, corresponding to 14·09 kilogrammes C; or 1 kilogramme C furnished 7·09 cubic metres gas.

From this it follows that the gas volume was much too great; the fuel is therefore present in diluted form.

The composition of the amount of gas which results from 1 kilogramme C and its resolution into its elements gives

	O cubic metre.	H cubic metre.	N cubic metre.
$0·0709 \times 7·0\,CO_2 = 0·50$ cubic metre CO_2 containing	0·50	—	—
$0·0709 \times 18·0\,CO = 1·28$,, CO ,,	0·64	—	—
$0·0709 \times 1·2\,CH_4 = 0·08$,, CH_4 ,,	—	0·16	—
1·86 cubic metre C-containing gas			
$0·0709 \times 15·0$ H $= 1·06$,, H gas . .	—	1·06	—
$0·0709 \times 0·3$ O $= 0·02$,, O ,, . .	0·02	—	—
$0·0709 \times 58·5$ N $= 4·15$,, N ,, . .	—	—	4·15
7·09 cubic metre gas	1·16	1·22	4·15
4·15 cubic metre N from air is accompanied by .	1·105		
Difference: surplus O	0·055		
If derived from H_2O corresponds to . . .	$0·055 \times 2 = 0·11$ H		
In consequence there remains		1·11 H_d	

which originates from the distillation gas.

It appears from this as if the steam addition to the air for gasification, 0·11 cubic metre, had been much too small.

This conclusion, however, could have been come to earlier, and it will also later turn out to be erroneous.

The gas exhibits a very high content of H_d, and therefore a very high combustible value would be expected, instead of which it shows the opposite. Further, it exhibits a much too high N content, which points to a large surplus of air. From this it could be inferred that the depth of the bed of fuel had been too small, but this, however, is carefully avoided in modern gas producer construction. Thus there are a quantity of contradictions to be cleared up, and to reconcile these, involves the trouble of a lengthy check calculation.

First, there should be ascertained the theoretical combustible value, which would have resulted from the fuel employed.

—	C-poorest Distillation Gas.	C-richest Distillation Gas.
Correction for H_d	$1·156 \times 1·11 = 1·28$ cbm. H_d	$1·09 \times 1·11 = 1·21$ cbm. H
C-content in distillation gas.	$1·28\,H_d \times 0·2 = 0·256$ kg. C	$1·21 \times 0·23 = 0·278$ kg. C
Hence C in steam-air gas.	$1 - 0·256 = 0·744$ kg. C	$1 - 0·278 = 0·722$ kg. C

Theoretical Combustible Value.	C-poorest Distillation Gas.	C-richest Distillation Gas.
	Cals.	Cals.
Distillation gas .	$1{\cdot}23\ H_d \times 3{,}850 = 4{,}928$	$1{\cdot}21\ H_d \times 4{,}060 = 4{,}912$
Steam-air gas .	0·744 kg. $C \times 6{,}200 = 4{,}613$	0·728 kg. $C \times 6{,}200 = 4{,}476$
Total combustible value . .	9,541	9,388

Difference 153 calories = 1·5 per cent. on both limit values.

In reality, the gas had a combustible value of 7·09 × 1,042 = 7,390 calories, thus showing about 2,000 calories less.

Marsh gas should be found in the gas.

CH_4 $1{\cdot}28\ H_d \times 0{\cdot}27 = 0{\cdot}34$ cbm. CH_4	$1{\cdot}21\ H_d \times 0{\cdot}35 = 0{\cdot}42$ cbm. CH_4
But there was present 0·08 ,, ,,	0·08 ,, ,,
Leaving balance 0·26 cbm. CH_4	0·34 cbm. CH_4

Such a large difference cannot possibly be explained alone by an anomalous composition of the distillation gas. A single assumption remains over, and this is, that the deficient amount of CH_4 has been burnt. In regard to this, free oxygen has been shown to be present in the gas, and from the combustion of CH_4 also, the high nitrogen would unreservedly admit of explanation. Then for combustion of 0·26 cubic metre CH_4, 0·52 cubic metre O would be required, which would introduce 1·96 cubic metre more nitrogen into the gas.

If the gas had not had its CH_4 selected for combustion, one must further add to the composition of the gas the amount of the CH_4 burnt, but deduct the products of combustion of the same.

For . .	0·26 cubic metre CH_4	0·34 cubic metre CH_4
O required is	0·52 ,, O	0·68 ,, O
The products of combustion are		
CO_2 . .	0·26	0·34 ,, CO_2
N . .	1·96	2·56 ,, N
H_2O vapour .	0·52	0·68 ,, H_2O vapour

The H_2O vapour does not come into consideration for this calculation.

Simultaneously with these products of combustion let the air excess of 0·02 O and 0·08 N be eliminated.

	C-poorest Distillation Gas.	C-richest Distillation Gas.
	CO_2 CO CH_4 H N	CO_2 CO CH_4 H N
Gas derivable from air .	0·50+1·28+0·08+1·06+4·07	0·50+1·28+0·08+1·06+4·07
Correction for failure to be burnt	−0·26 +0·26 −1·96	−0·34 +0·34 −2·56
The gas should have been . .	0·24+1·28+0·34+1·06+2·11	0·16+1·28+0·42+1·06+1·51

The composition of the distillation gas would be

1·28 cubic metre H_d	1·21 cubic metre H_d
Less 2×CH_4=2×0·34=0·68 ,, ,,	2×0·42=0·84 ,, ,,
free H_d=0·60 cubic metre	free H_d 0·37 cubic metre
CO_2 0·03×1·28=0·04 cubic metre CO_2	0·015×1·21=0·02 cubic metre CO_2
CO 0·07×1·28=0·09 ,, CO	0·07 ×1·21=0·08 ,, CO
N 0·03×1·28=0·04 ,, N	0·03 ×1·21=0·04 ,, N

	CO_2	CO	CH_4	H	N	CO_2	CO	CH_4	H	N
Total gas	0·24	1·28	0·34	1·06	2·11	0·16	1·28	0·42	1·06	1·51
Less distillation gas .	0·04	0·09	0·34	0·60	0·04	0·02	0·08	0·42	0·37	0·04
Leaving steam-air gas	0·20	1·19	—	0·46	2·07	0·14	1·20	—	0·69	1·47

N check according to

$$N=3{\cdot}762\left(CO_2+\frac{CO}{2}-\frac{H}{2}\right)$$

N=3·762×0·565=2·12 . . . . 3·762×0·395=1·49

Investigation of the proportions in which steam-air gas production took place yields the following:—

In the C-poorest gas there is contained in the steam-air gas 0·744 kilogramme C, and in the C-richest gas in the steam-air gas there is 0·722 kilogramme C. From formula (22) there would thus be also in the respective steam-air gas contents amounts of 0·744×0·24=0·18 cubic metre H and 0·722×0·24=0·17 cubic metre H, and 0·744×3·13=2·33 cubic metres N and 0·722×3·13=2·26 cubic metres N. The H and N actually present were 0·46 cubic metre H and 2·07 cubic metres N, and 0·69 cubic metre H and 1·47 cubic metre N. Thus the respective steam-air gases contained 0·28 cubic metre and 0·52 cubic metre excess of H, and 0·26 and 0·79 cubic metre respectively too little N.

It shows that in both cases too much steam and too little air were employed in the production of the steam-air gas.

In consequence, the temperature in the zone of steam-air gas production was too low; it had even possibly given rise to places in the fire through which air passed undecomposed, later to burn with the distillation gas.

Combustion of the Gas, however, must be regarded as the cause of the Marked Increase of Volume of the Gas in the overwhelming majority of Bad Producer Gases; which also furnishes the explanation of the considerable diminution of the Combustible Value.

This phenomenon, namely, combustion of a portion of the distillation gas, occurs very frequently, not to say always, in old producers, which work with feeble steam jet blasts, and the explanation here is simple. Thanks to the feeble blast pressure employed, only a shallower bed of fuel can be worked, whereby the possibility is presented of free oxygen reaching the upper surface of the same. But fuel lies here, the degasification of which is incomplete and is often only commencing, even; and its products of degasification then at the moment of their origin become greedily destroyed. In this manner, the most valuable constituents of the bitumen are lost.

The last figures in the foregoing calculation show that for bad gas qualities the method employed fails for quantitative purposes for the steam-air gas production, because in the example considered the figures for the H content of the steam-air gas fluctuated between 0·46 and 0·69 cubic metre, thus at best bringing the qualitative proof that in the main too much steam had entered into employment.

Under the circumstances, it does not also even allow this to be proved.

Let us assume that yet more air was forced into the gas space, and that in the foregoing gas, Example II.: (0·5 cubic metre CO_2, 1·28 cubic metre CO, 0·08 cubic metre CH_4, 1·06 cubic metre H, 4·07 cubic metres N), that all the CH_4 and, in addition, 0·56 cubic metre H be burnt.

For their combustion thus,

0·08 cubic metre CH_4 requires 0·16 cubic metre O and yields 0·08 cubic metre CO_2
0·56 ,, H ,, 0·28 ,, O and yields
0·44 cubic metre O burdened with 1·65 cubic metre N (*i.e.*, 2·09 cubic metre air),

the resultant products of combustion (excluding H_2O) thus being 0·08 cubic metre CO_2+1·65 cubic metre N, and thereby the composition of the gas would become

$$\begin{array}{rlrlrl} & \text{cbm.} & \text{cbm.} & \text{cbm.} & \text{cbm.} & \text{cbm.} \\ & 0{\cdot}5\ CO_2 & +1{\cdot}28\ CO & +0{\cdot}08\ CH_4 & +1{\cdot}06\ H & +4{\cdot}07\ N \\ & +0{\cdot}08\ CO_2 & & -0{\cdot}08\ CH_4 & -0{\cdot}56\ H & +1{\cdot}65\ N \\ \hline \textit{I.e.,} & 0{\cdot}58\ CO_2 & +1{\cdot}28\ CO & & +0{\cdot}50\ H & +5{\cdot}72\ N \end{array}$$

which at present shall be regarded as Example III.

By resolution of this gas into its elements and investigation of its manufacture, there results

CO_2 0·58 cbm.	containing	0·58 cbm. O+	cbm. H+	cbm. N
CO 1·28 ,,	,,	0·64 ,, O	—	—
H 0·50 ,,	,,	—	0·50	—
N 5·72 ,,	,,	— ,,	—	5·72
8·03 cbm. gas	containing	1·22 cbm. O	+0·50 cbm. H	+5·72cbm. N
5·72 cbm. N correspond to .		1·52 ,, O		
Thus there is a deficit in the gas of		0·30 cbm. O		
and this must correspond to		0·30 × 2	=0·60 cbm. H burnt	
which this time is to be added to the above 0·50 cbm. H				
There will be, therefore			1·10 H_d	

That is to say, one obtains precisely the same amount which was found on p. 87.

By further carrying out the calculation which here is only applied to the C-poorest distillation gas, there results the same correction for H_d and the same distillation gas (CO_2 0·04, CO 0·09, CH_4 0·34, H 0·60, N 0·04) as previously.

Now, in the gas to be considered, only 0·50 cubic metre H and no CH_4 is present; there is thus burnt out of the distillation gas

0·10 cubic metre H, which required 0·05 cubic metre O and yielded . . .	*nil* cbm. CO_2+0·19 cbm. N
and 0·34 cubic metre CH_4, which required 0·68 cubic metre O and yielded . .	0·34 ,, CO_2+2·56 ,, N
Thus originating products of combustion =	0·34 cbm. CO_2+2·75 cbm. N

Were the gas reviewed set right in respect to these burnt products and afterwards freed from distillation gas, there would result

Gas reviewed	CO_2 0·58+	CO 1·28+	CH_4 0·00+	H 0·50+	N 5·72
Products burnt reproduced	— 0·34	+	0·34+	0·10—	2·75
The original gas would have been	CO_2 0·24+	CO 1·28+	CH_4 0·34+	H 0·60+	N 2·97 cbm.
Less distillation gas	0·04	0·09	0·34	0·60	0·04 ,,
Balance steam-air gas.	CO_2 0·20+	CO 1·19			+N 2·93 cbm.

that is to say, the steam-air gas shows the same composition as in Example II., with the exception of 0·46 cubic metre H, which now is deficient, and increased nitrogen content corresponding thereto. There is thus in this case absolutely no H evidenced in the steam-air gas, although actually a considerable content thereof has been present. In order, however, to be in the position to judge whether actually no steam was decomposed, one must know the more detailed circumstances under which the production of steam-air gas ensued. It can be said in general that the hydrogen content of the steam-air gas found by this method is to be regarded as very unreliable.

For explanation of this phenomenon, it suffices to allude to the peculiarities both of the production and also of the combustion of the steam-air gas. The unit of weight of carbon, requires for its gasification into CO a specified amount, x, of oxygen, but for its complete combustion the double amount, *i.e.* $2x$. Were now the carbon first correctly gasified to CO, notwithstanding that a portion of the necessary oxygen were taken from steam, so must the amount of air for combustion be correspondingly diminished. As steam becomes decomposed, hydrogen must make its appearance in the gas, whereby, in consequence of the smaller amount of air, also correspondingly less nitrogen will be present in the gas. As long as the gas remains unchanged it admits of specification of the amounts of its hydrogen and nitrogen contents, as well as of the amounts of steam and air which will serve for its manufacture.

As soon, however, as this gas is burnt by means of air (even if only partially) the simile disappears. Hydrogen, to say the least, burns as easily as carbon monoxide, and forms thereby water. The amount of oxygen it requires brings a corresponding amount of nitrogen into the gas, and indeed there appears exactly the same amount as would have been present had as much less steam taken part in the gasification as hydrogen which has been burnt. The phenomenon has already been made clear for complete combustion (on p. 66.); for incomplete combustion the same holds good. This peculiarity results also from the universal formula (16) for steam-air gas, $N=3{\cdot}762\left(CO_2+\frac{CO}{2}-\frac{H}{2}\right)$, according to which the nitrogen content rises with reduction of the hydrogen content and sinks with increase of the same, whence the formula, under all circumstances, must retain its validity.

One is, therefore, not in the position to determine on the basis of the gas analysis whether the steam-air gas under investigation still exhibits its original composition, or whether it has already undergone partial combustion. Now, one could reply that steam must result from the combustion of hydrogen, and that one only requires to determine this in order to obtain explanation of the original composition of the steam-air gas and, therefore, also as to the conditions of its generation. On the other hand, however, it is to be replied that steam-air gas can only be faultily manufactured, in so far as undecomposed steam can pass through the carbon bed and reach the gas, and that this steam differs in no respect from steam which has resulted from the combustion of the hydrogen of the gas. In reality, however, the circumstances are more complicated, since one investigates not the steam-air gas, but the producer gas, which also contains the entire moisture of the fuel in the form of steam.

It is, therefore, impossible to find out a method which renders possible the determination of the exact composition of the steam-air gas as produced in its actual reaction zone. The method previously described, however, furnishes the possibility of finding out the amount of hydrogen which is derived from the distillation gas, and this method gives quite useful results, so long as the amounts of oxygen and nitrogen which go over from the fuel into the gas are not too large. For fuels which do not fulfil the latter conditions, such as wood or peat, it is, unfortunately, of little satisfaction.

The procedure explained may appear too intricate to the practical man, especially as not without pains results are established which are based on very unsafe assumptions, and are, therefore, uncertain. The foregoing investigations have however, shown that the amount of gas which will be obtained from 1 kilogramme of carbon is actually dependent on the working of the producer, and thereby a convenient means is given of correctly and rapidly explaining the gas analysis. Since the quantity of gas which contains 1 kilogramme C will be calculated from the gas analysis, so one only requires for criticism to add together the percentage by volume of the carbon-containing gases, *and if the total found be substantially less than* 35·6 *per cent., one can with safety conclude therefrom that distillation gas has been burnt, and that clumsy faults have been exhibited.*

Formerly, one used to regard a low carbon dioxide content in the gas as evidence of a good producer gas, and in so doing was generally right. In modern producers which are blown from below (with forced draught) and are worked with rich additions of steam to the air for gasification, this criterion is, however, not arrived at; and this one perceives, for example, in gas No. 17 in the Table G., which only contains 2 per cent. CO_2. On the ground of this low CO_2 content, one might be induced to assume that the producer working had been faultless, and in consequence attribute the low quality of the gas solely to the fuel. But actually such a chain of reasoning would be erroneous. If one sums up the C-containing gases, namely, 2 per cent. CO_2, 29·4 per cent. CO, and 1 per cent. CH_4, one obtains a total of only 32·4 per cent., *i.e.*, considerably less than 35·6 per cent. It must thus have resulted from an abnormal course of reactions in the producer, which involved the not inconsiderable increase of the volume of the gas. If one carries out therefrom the detailed calculations in the manner given, one finds that the gas per kilogramme C ought to have had a combustible value of about 7,400 calories, whilst it actually reached only 6,269 calories. Thus about 15 per cent. of the combustible value of the fuel had been lost, and indeed, as shown by the same calculation, that about 0·09 cubic metre CH_4 or 60 per cent. of the CH_4 present in the distillation gas had been burnt.

In investigation of the working of the producer, it will be well to check the temperature of the gas for a specified fuel, which is constant in correct working of the process, but which must correspondingly be increaseed, if the distillation gas is burnt in the producer in large measure.

CHAPTER XII

THE TEMPERATURES IN THE PRODUCER

As in the previous calculations the reaction temperature desired is taken at 1150° from the researches of Harries, the gas in the reaction zone, therefore, for a moment possesses this temperature. In rising, however, it comes into contact with fresh fuel, to which it must give up heat, whereby it naturally is correspondingly cooled. The available heat which this gas receives in the reaction zone has in the main to fulfil the following four functions:—

(1) It must cover the loss of heat resulting from radiation and conduction.

(2) It must raise the fresh fuel to the reaction temperature.

(3) It must drive off the distillation gas from the fuel.

(4) It must remove the humidity of the fuel.

The total amount of heat for the functions 2 to 4, as well as the distribution of heat to the individual items, does not admit of being laid down in general, since the amount of heat utilised therefor naturally is dependent throughout on the nature of the fuel employed.

As a source of heat, only the available heat of the steam-air gas is at disposal; thus it is necessary in each case to know the ratio $\frac{\text{C for distillation gas}}{\text{C for steam-air gas}}$. For good gas coal it has been taken on p. 78 that of a total of 1 kilogramme C a mean of 0·88 kilogramme C is allotable to gasification into steam-air gas, from which there results 4·59 cubic metres steam-air gas which, at 1,150°, must take up 4·59×0·3515×1,150=1,855 calories.

	Calories
1. Hereof is for item 1, *i.e.*, for covering the loss by radiation and conduction arbitrarily taken at 5 per cent.	90
2. The fuel which reaches the reaction zone, *i.e.*, 0·88 kilogramme C, which must be heated up to 1,150°, thus requiring 0·88×313 calories . . . . =	275
Carried forward	365

	Calories
Brought forward	365
3. There is 0·42 cubic metre distillation gas driven off, and for the requisite amount of heat for this, there are scarcely any estimates at disposal. In order to obtain some sort of data, and not to place it too low, let it be assumed that the distillation gas requires a little more heat for its formation than steam on its formation from water, which possesses the highest latent heat of vaporisation of all known substances; then 0·42 cubic metre distillation gas requires about . .	200
4. The coal contains 3 per cent. hygroscopic and 12 per cent. of chemically combined water, thus together 15 per cent., with 75 per cent. carbon; thus there is with 1 kilogramme C 20 per cent. of water, and this requires for its evaporation $0·20 \times 600 =$	120
Or the total required . . . . . . =	685

so that of the 1,855 calories which the available heat of the steam-air gas, amounted to $1,855 - 685 = 1,170$ remain as available heat of the escaping gases.

The quantity of gas amounts now, however, no longer to 5·01 cubic metres, as was given on p. 78, but it has increased itself to the extent of 0·20 kilogramme water-vapour = 0·25 cubic metre steam.

For determination of the temperature which this amount of gas must possess at an available heat corresponding to 1,170 calories, the values for the mean specific heats of the gases at 700° are used, from which the mean specific heats of the gases are

5·01 cubic metre producer gas	$\times 0·3341$	$= 1·6738$
0·25 ,, steam	$\times 0·05172$	$= 0·1293$
5·26 cubic metre gases		$C_o^t = 1·8031$

and the temperature of outgoing gas results as $t = \frac{Q}{c} = \frac{1,170}{1·8031} =$ 650°.

For a specified fuel, the temperature of the gas must remain constant, so long as the working of the producer remains normal, since then no cause would be present to prevent its attaining a permanency.

On the other hand, variations of the normal gas temperature must bring one to the conclusion that some abnormal conditions have occurred.

Of such variations, one finds most frequently highly increased temperature, and this can easily occur through combustion of the distillation gas. This may be due to too shallow a bed of fuel, owing to neglectfulness of the workmen; or is given rise to permanently in consequence of too feeble a blast, which does not permit of the mastery of a thick bed of fuel; sometimes, however, also to the, above all, undesirable property of some kinds of coal of baking hard. With the object of rendering possible the passage of air, there must be in such cases frequent "pottering"—that is to say, one must industriously prick holes through the bed of coal with long potter bars. These holes, however, form small passages, through which fresh air can easily make its way into the gas space, and its work of destruction can do harm to the previously good quality of gas. It is as yet not a practically solved question whether it is not possible to remove this undesirable property, without prejudice to the quality of gas, by means of admixing non-caking lean fuel, say, small coke, which in many works forms a nearly valueless waste product. The consideration that, owing to such admixtures, the quality of the gas would be prejudiced may not be justified, since the steam-air gas from pure carbon, with its combustible value of 1,186 calories per cubic metre, so much exceeds that of many gases, which have been faultily produced from bituminous fuels, as shown, for example, by the gases 15 to 20 in Table G (on p. 81).

On the contrary, one would, by such admixtures, in the event of the caking of the main fuel being able to be reduced, be able to considerably economise labour, owing to diminution of pottering.

THE VOLUME OF THE INCANDESCENT BED IN THE PRODUCER.

It is a question whether it is possible, owing to the mutual dependence of the temperature of the current of gas and the fuel coming in contact with it, to have in the producer a bed of incandescent fuel, to serve in some measure as a safety device, in order to compensate for the before-mentioned faults in the steam-gas production, in that it in some way reduces carbonic acid to CO. The question is obviously to be answered in the affirmative, albeit practical experiments hereon have not appeared. To be sure, in some modern producer systems, sight holes are provided through which the temperature in the interior can be checked ; however, it has not been known whether they have been used for the object named, and have rendered good service.

In the reaction zone, air-gas or steam-air gas are produced in the neighbourhood of the reaction temperature, and this gas will, in the event of its being properly produced—that is to say, consisting only of CO, H and N—only come across an inert material in the superposed incandescent bed of fuel, which neither attacks it nor admits of itself being attacked. If this incandescent bed is at the same temperature as the reaction zone, so in its passage the hot gas will be able to undergo no change of temperature. As soon as, however, a fault occurs in the generation of the gas, whereby CO_2 is formed, so will this be reduced to CO by the incandescent bed whereby it of course must correspondingly undergo cooling. Should, nevertheless, the steam content of air supply be properly regulated, so by the formation of CO_2 in the reaction zone the reaction temperature is raised, and also the gases are passed hotter into the incandescent filter than under normal conditions, and the two values, the chilling of the bed of coal and the higher temperature of the entering gases, must equalise themselves. Under the circumstances described, a formation of CO_2 is, however, always possible in the hollow spaces between the individual pieces of coal in the neighbourhood of the air inlet.

The production of such an incandescent bed is evidently possible (since there stands no hindrance in the way in the producer) by means of the incandescent coke, which is eventually produced from the fuel employed itself, being replenished up to a known height, and it must then also be maintained at this height by a proper carrying out of the production of steam-air gas. If, however, later too much steam is employed, so that the reaction temperature sinks and formation of CO_2 commences, then naturally with the regeneration of the CO_2 (to CO) the stock of heat in the incandescent bed will be continually diminished, and this will finally be rendered inoperative. It is then, however, able to be again renewed by partially or totally shutting off the steam, and blowing the producer hot again by means of dry air. There has been no statement hitherto under discussion bearing on the advantageous thickness of the incandescent bed. The sizes of the lumps of fuel and their behaviour under, and the extent of their caking, has a decided influence. From some old data, the thickness of the bed of fuel above the step fire bars, should amount to 600 millimetres to 1 metre; still this might not suffice for the most perfect possible prevention of CO_2 making its entry into the steam-air gas with the forced working of the present time. There is, however, opposed to increasing the depth of the bed of fuel, the resistance, which obstructs the passage of the air for gasifying, and this resistance can be easily overcome by means of the employment of a more powerful blast. A steam jet blast, however, might not be able to be regulated correspondingly to the demands of producer working. Recently, Bone and Wheeler have published experiments with producers in "Metallurgie," 1908, pp. 686 and 687, wherein they give the statement that they gave the bed of fuel a thickness of 2·13 metres, but they were able to go down to 1·06 metres, after they had reduced the steam content of the air supply for gasification. The authors give also an ideal means whereby one may voluntarily set up and maintain at equal height this steam content. They employ air, which is maintained at a constant specified temperature, saturated with moisture. The best results were obtained if the temperature amounted to 45°, whereby the gas contained 36·95 per cent. of carbon-containing gas.

STEAM CONTENT OF PRODUCER GAS.

Producer gas always in practice contains steam, since the entire hygroscopic water, as well as the greater portion of the so-called chemically combined water, is carried over as steam into the gas.

As shown, the content of steam from the hygroscopic water of the fuel is able to amount in a good gas coal to 0·2 kilogrammes per 1 kilogramme C, or, since from 1 kilogramme C 5 cubic metres gas is produced, amount to 40 grammes per cubic metre.

Dr. Ing. Cararis ("Stahl und Eisen," 1908, p. 538) has adopted the view that the steam content of the gas should not exceed 30 grammes per cubic metre, and that in the economical working of an open-hearth plant a continual steam content of over 60 grammes per cubic metre should in general be excluded. He found in gas producers with water seals, in working slagging and caking Westphalian coals, that it was impossible to produce a gas with under 50 to 60 grammes of steam per cubic metre, and he had often 60 to over 100 grammes.

The question of the injurious influence of steam on the working of the furnace is as yet little cleared up, and it will be further reverted to afterwards. Nevertheless, the above-given specification appears too severe, since a gas which contains less than 30 grammes per cubic metre might only admit of being produced if one cooled down the gas, and separated the steam by means of condensation. There are now, however, many open-hearth works working with gases, which are manufactured from coals with high water contents, and even with wood and peat, without cooling of the gas and condensation of the steam, and working often by no means badly. Yet, however, it is at all times an undesirable substance for furnace working, and one should employ all means to avoid an excess thereof. Now, however, the air blast forms a clearly perceptible source for an increased steam content of the gas, if too much steam be added to the same. The steam lowers thus the reaction temperature, and as has been established from the numerous researches of Harries, and from the measurements of Quasebart ("Metallurgie," 1908, pp. 224 *et seq.*) and Professor Mayer of Aachen (Stahl und Eisen, 1908, p. 725), and others, it follows that 50 per cent. or more of the amount of steam employed is able to pass undecomposed through the producer and go over into the gas. Further, this steam can be the indirect cause of the Marsh gas being burnt, as is shown in the chapter on "Judgment of Producer Gas from the Analysis," whereby likewise not inconsiderable amounts of steam are created in the gas and its quality further diminished.

Therefore the most weighty consideration for the working of a producer is that only so much steam should be added to the air supply as is necessary for the reduction of the temperature to 1,150°, whereby always the prevention of sintering of ashes will be well achieved. If, however, the cessation of this condition is carefully looked out for, then is spared also the (often too much asked for) check on the steam content of the producer gas.

With regard to the steam content of producer gas, attention will be devoted also to the raw fuels. For all fuels, which contain little combined and hygroscopic water, one will take suitable care, in the winning and storage thereof, that the taking up of water, which will be brought about by atmospheric influences, remains small. In fuels, however, which contain too much water, and in those which must involve cooling of the gas and removal of the water by means of condensation, as is involved in the employment of wood and peat, an excess of water up to a known amount is convenient, in that it lowers the temperature of the gas and thereby facilitates condensation. In regard to the condensation, it is, however, to be weighed in one's mind always that gases saturated with moisture proceed from the same, and that they will only furnish a good degree of working, if the chilling is driven to a sufficiently low temperature.

1 cubic metre gas at 0° and 760 millimetres pressure is able to take up, viz., about

At 0° C.	5 grammes H_2O	At 60° C.	190 grammes H_2O
,, 10°	9 ,, ,,	,, 70°	350 ,, ,,
,, 20°	19 ,, ,,	,, 75°	490 ,, ,,
,, 30°	36 ,, ,,	,, 80°	700 ,, ,,
,, 40°	62 ,, ,,	,, 90°	1,800 ,, ,,
,, 50°	110 ,, ,,		

From which it follows that the chilling in a hot summer must at the least be brought down to 40° to 50° in order to permit of the desired result.

CHAPTER XIII

THE CHANGES IN THE COMPOSITION OF THE GAS IN THE CONDUITS AND REGENERATOR CHAMBERS

THE gases produced in the producer are able, under the circumstances, to enter into reaction with one another, thereby frequently causing a change in the composition of the gas. On a change occurring, its being able to be produced through combustion of CH_4, H and CO, by entry of air into the gas space, can be looked out for; there comes chiefly into consideration here, the already described attack of steam on the methane, and specially on the carbon monoxide,

TABLE H.—COMMUNICATION FROM WITTENBERGER (STAHL UND EISEN, 1903, P. 447).

		Gas Composition. Volume per cent.							Gas containing 1 kilogramme C.						
		CO_2 per cent.	O per cent.	CO per cent.	H per cent.	CH*n* per cent.	N per cent.	Combustible Value. 1 cubic metre Gas.	CO_2 per cent.	O per cent.	CO per cent.	H per cent.	CH*n* per cent.	N per cent.	Combustible Value. Gas from 1 kg. C.
1	From conduits	5·6	0·4	23·0	11·3	2·0	58·3	1,172	0·31	0·02	1·43	0·70	1·12	3·61	7,255
	From chambers	7·2	0·2	20·6	12·0	1·6	59·0	1,064	0·46	0·01	1·29	0·77	0·10	3·80	6,866
2	From conduits	5·2	0·2	23·8	11·5	2·2	57·1	1,219	0·31	0·01	1·42	0·68	0·13	3·40	7,253
	From chambers	7·4	0·6	20·2	12·4	1·4	58·0	1,064	0·47	0·04	1·29	0·79	0·09	3·72	6,810
3	From conduits	5·0	0·2	24·3	10·9	2·2	57·4	1,219	0·30	0·01	1·43	0·64	0·13	3·39	7,192
	From chambers	7·2	0·4	21·0	12·0	1·6	57·8	1,095	0·45	0·02	1·31	0·75	0·10	3·61	6,832
4	From conduits	4·8	—	24·4	10·6	2·4	57·8	1,231	0·28	—	1·43	0·62	0·14	3·40	7,240
	From chambers	7·2	0·4	22·0	12·1	1·0	57·3	1,076	0·44	0·02	1·35	0·74	0·06	3·52	6,617
5	From conduits	4·2	2·0	24·0	10·8	2·2	56·8	1,207	0·26	0·12	1·47	0·66	0·13	3·47	7,376
	From chambers	6·0	1·4	22·0	11·9	1·4	57·3	1,006	0·38	0·09	1·39	0·75	0·09	3·63	6,368
6	From conduits	5·4	1·2	24·8	11·0	1·8	55·8	1,202	0·31	0·07	1·44	0·64	0·10	3·24	6,987
	From chambers	7·2	0·8	22·0	12·4	1·2	56·4	1.101	0·44	0·05	1·35	0·76	0·07	3·47	6,776

possibly also at times the attack of CO_2 on CH_4. In good gases, which contain little CO_2 and H_2O vapour, the transformation is not able to be considerable.

An illustration of the changes in the composition of the gas observed in practice, which result, so to say, by intermolecular reaction by the aid of the available heat or by heating in the regenerator chambers, is set out in Table H.

If one sums up the combustible value of all six gas tests, in order to obtain the mean value of the loss of combustible value per 1 cubic metre of gas, one obtains

	Calories.
Combustible value 6 cubic metres gas from conduits .	7,250
Less combustible value 6 cubic metres gas from conduits regenerator chambers	6,406
Loss in combustible value in 6 cubic metres gas from chambers	844

or, roundly, 12 per cent. of the original combustible value. But if one sums up the figures which result for the combustible value of the quantities of gas derived from 1 kilogramme C, one thus obtains

	Calories.
Combustible value of the gas from 1 kilogramme C from conduits	43,303
Combustible value of the gas from 1 kilogramme C from chambers	40.269
Loss of combustible value of the gas from 6 kilogrammes C	3,034

or, roundly, only 7·5 per cent. of the combustible value is lost.

In explanation of the occurrences which caused these changes in the gas composition one may consider the relative amounts of the gases from 6 kilogrammes C, which one obtains from the addition of the amounts given for 1 kilogramme C.

	Cubic metre.	Cubic metre.	Cubic metre.	Cubic metre.	Cubic metre.	Cubic metre.
Gas from conduits from 6 kilogramme C	CO_2 1·77+	O 0·23+	CO 8·60+	H 3·94+	CH_4 0·75+	N 20·57
Gas from chambers from 6 kilogramme C	2·64+	0·23+	7·98+	4·56+	0·51+	21·75
Thus increases	CO_2 0·87			H 0·62		N 1·1
,, decreases			CO 0·62		CH_4 0·24	

An explanation is scarcely derivable, however, herefrom. Resolving the gas into its elements, one obtains

	Cubic metre.	Cubic metre.	Cubic metre.
Gas from 6 kilogrammes C from conduits had	6·31 O+	5·44 H+	20·51 N
,, 6 ,, C ,, chambers ,,	6·86 O+	5·58 H+	21·75 N
Gas from chambers from 6 kilogrammes C had excess	0·55 O+	0·14 H+	1·24 N

If the 0·14 cubic metres H originated from the decomposition of water, there must have correspondingly been 0·14 × 0·5 O therein. Thus 0·55 cubic metre—0·07 cubic metre = 0·48 cubic metre O originated from another source. This circumstance, as well as the increase in the N content of the gas admits of one's concluding that air has reached the gas. Then, however, is explained the diminution of the combustible value of the gas derived from 1 kilogramme C, probably absolutely unconstrained. The air has principally burnt CH_4 and H, probably some CO, and secondarily also there has occurred inter-reaction between some steam and CO, possibly also CH_4. Quantitative data as to this are not able to be derived. Also, these gases with their content of 30 to 32 per cent. of C-containing gases belong to those in which a considerable portion of the distillation gas has been already burnt in the producer.

TABLE I.

		Composition. Volume per cent.						Gas containing 1 kilogramme C.					
		CO_2 per cent.	O per cent.	CO per cent.	H per cent.	CH_4 per cent.	Combustible Value 1 cubic metre.	CO_2 cbm.	O cbm.	CO cbm.	H cbm.	CH_4 cbm.	Combustible Value.
							Calories.						
1	In front of cleaner	5·6	—	25·4	14·8	0·1	1,183	0·33	—	1·52	0·89	0·01	7,072
	Behind cleaner .	6·0	—	25·0	15·9	—	—	—	—	—	—	—	—
	Before gas valve .	7·2	—	23·8	16·5	—	1,161	0·43	—	1·43	0·99	—	6,966
2	In front of cleaner	4·8	—	25·9	14·8	0·6	1,332	0·28	—	1·54	0·88	0·04	7,566
	Behind cleaner .	5·9	—	24·3	16·9	0·1	—	—	—	—	—	—	—
	Before gas valve .	6·4	—	23·8	17·6	—	1,190	0·39	—	1·47	1·09	—	7,358
3	In front of cleaner	4·2	—	28·0	13·8	0·8	1,280	0·24	—	1·58	0·78	—	7,226
	Behind cleaner .	4·8	—	29·9	14·9	0·2	—	—	—	—	—	—	—
	Before gas valve .	5·6	—	25·4	16·2	—	1,200	0·34	—	1·52	0·97	—	7,200

Ledebur communicates through a contribution to "Stahl und Eisen," 1903, p. 694, similar analyses as to the changes of the gas in the conduits. The gas conduits were provided with gas cleansers and water-seals, and the gas temperature between the producer and the cleanser amounted to about 860° and between the cleanser and gas valve to about 760° C.

The gases showed compositions as follows:—

The loss of combustible value amounts here to

Combustible value:

		Calories.		Calories.
Total 1 to 3	Before cleaner 3 cubic metre gas	3,795	Gas from 3 kilogrammes C	21,864
Total 1 to 3	Behind cleaner 3 cubic metre gas	3,551	Gas from 3 kilogrammes C	21,554
Loss in combustible value .		244		310

Thus, taken on original combustible values,

For 1 cubic metre gas, 7 per cent.

For gas from 1 kilogramme C, 1·5 per cent.

In another instance, at a temperature of only about 360° C., the gas composition was

		Per cent.	Per cent.	Per cent.	Per cent.
4	Before cleanser	CO_2 3·8+	CO 28·0+	H 12·1+	CH_4 2·1
	After cleanser.	,, 3·6+	,, 28·4+	,, 11·1+	,, 2·3
5	Before cleanser	,, 3·9+	,, 26·2+	,, 12·2+	,, 2·3
	After cleanser.	,, 4·0+	,, 26·0+	,, 12·0+	,, 2·5

Here a change of gas composition was scarcely provable.

Professor Mayer ("Stahl und Eisen," 1908, p. 766) found as a mean

	CO_2 per cent.	O per cent.	CO per cent.	H per cent.	CH_4 per cent.	C_mH_n per cent.	N per cent.
Gas in conduits	6·3+	0·2+	22·7+	13·4+	2·6+	0·3+	54·5
Gas from top of regenerator chamber	6·4+	0·2+	23·3+	16·6+	0·8+	0·2+	52·5

Combustible value of the gas in conduits per cubic metre=1,435 calories.

Combustible value of the gas from regenerator chamber=1,371 calories.

Calculated per 1 kilogramme C this gives

Combustible value of the gas per 1 kilogramme C from conduits 8,280 calories.

Combustible value of the gas per 1 kilogramme C from chambers 8,308 calories.

Thus the loss of combustible value which is called into being by the reciprocal attack of the constituents of the gas on one another is not very important, in the cases cited by Ledebur and Mayer, in respect of the combustible value per cubic metre, and is, however, diminished in respect of the gas resulting from the unit of weight. One may thus well assume that in well-manufactured producer gases this loss will be still smaller, and, therefore, less important. Therefore one will seek to feasibly avoid the presence of greater amounts of H_2O vapour in the gas, and likewise strive to obtain only a medium content of hydrocarbons. This would again further indicate that one can improve too strongly caking coals by means of an addition of lean fuel, since there is no object in manufacturing gas with high hydrocarbon content, if this gas is ultimately decomposed in the regenerator chambers before its entry into the combustion chamber of the furnace.

CHAPTER XIV

AIR REQUIREMENT FOR COMBUSTION OF THE GAS IN THE OPEN-HEARTH FURNACE.

As a result of practice it is shown that the fuel will be completely burnt in the open-hearth furnace with 1·3 times the theoretical amount of air, since analyses from different works show that with such air ratios no trace of combustible gas is any more contained in the waste gases. Professor Mayer found, on the other hand (“ Stahl und Eisen,” 1908, p. 725), that with 1·21 times the amount of air, still not quite complete combustion took place, in that the composition of the waste gas, viz. :—CO_2 14·2 per cent. + CO 0·1 per cent. + O 3·8 per cent. + N 81·9 per cent., still showed perceptible CO content.

The determination of the quantity of air to introduce into the furnace may therefore, however, not be based on the theoretical air requirement, which is required for the combustion of the gas, since, if one increases this amount up to 1·30 times the quantity of air will in accordance with practice turn out too low. *The figure* 1·3 *relates to the total quantity of air requisite for the combustion of the raw fuel,* of which, however, a portion has already been employed for gasification, and this portion may not be disregarded.

If one wishes to accurately determine the air requirement, which indeed is of value for theoretical considerations, one cannot well proceed from the elementary analysis of the fuel, but one may suitably select the products of complete combustion as a basis, or else, in case the composition of the heating gas is determined, obtain all requisite data from this. As an example of such a calculation, let the so-called best producer gas on p. 78 be selected.

The quantity of air required for its complete combustion and the resultant products of combustion are furnished as under :—

Gas from 1 kilogramme C.		O required.	CO_2 yielded.	N.	H_2O vapour.
	Cubic metre.	Cubic metre.	Cubic metre.	Cubic metre.	Cubic metre.
CO_2	0·05	—	0·05	—	—
CO	1·63	0·815	1·63	—	—
C_mH_n	0·02	0·06	0·04	—	0·04
CH_4	0·14	0·28	0·14	—	0·28
H	0·41	0·205	—	—	0·41
N	2·76	—	—	2·76	—
5·01 gas accompanied by		1·360 5·115 N	—	5·115	—
5·01 requiring		6·475 air			
yielding as products of combustion		—	1·86	+7·875	+0·73

The 7·785 cubic metres N are derived practically entirely from the air. If, however, one wishes to take into account the N derived from the fuel, so one is able to deduct 0·01, and then one obtains nitrogen derived from air 7·865 cubic metres. In 1·3 times the amount of air the nitrogen must amount

Cubic metre.
to 1·3 × 7·865 = 10·22
In the gas there is already N derived from air . = 2·75

Hence there must be introduced from air . . 7·47 N
Which carries with it . . . . 1·99 O

Thus the practical air requirement for 5·01 cubic metre gas from 1 kilogramme C . . . . = 9·46 (air)

Or the practical air requirement for 1 cubic metre gas $= \frac{9{\cdot}46}{5{\cdot}01} = 1{\cdot}89$ cbm.

If one wishes to ascertain values, which also shall be valid for the most unfavourable working conditions of the year, so one must take into consideration the humidity of the air, and this is able (from p. 24) to amount up to 0·04 cubic metre steam per cubic metre air, taken at 0° and 760 millimetres. Then the air requirement for 1 cubic metre gas would be

$$1{\cdot}89+1{\cdot}89\times0{\cdot}04=1{\cdot}96 \text{ cubic metre air.}$$

AIR REQUIREMENT FOR BAD GAS.

In the installation of furnaces, it must be taken into consideration that the working of producers is able to be faulty at times, and that the furnace should also in these cases fulfil its function of giving up great amounts of heat at high temperature. In this connection it is requisite also to know the quantity of air which must be introduced into the furnace with bad quality gas. Only in order first of all to fix the lowest limit value for the worst gas, let the exaggerated assumption be made that 50 per cent. more air has entered the producer than is necessary for gasification, whereby this excess of air has partially burnt the gases formed. Further, let it be assumed that also an excess of steam has been present, so that, as indeed has often been practically observed, 50 per cent. of the steam employed has gone over into the gas undecomposed—that is to say, 0·21 cubic metre (as in steam-air gas from 0·88 kilogramme C, *vide* p. 78, 0·21 cubic metre H is present, which results from 0·21 cubic metre steam).

From the resolution into its elements of the best producer gas considered in the previous example, the O excess taken at 50 per cent. calculates out at 0·43 cubic metre, which has burnt the entire methane and 0·18 cubic metre CO, whereby from the methane a further 0·32 cubic metre water-vapour has originated. On this estimate the composition of the gas from 1 kilogramme C calculates out at

CO_2 0·41 cubic metre+CO 1·45 cubic metre+H 0·41 cubic metre+N 4·38 cubic metres=6·55 cubic metres of dry gas+0·53 cubic metre steam, or a grand total of 7·18 cubic metres with consequently resulting analysis.

CO_2 5·1 per cent.+CO 21·8 per cent.+H 6·1 per cent.+ N 66·2 per cent.

and a combustible value of 827 calories per cubic metre or 5,515 calories per kilogramme C.

The amount of air necessary for the complete combustion of this gas is calculated thus:—

Gas.		O required.	CO_2 yielded.	N	H O vapour.
	Cubic metre.	Cubic metre.	Cubic metre.	Cubic metre.	Cubic metre.
CO_2	0·41	—	0·41	—	—
CO	1·45	0·725	1·45	—	—
H	0·41	0·205	—	—	0·41
N	4·38	—	—	4·38	—
	6·65	0·930	carrying	3·49	—
6·65 cubic metres. gas yielding products of combustion			1·86	+ 7·87	+ 0·41
H_2O from gas . . .			—	—	0·53
Grand total products of combustion			1·86	+ 7·87	+ 0·94

The amount of nitrogen from combustion with the theoretical amount of air is equal to 7·87 cubic metres, practically it will be 1·3 × 7·89 = 10·23 cubic metres N (as before, p. 80) of which, however, there is already present in the gas 4·38 cubic metres, thus leaving 5·85 cubic metres N which is accompanied by 1·56 cubic metre O, representing 7·41 cubic metres air, for 6·65 cubic metres gas; or the practical amount of gas for 1 cubic metre gas will be $\frac{7{\cdot}41}{6{\cdot}65} = 1{\cdot}11$ cubic metre dry or $1{\cdot}11 + 1{\cdot}11 \times 0{\cdot}026 = 1{\cdot}14$ cubic metre damp air (air taken at 30° saturated with moisture).

It shows that with deterioration of the quality of the gas the air requirement goes down largely, since in the second instance for 1 cubic metre gas only about 60 per cent. of the air is required which is necessary for good gas.

It will, therefore, be retained in view that with improvement in the gas quality of present installations the air requirement must be correspondingly raised, and that therefore also the demands which will be placed on the chambers for preheating the air are able to be considerably higher than when employing bad gas.

Summarising the results obtained

Highest Limit Values. Best producer Gas from Gas Coal.	Lowest Limit Values. Conceivable worst producer Gas from good Gas Coal.
1 cbm. gas requires . 1·96	1·14 cubic metre air.
1 ,, develops . 1,507 cals.	827 calories.
The products of combustion of gas containing 1 kg. C are :—	
CO_2 1·86 cbm. + O, 0·63 cbm. + N 10·23 cbm. + steam 0·98 cbm.	CO_2 1·86 cbm. × O 0·63 cbm. + N 10·23 cbm. + steam 1·13 cbm.
N.B. The content of free oxygen is ascertained as under :—	
O introduced . . 1·99 cbm.	1·56 cubic metre.
O theoretically necessary . . . 1·36 ,,	0·93 ,,
O excess . . . 0·63 cbm.	0·63 cubic metre.
The steam content of the gas is ascertained as follows :—	
Steam from the products of combustion 0·73 cbm.	0·73 cbm. (0·41 + 0·32 cbm.)
Steam as undecomposed steam . . —	0·21 ,,
From the humidity of the air 1·89 × 5·01 × 0·026 . . = 0·25 ,,	0·19 ,, (1·11 × 6·65 × 0 026).
Total . . 0·98 cbm.	1·13 cbm. steam.

CHAPTER XV

THE TEMPERATURES AND TRANSMISSION OF HEAT IN THE COMBUSTION CHAMBER OF THE OPEN-HEARTH FURNACE.

In all open-hearth furnaces one observes during working a flame temperature of approximately 1,800° maximum in the combustion chamber and of about 1,700° at the exit ports, and one may well assume that the former signifies the maximum which the furnace chamber is capable of, whilst the latter constitutes the minimum which is absolutely necessary for practical possibility of steel making.

As to the ways and means of the utilisation of the heat in the combustion chamber, and especially as to the extent of this utilisation, there has hitherto been scarcely anything written or uttered. In the following views as to this question let it be at once remarked that these figures are taken as purely personal observations of the writer's and that they were not able to be tested by practical experiments.

The heating of materials on the hearth of an open-hearth furnace is in principle a very simple matter. A hotter flame plays on a cooler object and heats this in consequence of the difference of temperature which is present between the two, whereby the flame itself naturally suffers loss of heat.

The correctness of this fundamental principle will also endorse the introductory data cited, since the highest temperature of the flame amounted to 1,800°, but in consequence of the work done (on the hearth) was cooled down to 1,700°. The work can have been performed in different ways, in that heat can have been given off through direct contact, by conduction or indirectly by radiation; in the combustion chamber both kinds of heat transmission take place. For the flame both are as yet little investigated; if one, nevertheless, takes the heat as being merely a form of energy, and contents oneself provisionally only in ascertaining the total amount of energy which will be transmitted from the flame to the combustion chamber, one is placed in the position to ascertain this value by measurement. This will be equal to the difference between the total quantity of energy which is brought into the combustion chamber and that which leaves it.

For example, let it be assumed that in an open-hearth furnace both the producer gases named have been employed—at the one time the best, at the other, the worst producer gas. Let the 1·3 times amount of air have been employed for combustion, and let the preheating of the gas and air have been driven to the point that the resultant temperature of the flame will have exactly reached 1,800°, whilst the available

ENERGY SUPPLIED TO THE COMBUSTION CHAMBER.

	Best Gas.	Worst Gas.
(*a*) Available heat of the products of combustion of an amount of gas containing 1 kilogramme C at 1,800° C:	Calories.	Calories
CO_2	1·86 ×0·8378=1·5585	1·86 ×0·8378=1·5585
O . . . . . N	0·63 10·23 } ×0·3764=4·0877	0·63 10·23 } ×0·3764=4·0877
Steam . . .	0·98 ×0·7713=0·7758	1·13 ×0·7713=0·8716
	6·4020	6·5178
	× 1,800	× 1,800
	11,524	11,732
(*b*) Energy drawn off from the combustion chamber. Available heat of the waste gases at 1,700°:		
CO_2	1·86 ×0·8128=1·5118	1·86 ×0·8128=1·5118
O . . . . . N	0·63 10·23 } ×0·3725=4·0453	0·63 10·23 } ×0·3725=4·0453
Steam . . .	0·98 ×0·7482=0·7332	1·13 ×0·7482=0·8454
	6·2903	6·4025
	× 1,700	× 1,700
Given up to combustion chamber.	Calories.	Calories.
a . . .	11,524	11,732
−*b* . . .	−10,643	−10,884
a−*b* . . .	831	848

heat of the waste gases will be placed at 1,700° by the quantity of energy which will be carried off from the combustion chamber (*vide* calculation on p. 114).

The difference between these two values yields the amount of energy which has remained in the combustion chamber.

The available heat of the gas is furnished by multiplication of the individual constituents of the waste gases by the temperature and the mean specific heat C_0^t valid therefor (see table in Appendix).

Now it should certainly not be asserted that these numerical values have any sort of claim to exactitude, since values taken for the specific heats at such high temperatures are much too unsafe.

Nevertheless, one has found some ground for comparisons, and this may suffice to prove two facts well founded:—

1. The certainly startling result that under the conditions in the combustion chamber an equally high amount of heat can be available from a quite bad gas as by employment of the best gas.

2. That the utilisation of the heat in reality takes place differently to what was hitherto assumed.

This last conclusion is proved by the fact that about 400 calories are necessary for the production of 1 kilogramme of steel; so that it would not be possible to produce more than 2 kilogrammes of steel with 1 kilogramme C, even on the certainly inadmissible assumption that the whole amount of 830 calories shown to be given up in the combustion chamber could be used without any loss for the production of steel. In practice, however, already up to 5 kilogrammes steel per kilogramme C have been produced, and such an important difference demands another explanation than could be given by means of more exact values for the specific heats at high temperature. In the preceding the amount of heat energy which will be introduced into the combustion chamber has been ascertained from the available heat of the products of combustion. There is still another way to find this value; it must be, *i.e.*, the amounts of the available heats possessed by the gas and air *plus* the combustible value of the gas, since no other energy is at disposal. Now, one could easily ascertain the degree of temperature to which the gas and air must be heated in order to receive reinforcement of the combustible value of the gas by the hereinbefore ascertained total amount of energy of about 11,600 calories. Would then, however, the temperature demanded result under all circumstances from the combustion of the gas?

The question is absolutely to be answered in the negative, and the fact previously quoted that in steel manufacture the utilisation of the fuel can be much better than as hereinbefore calculated, turns out to be the actual cause of the latter phenomenon, in spite of the fact that a temperature over 1,800° will never be observed in the combustion chamber. If, that is to say, the conditions for a consumption of heat are present in the combustion chamber, at the moment of combustion the total amount of energy of the products of combustion could not be taken away, but a portion thereof be immediately removed by the remaining heat consumers present, and as a consequence thereof must produce a lower temperature of combustion than potentially obtainable from the sources of energy and products of combustion present were they isolated.

Now since in an empty furnace the losses by radiation are quite considerable, the existence of a consumption of heat is proved to exist, thus the minimum temperature required will only admit of being obtained at all if the gas and air are always so much the more preheated, as stipulated for by this capacity for heat consumption. The extent thereof is not by any means easy to determine, and if one could do so it would not help much, for the capacity of the combustion chamber for consuming heat is different at different times in the course of the charge, whilst on the other hand it is not possible rapidly and at will to alter the temperature of the regenerator chambers and the composition of the gas. But in order, nevertheless, to regulate the temperature in the combustion chamber and to maintain it at the requisite height, one only requires to correspondingly diminish the quantities of gas and air led into the furnace per unit of time; if the gas and air be loaded with too great a store of energy, and thereby to let only so large quantities of energy be set free as just suffice to satisfy the heat absorption capacity of the combustion chamber, so that thus an excess of energy cannot originate.

If this chain of reasoning be regarded as correct, then, with the object of economical employment of the fuel, the preheating of the gas and air must be driven as far as possible, as one can importantly increase the amount of energy which is won from the fuel, owing to the increased available heat of the gaseous media.

Now, a limit is placed on the extent of such preheating by the temperature of the gases drawn off from the combustion chamber, since if the flame be only heated to 1,700° the gases preheated through its means cannot well be heated higher than 1,600° to 1,650°.

In opposition to this theory it has, however, been shown in practice that by such high preheating in many furnaces the limit is overstepped in which the best results have been achieved. It has been observed that by too strongly preheating gas and air the production of the furnaces rather goes down than rises, whilst the chambers, especially in their upper portions, become overheated, so that the checkers melt and even the arches of the chambers threaten to sink, which must have as a consequence the shutting down of the furnace. One has further remarked that it is very difficult and requires very much time to again bring such highly-heated chambers to lower temperatures by usual means, and one is compelled to provide special cooling openings in the ports which lead to the chambers and through which cold air can be led into the same if they stand in direct communication with the chambers. This arrangement may, from the point of view of frugal economy of heat, be regarded as totally faulty. It must, however, be retained until one has succeeded in producing the correct equilibrium between the heat production and consumption, somehow or other by the previously mentioned methods, for the diminution of the amounts of gas and air.

So long as the working of the furnace is damaged by too high preheating one dare not employ it, and let it be assumed from the following calculations that the degree of preheating

TABLE J.

		Air-gas manufactured with		
		Theoretical amount of Air.	Air Excess.	
			20 per cent.	40 per cent.
		Cubic metre. Per cent.	Cubic metre. Per cent.	Cubic metre. Per cent.
Composition of the air-gas from 1 kilogramme C	CO_2	0·00	0·37 = 6·1	0·47 = 10·9
	CO	1·86 = 34·7	1·49 = 24·6	1·12 = 16·6
	N	3·50 = 65·3	4·20 = 69·3	4·90 = 72·5
Volume of gas		5·36	6·06	6·76
Amount of air		7·10	6·20	5·32
Combustible value of gas—				
from 1 kilogramme C		5,693 cals.	4,557 cals.	3,418 cals.
from 1 cubic metre		(1,062 ,,)	(752 ,,)	(506 ,,)
Available heat of gas from 1 kilogramme C at 1,200° C.		2,268 cals.	2,712 cals.	3,168 cals.
,, ,, air ,, 1 ,, ,, 1,200° C.		2,987 ,,	2,601 ,,	2,232 ,,
Total available heat		5,255 cals.	5,313 cals.	5,400 cals.
+ Combustible value		5,693 ,,	4,557 ,,	3,418 ,,
Total energy of the entering flame		10,948 cals.	9,870 cals.	8,818 cals.
Less energy in waste gases at 1,700° C.		8,678 ,,	8,678 ,,	8,678 ,,
Remainder energy useable in combustion chamber		2,270 cals.	1,192 cals.	140 cals.
Waste gas: CO_2 1·86 cubic metre + O 0·36 cubic metre + N 9·11 cubic metre.		11·53 cbm.	11·53 cbm.	11·53 cbm.

of the gas, as well as the air, be 1,200°, a preheating which may practically be well endured without harm by all furnaces and heating gases.

INFLUENCE OF THE QUALITY OF THE GAS ON THE UTILISATION OF HEAT IN THE COMBUSTION CHAMBER.

In order to show the influence of the quality of the gas and the amounts of heat which may be given off in the combustion chamber the Tables J (on p. 118) have been calculated. The mode of calculation is, without anything further, clear, and therefore only the suppositions which serve as bases require comment. The amount of air for combustion has been taken throughout at 1·3 times that of the theoretical quantity for the raw fuel. It has been assumed that the gas and air were preheated to 1,200° and the gases were drawn off from the combustion chamber at 1,700°, and combustion therein as having taken place completely.

First, let air-gas be considered in different degrees of purity.

With the best air-gas the maximum amount of heat which can be uniformly averaged in the combustion chamber is 2,261 calories, whilst an air-gas which has been manufactured with a 20 per cent. excess of air goes down to half. With 40 per cent. excess of air in the producer and preheating of the gas and air to 1,200°, steel melting would become an impossibility.

The influence of the addition of steam to air for gasification is shown in Table K., p. 120.

One sees that the maximum amount of heat from 1 kilogramme C which can be placed at disposal of the combustion chamber is the greater the more H contained in the gas. This nevertheless attains its limit if the H production is driven so far that CO_2 formation must result, since in this case a diminution of the useful effect makes its appearance. This phenomenon is clear in respect to the pure water-gases (compare column 2 against 1), although these gases do not come actually into the question for open-hearth furnace working. Still more clearly one sees this from the next to the last column, for steam-air gas which is regarded as

TABLE K.

	Theoretical.					
	Water-gas.		Steam-air Gas.			Air-gas.
	I. CO+H.	II. CO_2+2H.	Pure CO Formation.		Pure CO_2 Formation from cold Air.	
			From Air heated to 500°.	From cold Air.		
Number of Column.	1.	2.	3.	4.	5.	6.
Composition of gas from 1 kilogramme C CO_2	—	1·86 cbm.	—	—	1·86 cbm.	—
CO	1·86 cbm.	—	1·86 cbm.	1·86 cbm.	—	1·86 cbm.
H	1·86 ,,	3·72 cbm.	0·48 ,,	0·24 ,,	2·48 cbm.	—
N	—	—	0·60 ,,	3·04 ,,	2·32 ,,	3·50 cbm.
Gas volume containing 1 kilogramme C	3·72 cbm.	5·58 cbm.	2·94 cbm.	5·14 cbm.	6·66 cbm.	5·36 cbm.
Combustible value of the gas from 1 kilogramme C.	10,750 cals.	9,746 cals.	6,941 cals.	6,303 cals.	6,507 cals.	5,693 cals.
Combustible value of the gas from 1 cubic metre.	(2,841)	(1,746)	(1,405)	(1,226)	(997)	(1,062)
Amount of air	11·52 cbm.	11·52 cbm.	8·23 cbm.	7·66 cbm.	8·57 cbm.	7 1 cbm.
Available heat gas 1,200° . . .	1,577 cals.	3,111 cals.	2,094 cals.	2,179 cals.	3,569 cals.	2,268 cals.
,, ,, air 1,200° . . .	4,884 ,,	4,884 ,,	3,490 ,,	3,247 ,,	3,633 ,,	5,693 ,,
Total available heat	6,461 cals.	7,995 cals.	5,584 cals.	5,426 cals.	7,202 cals.	5,246 cals.
+Combustible value	10,570 ,,	9,746 ,,	6,941 ,,	6,303 ,,	6,507 ,,	5,693 ,,
Total energy in flame	17,031 cals.	17,741 cals.	12,525 cals.	11,729 cals.	13,709 cals.	10·939 cals.
Less that in waste gases at 1,700° .	11,052 ,,	13,417 ,,	9,297 ,,	8,992 ,,	11,632 ,,	8,678 ,,
Energy for the combustion chamber .	5,979 cals.	4,324 cals.	3,228 cals.	2,737 cals.	2,077 cals.	2,261 cals.
Composition of the waste gases CO_2 . .	1·86 cbm.	1·86 cbm.	1·86 cbm.	1·86 cbm.	1·86 cbm.	1·86 cbm.
O . . .	0·56 ,,	0·56 ,,	0·56 ,,	0·56 ,,	0·56 ,,	0·56 ,,
N . . .	9·10 ,,	9·10 ,,	9·10 ,,	9·10 ,,	9·10 ,,	9·10 ,,
Water-vapour	1·86 ,,	3·72 ,,	0·48 ,,	0·24 ,,	2·32 ,,	—
Total waste gases.	13·38 cbm.	15·24 cbm.	12·00 cbm.	11·76 cbm.	13·84 cbm.	11·52 cbm.

TABLE L. PRODUCER GAS.

		From good gas coal. 12 per cent. of C in the distillation gas.	From good gas coal. 16 per cent. C in the distillation gas.		Steam-air Gas produced with cold air.
		Theoretical.	Theoretical.	Practical.	Theoretical.
No. of Column.		7.	8.	9	19.
Gas composition per 1 kilogramme C .	CO_2	0·05 cbm.	0·05 cbm.	0·36 cbm.	—
	CO	1·63 ,,	1·59 ,,	1·31 ,,	1·86 cbm.
	C_mH_n	0·02 ,,	0·02 ,,	0·02 ,,	—
	CH_4	0·14 ,,	0·18 ,,	0·15 ,,	—
	H	0·41 ,,	0·60 ,,	0·77 ,,	0·24 ,,
	N	2·76 ,,	2·64 ,,	0·11 ,,	3·04 ,,
	H_2O	0·25 ,,	0·25 ,,	0·68 ,,	—
Cubic metre gas from 1 kilogramme C . . .		5·26 cbm.	5·33 cbm.	6·40 cbm.	5·14 cbm.
Combustible value of gas per 1 kilogramme C .		7,554 cals.	8,272 cals.	7,601 cals.	6,303 cals.
,, ,, ,, per 1 cubic metre . .		(1,507 ,,)	(1,628 ,,)	(1,236 ,,)	(1,226 ,,)
Amount of air, cubic metres		9·46 cbm.	10·38 cbm.	9·85 cbm.	7·66 cbm.
Available heat gas from 1 kilogramme C . .		2,571 cals.	2,395 cals.	3,112 cals.	2,179 cals.
,, ,, air		4,012 ,,	4,401 ,,	4,176 ,,	3,247 ,,
Total available heat		6,583 cals.	6,796 cals.	7,288 cals.	5,426 cals.
+Combustible value		7,554 ,,	8,272 ,,	7,601 ,,	6,303 ,,
Total energy of the flame		14,137 cals.	15,068 cals.	14,889 cals.	11,729 cals.
Less energy in the waste gases at 1,700° .		10,693 ,,	11,477 ,,	12,162 ,,	8,992 ,,
Energy utilised in combustion chamber . .		3,444 cals.	3,591 cals.	2,727 cals.	2,737 cals.
Composition of the waste gases . .	CO_2	1·86 cbm.	1·86 cbm.	1·86 cbm.	1·86 cbm.
	O	0·63 ,,	0·67 ,,	0·67 ,,	0·56 ,,
	N	10·23 ,,	10·98 ,,	10·98 ,,	9·10 ,,
	H_2O	0·98 ,,	1·25 ,,	1·54 ,,	0·24 ,,
Total waste gases, cubic metres		13·70 cbm.	14·76 cbm.	15·05 cbm.	11·76 cbm.

having been produced from cold air, and as if it were possible to manufacture CO-free steam-air gas. Here the amount of heat available for the combustion chamber is, notwithstanding the tremendous amount of hydrogen, smaller than with employment of pure air-gas, which for comparison is placed alongside it. The circumstances are given rise to by the high specific heat of steam 0·7482 × 1,700° = 1,272 calories per cubic metre, owing to which the amount of energy going to loss which is contained in the gases drawn off, is considerably increased.

Table L, on p. 121, shows the influence which constituents of the distillation gas exercise on the heat energy, which can be placed at disposal of the combustion chamber under the conditions given. In the first column, numbered 7, is represented the best average producer gas manufactured from a fuel in which 12 per cent. of carbon goes over into the gas as distillation gas; in the third column, numbered 9, is set out a gas from practical working, the fuel of which permitted of 16 per cent. carbon going over into the distillation gas. This gas has not been irreproachably made. Column numbered 8 shows how it should have appeared in case it had been actually made according to the theories developed under the headings "Distillation Gas" and "Producer Gas." In the last column the theoretical steam-air gas is set out for comparison.

Calculations yield as available in the combustion chamber—

	For correctly manufactured Gas.			For faultily manufactured Gas.	
	Cals.	Column.		Cals.	Column.
Pure air-gas . . .	2,261	6	TABLE K	—	—
Steam-air gas from cold air.	2,737	4		2,077	5
Steam-air gas produced from air heated to 500°.	3,228	3		—	—
Average producer gas . .	3,444	7	TABLE L	—	—
Producer gas from coal with 16 per cent. of volatilisable carbon.	3,591	8		2,727	9

One sees that gas manufactured from richly bituminous fuels can give far higher values than gas from pure C. Should, nevertheless (as in column 9), there be present comparatively not very important faults, yet the capacity for utilisation in the combustion chamber goes down considerably.

The figures ascertained make not the smallest claim on absolute accuracy, and the illustration is able to suffer considerable disarrangement, through the capability of the individual gases to endure higher preheating or not. Nevertheless, the figures cannot very well be denied a real value for comparison. Now, from these and from the circumstance that with the faultily manufactured gas set out in column 9, as well as with demonstratively much worse gases, steel is produced with a consumption of 25 kilogrammes coal per 100 kilogrammes steel; so the conclusion appears correct that in open-hearth furnace working in respect of economy of fuel, the last word has not yet been spoken.

But, likewise, the considerations demonstrate the value of faultless working of the producer for good utilisation of the fuel in melting steel.

The figures given in the preceding section give the total amounts of heat which will be given off to the combustion chamber. This total amount can naturally not be completely utilised for steel production since the very considerable portion thereof, which can be different for all different furnaces, goes to loss through radiation and conduction. In general, the extent of this loss is difficult to estimate. Nevertheless, however, it can be taken that for one and the same furnace it amounts to approximately the same value per unit of time. Thus all measures which give rise to a shortening of the "chargedure"[1] must effect an increase in the quantity of heat which is transferred in the unit of time, whilst the radiation loss remains constant, and thus admit of the total quantity of fuel employed appearing smaller.

There is, therefore, likewise given a means of favourably influencing the fuel consumption in open-hearth furnace

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[1] Note by translator.—This word has been coined by the translator for the purposes of this book. The German word "chargendauer" has no English equivalent. It means the period from commencement of charging to emptying the furnace. The word "charge" in English is used often in the restricted sense of original charge, and does not apply to the smelted product or "heat." The expressions used in English steel works are so loosely employed as to render consideration of the context necessary in most cases.

working, in the increase of the quantity of heat yielded up to the combustion chamber.

UTILISATION OF HEAT IN THE CHAMBERS.

By means of the previously ascertained figures it is easy to reach a conclusion as to the utilisation of heat in the chambers. The amount of heat which the waste gases give up to the chambers must be equal to the available heat of the waste gases on their entry into the chambers, less their available heat on their exit therefrom. The temperature of the waste gases on their entry into the chambers amounts now to 1,700°, and the value of the available heat can be taken directly from the foregoing tables, whilst for determination of the amount of heat issuing, the basis has to be established. For this let it be assumed that the exit temperature should amount to 700°.

TABLE M.—UTILISATION OF THE WASTE GASES IN THE CHAMBERS.

	Gas from coal with 16 per cent. volatile C.	Average producer gas.	Steam-air gas made from air heated 500°.	Steam-air gas made from cold air.	Gas from coal with 16 per cent. volatile C.	Air-Gas
	Theoretical. Cals.	Theoretical. Cals.	Theoretical. Cals.	Theoretical. Cals.	Practical. Cals.	Theoretical. Cals.
Available heat of the entering waste gases at 1,700° . . .	11,477	10,693	9,297	8,992	12,162	8,678
Available heat of the outgoing waste gases at 700° . . .	3,887	3,625	3,184	3,077	4,082	2,990
Energy given up to the chambers . .	7,590	7,068	6,113	5,915	8,080	5,688
Necessary for preheating (*vide* preceding table) . . .	6,796	6,583	5,584	5,426	7,288	5,246
Surplus energy . .	794	485	529	489	792	442
Waste gases . .	14·76 cbm.	13·70 cbm.	12·00 cbm.	11·76 cbm.	15·05 cbm.	11·53 cmb.

In order to review as to whether the amount of heat delivered to the chambers suffices for preheating the freshly entering gases, the necessary amounts of heat therefor are taken for comparison from the preceding table.

As apparent, the quantity of heat left behind in the chambers by reduction of the temperature of the waste gases to 700° suffices to warm the gas and air up from 0° to 1,200°; there remains even a small excess of heat, which could be radiated, but the losses from radiation are without question higher, but the gas generally comes into the chambers from the producers with a considerable available heat. Should this reserve not be sufficient (one will naturally as much as possible cover the chambers with good insulation, and as much as possible guard against small heat losses therefrom) there remains only one means, and that that one may not have utilised to its extreme maximum the heat produced in the combustion chamber. One must thus produce more heat in the combustion chamber than is required in the same, and let the flame strike into the chambers.

Loss of Heat in the Waste Gases in Open-Hearth Furnace Working.

The extent of the utilisation of the available heat of the waste gases depends on the temperature at which they are discharged. This outlet temperature stands in relation to the size of the chambers, and also to the temperature of the freshly entering gases, and on the intervals between reversals. H. H. Campbell comments on this, relatively to the effect of the temperature of the heating gas, as follows:—

"It is well, however, to keep the principle in mind that if the gas is hot there is less work for the chamber to do, and the fact that the gases escaping to the chimney are at a high temperature has nothing to do with the case, for if the entering gases are hot, the escaping gases must be hotter."

And in another place:—

"Air always enters cold, but it is believed by some furnace men that it is economical to have the gas as hot as possible. To some extent this is an error, for the checkers in the outer end of the gas chamber cannot be cooled below the temperature of the entering gas, and the products of combustion cannot be cooled below the temperature of these checkers, so that the heat carried in by hotter fuel is carried out by hotter waste gases, and no economy is obtained."

Moreover, the outlet temperature of the waste gases can be unfavourably influenced, owing to too long intervals between reversals, which is easily apparent from the following consideration:—The gas coming from the producer yields on combustion with cold air a certain temperature of combustion, assumed at 1,100° ; and it is clear that one is able to heat the entire furnace system up to the chimney flue nearly to this temperature, if one allows the gas to pass long enough in one direction. The temperature at the outlet end will only thus be lowered as much as corresponds with the loss of heat in the entire furnace system owing to radiation and conduction, and one naturally is always endeavouring to make these losses as small as possible. When in this manner one end of the furnace has been warmed up, and one allows the gas stream to be drawn through the furnace in the reverse direction, one obtains preheated air and gas in the furnace, whereby the temperature of combustion is raised, and the second half of the furnace admits of being brought in a shorter time to the temperature of the first half of the furnace than this itself required, and this first half of the furnace could not, therefore, cool down again to the temperature at the commencement. In this way it is thus possible to overheat at the bottom even a furnace with very large chambers, and to obtain much too high outlet temperatures.

In the calculations in the previous section, it is assumed that the waste gases are drawn into the chimney at 700°, a temperature below which will be observed in the least good-running open-hearth furnaces. But the waste gases themselves per kilogramme of carbon burnt at this relatively low temperature (one very frequently finds much more) carry off (*vide* Table M, p. 124) 3,000 to 4,000 calories, *i.e.*, more than 40 per cent. of the total energy liberated from the fuel. Up to the present this quantity of heat has completely gone to loss, and there is little prospect that out of it an at all considerable portion can be able to be returned for the working of the furnace itself.[1] Of course, here the available heat of the heating gases given off by the producer is taken into account, since if this entered cold into the furnace, the outlet temperature of the waste gases could obviously be lowered. A direct utilisation of the available heat of the heating gases scarcely admits of being accomplished, as it presents too many technical difficulties. Besides, the total available heat of the heating gas again is present in the waste gases, and if one could abstract the heat from the latter, one thereby also would have found the solution for the former problem.

The advantage which one could obtain by production of steam-air gas with preheated air, admits of the hope that the available heat of the waste gases could be eventually utilised for this purpose, and it is interesting to learn how much the amount of heat turns out to be which would be thus won back. For the gasification of 1 kilogramme C from good "black" coal in the producer, with gas of average composition (p. 78), about 4 cubic metres air was required, and if this were preheated to 500° it must have had $0{\cdot}326 \times 5500 \times 4 = 653$ calories expended on it. Of the about 3,000 calories per kilogramme C which are uselessly drawn off into the chimney, one could therefore render one-fifth useful, whilst four-fifths, or about 2,400 calories per kilogramme C, would still be lost.

Regulation of Temperature in the Combustion Chamber.

The principal function which an open-hearth furnace for steel production must fulfil is to provide a flame at high temperature, which is capable of equally sweeping the entire hearth, and clinging to it like a soft rug.

The flame originates as a consequence of the union of gas and air; nevertheless each gas molecule can only form a portion of the flame a short moment, viz., only at the instant of combustion, in which it bursts into flame, at once to be put out. Hence the production of a long flame is only possible, if in

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[1] The latest plans with different firing systems, namely the replacement of chimney draught by mechanical means, admits also possibly of being employed in open-hearth furnace working. By this means this question possibly would appear in a different light.

the course of their passage a whole series of gas molecules are simultaneously ignited, and if the flame is to be continuous, there must be for each gas molecule burnt a new one ready for combustion, and the necessary conditions obtaining therefor.

The flame in the combustion chamber extends no further than the veil of the streams of gas blown in. For the possibility of its existence, therefore, free oxygen must be continually received into the combustion chamber in quite free expansion, and this must be able to reach all sides on which the gas stream should burn, it being thereby continuously consumed, and must therefore also be continuously freshly supplied.

From union with gas, products of combustion result which force their way between gas and air, and obstruct their further meeting. On this ground, it is impossible to completely use up both media. If one wishes to completely burn the gas in the combustion chamber, so one must introduce air in absolute excess. The smaller one selects this excess of air the slower the combustion takes place, and the greater the surface which is swept by the flame, and the longer this will be.

From the aforesaid, it follows that the direction and the form, and the guidance of the flame, are essentially dependent on the direction and form of the gas stream, from which the flame is again renewed, as well as from the active force, which is contained in the gas stream, and enables it not to be caused to swerve, owing to small opposing resistances. One gives the gas current its direction by means of suitable port-blocks or burners built in furnace heads for the purpose of allowing them to enter suitably. These blocks contain ports, which lie in the direction of the major axis of the hearth, parallel to the side walls and a slightly dipping bottom resting on the upper surface of the hearth, whilst their covering possesses a great angle of depression. By these means the ports are narrowed in a downward direction, whereby the gases in their outlet openings receive increased velocity, and are hindered in their endeavour to rise. In consequence, one selects the port openings small in comparison to the upper sections of the upper gas passages, so that the outlet velocities in consequence of the gas pressure and the buoyancy must become quite important. The gases hereby receive a certain guidance, which is given somewhat like that to high-pressure water through the jet nozzle of a fire hose. To attain this aim one makes the burners as long as possible, providing that their undersides are continuously smooth, remaining without depressions or raised portions, and that also in the combustion chamber no projections exist which the gases could beat upon. By these means one prevents the flame from deviating upwards, whilst its spreading sideways is less hemmed in. The air leads in the blocks were formerly frequently arranged parallel to the gas ports and so that there was an air port each side of a gas port, and gas and air were side by side in the combustion chamber. Nowadays, one most often arranges the air ports above the gas ports, and gives the air leads in the burners greater pitch than the gas leads, so that the axes of these ports cut across each other at a certain distance from the face of the port blocks. Also one often lays the air ports askew, so that the air broadens out fan-like above the gas. One achieves thus a decidedly better apportionment of the air, to the entire combustion chamber, and it may well be maintained that furnaces provided with such kinds of port blocks work more sharply than furnaces in which the gas and air passages lie alongside each other.

The checking of the temperature, and the production of the necessary amount of heat, at each instant, forms the main task of the melter, and they are a people exclusively given up to practical experience, who are only seldom receptive of theoretical considerations as to the phenomena of combustion. Nevertheless, it must be confessed that indeed most frequently the correct ones will be found. For usually the melter at the beginning of the heat admits as much gas into the furnace as an open chimney damper and air valve admit this to lay hold of, and perceives an excess thereof, in that the flame begins to lap out of the doorways, which naturally must be avoided. In proportion as the charge melts down, he increases the temperature of the furnace, and at the conclusion of the "heat," where the receptibility of the charge for heat has gone down considerably, it can become so great as to be dangerous to the furnace structure. At this point the art of the melter commences, who must understand how to "hold the heat," that is to say, to achieve the greatest possible attack of heat on the bath without at the same time injury to the furnace. He observes the white-hot flame diligently through a coloured glass, whereby the degree of brightness of the flame gives an approximate scale for its temperature. In consequence of the changing outside light, this is a very unsafe method of estimation of temperature, and it would fare badly for the durability of furnaces, if in practice yet another simple means of control had not been found. It consists in the comparison of the brightness of the flame with the furnace structure, especially the port blocks and roof arch. So long as the latter are cooler than the flame, they are darker than this, and stand clearly out against it in all their contours, and as long as this happens no danger is present. In proportion, however, as they begin to be overheated, their degree of brightness approaches that of the flame, their outlines become indistinct and difficult to perceive. As soon as this takes place, with a clean flame in the furnace, danger is present, and it must be intercepted.

A skilled melter generally does not let it come to this appearance, at least not so long as the direction of the flame is good, and normal working continues. He perceives, that is to say, instinctively how the heat requirement of the charge decreases and reduces the supply of gas and air, in which case he still knows so to hold the flame that it covers the entire upper surface of the bath, and that the temperature does not come into the descendent, but rather rises. If he is very skilled he will at the same time reduce the chimney draught, and in this manner deal really economically with fuel and furnace structure.

If, however, from whatsoever conditions the furnace once is overheated and "burnt," then it is often not easy to find the proper remedy. One terms "burning" the overheating of the refractory materials of which the port-blocks and main roof are manufactured, up to above their melting point, so that they melt off, and begin to sink down in long "icicles" into the bath. If it once happens that the melting point of the refractory bricks of the smooth covering surface of the roof is reached, so this itself forms a thin layer of fluid material, which, owing to adhesion is held fast by the cover, and does not further appear an evil. But if it has, however, reached formation of "icicles," so now these "icicles" always draw away the freshly melted masses from the cover, and thus always expose new portions thereof to the action of the flame. In order to bring this destruction to a cessation, the cooling down of the furnace must now be carried further, than otherwise, and of this many melters have an unjustifiable timidity, since they fear thereby to cool down the charge, and thus cause still greater calamity.

Usually the outlet end of the furnace is overheated, and such overheating is most simply put an end to again by reversal of the direction of the flame. Bad melters see therefrom, in reversal, the only healing remedy for the furnace if it is burnt, and perform this at random in ever smaller intervals. But if the port-blocks and the roof at the furnace end are overheated, so indeed also the chambers belonging to them become hotter, and in consequence the temperature of combustion, if now again the overheated end is made into the entrance end, be higher than in normal working. Thus one must, in order to again attain a normal condition, let the flame now go longer from this end, and just so long as the chambers are again brought to their normal temperature. The means would be proved, if thereby the other end of the furnace were not too highly heated, and the same bad phenomenon would not appear there. In order to hinder this there is only one means, and that is the diminution of the quantity of heat absolutely produced, which can only be obtained by diminution of the gas supplied.

Of course, one can employ other quicker-acting means, but which are of smaller duration, such as completely cutting off the air for combustion, or totally shutting off the heating gas, and passing of air alone through the furnace for some minutes.

Further, it will often be proposed in such cases to artificially reduce the temperature of combustion, in such manner that one increases the amount of the products of combustion, which at the moment of combustion take up the heat generated.

This could happen by two methods, either by relative increase of the amount of air, *i.e.*, combustion with an excess of air, or relative diminution of the same, *i.e.*, by means of incomplete combustion. Let the trial be made of investigating in exact figures examples of the action of such methods of working, in furnace management.

As fuel, let the average theoretical producer gas (*vide* p. 78), be selected which requires 9·46 cubic metres of dry air for the amount of gas which is obtained from 1 kilogramme C, for practical complete combustion, and let it be assumed that at one time 50 per cent. more air, or 14·19 cubic metres, and at the other time 50 per cent. less air, or 4·73 cubic metres is used for combustion. In the first case, then, the products of combustion would be increased by 4·73 cubic metres, in the second case let it be assumed that of the combustible gases 0·73 cubic metre CO with a combustible value of 2,236 calories remains unburnt, whereby the combustible value of the amount of gas utilised now is placed at $7{,}554-2{,}236=5{,}318$ calories. In this connection it is assumed, in this case, that the entire O content has been brought into use.

On these assumptions, the following Table N has been calculated, from which under "Utilisation of heat in the combustion chamber" it is to be perceived that by these means the heat in the combustion chamber actually admits of being reduced, inasmuch as instead of 3,444 calories now only 2,454 and correspondingly 2,513 calories appear. Combustion, with deficient air, appears the most favourable in regard to reduction of the free energy.

It would be interesting to obtain an explanation of the resulting combustion temperatures; nevertheless, this is difficult, as the great influences of radiation and conduction are unknown, as to be sure, also, the proportions of mixture of gas, air and products of combustion at each point of the flame are not ascertainable. If one wishes notwithstanding to establish values, which to some extent render a comparison possible, one can regard the radiation and conduction losses which have happened here as equal and negligible. In the following table the values of C_0^t for 2,000° have been used for the specific heat of the individual gases, and hereby the

TABLE N.—5·26 CBM. BEST PRODUCER GAS (5·01 CBM. GAS+0·25 CBM. STEAM) BUT WITH CHANGING QUANTITIES OF AIR.

	1·3 times Air amount.	50 per cent. more Air than 1·3 times.	50 per cent. less Air than 1·3 times.
Amount of gas	5·26 cbm.	5·26 cbm.	5·26 cbm.
Amount of air	9·46 ,,	14·19 ,,	4·73 ,,
Combustible value of gas burnt	7,554 cals.	7,554 cals.	5,318 cals.
Composition of the products of combustion. CO_2	1·86 cbm.	1·86 cbm.	1·13 cbm.
CO	—	—	0·73 ,,
O	0·63 ,,	1·62 ,,	—
N	10·23 ,,	13·97 ,,	6·50 ,,
Water-vapour	0·98 ,,	0·98 ,,	0·98 ,,
Utilisation of heat in the combustion chamber—			
Available heat of gas at 1,200°	2,571 cals.	2,571 cals.	2,571 cals.
,, ,, ,, air ,, ,,	4,012 ,,	6,018 ,,	2,006 ,,
Total available heat	6,583 cals.	8,589 cals.	4,577 cals.
+ combustible value	7,554 ,,	7,554 ,,	5,318 ,,
Total energy in combustion chamber	14,137 cals.	16,143 cals.	9,895 cals.
Less energy in waste gases at 1,700°	10,693 ,,	13,689 ,,	7,382 ,,
Utilised in combustion chamber	3,444 cals.	2,454 cals.	2,513 cals.
Calculated temperature of combustion in combustion chamber, without taking into consideration radiation, etc.— Values for C_0^t for 2,000° employed	2,134° C.	1,912° C.	2,159° C.
Utilisation in the chambers—			
Available heat waste gases 1,700°	10,693 cals.	13,689 cals.	7,382 cals.
,, ,, ,, ,, 700°	3,625 ,,	4,731 ,,	2,490 ,,
Remaining in chambers	7,068 cals.	8,958 cals.	4,982 cals.
Heat lost in waste gases—			
Available heat of waste gases at 700°	3,625 cals.	4,731 cals.	2,490 cals.
Combustible value of waste gases at 700°	—	—	2,236 ,,
Total loss	3,625 cals.	4,731 cals.	4,726 cals.

temperature values ascertained. One sees that with such great changes in the quantity of air, also with excess air, the temperature itself remains outside the admissible limit, and this certainly at the places where high temperature should be quite avoided, namely, where the flame beats on the roof, which possesses only very little receptivity for heat. Owing to this the temperature on the upper surface of the bath is able to be too low for the heating of the bath, as this is in the position to take up most heat.

Working with an air deficit, furnishes, in regard to lowering of temperature, even negative results, in case, as assumed herein, the oxygen is actually completely utilised.

The chambers are little influenced by means of changing the quantity of air, as is to be seen from what is given under the heading "Utilisation in the chambers," inasmuch as the heat retained of 7,068, 8,958, 4,982 calories, respectively, is still at all times greater than the available heat of the gas and air, which must be again led into the furnace proper, and which from statements, "Utilisation in the combustion chamber," amounts to 6,583, 8,589, 4,577 calories respectively. There thus remains in all cases an excess of 485, 469, and 405 calories respectively, so that the chambers cannot be cooled in this way, unless by the presence of very large radiation losses.

The last items under the heading "Heat lost in waste gases" are interesting, in which is shown that in both instances, working with an incorrect amount of air, the loss amounts to about 3 per cent. higher than with correct quantities of air, but that, at least, for this example it practically possesses exactly equal height; inasmuch as, with air deficit, it is true that a portion of the combustible value goes to loss in the waste gases, this value, nevertheless, although it increases the available heat of the smaller waste gases, does not become higher than the available heat of the much larger quantity of waste gas with excess of air.

These means can thus exercise no great effect. If one is, however, compelled to make use of them, working with air deficit only can be taken into consideration. By working with excess air, one may well on the whole, attain the observed reaction, in particular; one will be obliged, however, to reckon on the entrance of one or more short flames, whose action it is impossible to prophesy.

All the artifices cited, only then have a result, if the path of the flame has remained good. In other cases, one must hurry up, to bring the charge out as well as possible, but afterwards take care, as being of prime importance, that the flame goes faultlessly, since otherwise the difficulties re-occur with each charge, and the furnace comes to a stoppage.

But with good flame guidance, it should be carefully seen to that both ends of the furnace exhibit equal heats, and if one end shows overheating, so one should rectify it by utilising the interval between the charges, the charging and melting down periods, for establishing an equilibrium of heat, by allowing the gas to enter longer through the hottest end of the furnace. At the end of the heat, if the highest temperatures rule in the furnace, such a regulation is often not able to be carried out.

CHAPTER XVI

GAS AND AIR ON THEIR WAY THROUGH THE FURNACE SYSTEM

The gas and air must, on their way through the entire furnace system, be kept well apart from each other and only be allowed opportunity to unite in the combustion chamber.

Producer gas possesses a tolerably high ignition temperature, and if air reaches the gas at high temperature, it burns a portion of the gas, and this becomes lowered in value correspondingly to the air introduced. If, however, the air enters the gas below its ignition point, an explosive mixture results, which on ignition by a hot part of the furnace system is able to be the cause of the most serious disasters.

Precautions must, therefore, be taken that the air cannot enter the gas conduits, and that is achieved most simply if the gas in the conduits *continually is under surplus pressure*, whereby the consequence of any leak holes is only that some gas makes its way into the free atmosphere. In the furnace itself the walls which divide the gas spaces from the air spaces in the ports and chambers must be absolutely gas-tight, and during each furnace repair must be carefully tested and correspondingly brought into good condition, since otherwise the furnace soon comes to a stoppage. Also the reversing arrangements must be gas-tight.

At this place, it is unavoidable, however, at odd times to avoid a coming together of gas and air, namely, during the changing of direction of the flame by reversing. At this instant, the air passages, as well as the gas passages, are brought into direct communication with the chimney, which then simultaneously sucks out gas and air. Of course, this occurrence can be somewhat modified according to the kind of reversing devices. With the old Siemens clappers, one reversed each valve by itself, and each such operation was ended in a very short time. One can thereby attain that very little gas finds its way from the gas tube into the chimney flue. But after the gas flapper has been reversed, the entire contents of the gas chamber (which now becomes a waste gas chamber) must likewise go into the chimney. If one awaits the emptying out of the gas chamber, and then only reverses the air, so all must go smoothly; if one reverses the air flapper earlier, so must gas and air meet together in the chimney flue, and if now here the ignition temperature is present, so will the gas burn forthwith and also still all go well. If, however, the chimney flue is cooler, or by suddenly in-streaming large quantities of air, the gas temperature becomes lowered below the ignition point, an explosible mixture is able to result, and this must ignite explosively if it is brought into contact with an incandescent wall surface, or if an incandescent particle of dust is sucked from the furnace into it.

The means for prevention of explosions consist, above all, in cutting off the supply of gas and air to the furnace during the reversals, and this method of proceeding is nowadays already met with in probably all furnaces on economical grounds, as otherwise gas is sucked out by the chimney in relatively considerable amounts and is uselessly allowed to escape into the atmosphere. A further means is the pausing for a specified time between the reversal of the gas and that of the air, which is easily carried out with the simple Siemens flappers. These have, however, the disadvantage in working, of easily becoming leaky, and then they are the cause of considerable losses of gas, but very difficult of perception. Therefore, one has frequently adopted other devices, for example, mushroom valves, and these are most frequently so arranged, that gas and air are simultaneously reversed. Also hereby explosions can be avoided, if the chimney flue is throughout heated above the ignition temperature of the gas, and one has, therefore, only to take care that on reversal no great amount of cold air from outside is able to be sucked in, which in eventual denial of water seals can easily occur, and, as before-mentioned, brings about sudden cooling. But if one for the purpose of obtaining smaller heat losses should therefore turn to employing lower regenerator chamber temperatures, so will attention be directed to the possibility of the origination of explosible mixtures, and one will, perhaps, again meet with the arrangement, that gas and air be separately reversed.

Explosions in the gas conduits, or in the starting up of a new furnace, in this itself, are able to be more unpleasant and more dangerous than these explosions on reversal, which, however, nevertheless, have unfavourably influenced the life of so many chimneys. Such will be avoided by the adoption of long-known rules, according to which a newly-started producer may then only be connected with the gas conduits if it gives off faultlessly good gas; that gas only may be admitted to the furnace after the gas flues have been completely swept clean of air, which is achieved by permitting the streaming out of gas into the atmosphere through an opening which is provided close in front of the gas inlet valve; and lastly, that gas be never admitted into a cold furnace, but that this must be always well preheated by means of solid fuel.

It would be decidedly desirable for gas-furnace working if one could conveniently and safely fix how much gas and how much air in each moment entered the furnace, but unfortunately, up to the present no instrument has been found which solves this problem in a practical manner. At present, one can only obtain disclosure as to the required amount of gas, by the very round-about way of ascertaining the amount of solid fuel required in a lengthy space of time, and from the carbon content of the same, and the composition of the gases produced during this space of time. The amount of air yields itself from the combination of values obtained for the gas, and the composition of the waste gases.

One is able, indeed, to easily assure oneself by means of the appearance, whether the furnace receives enough gas, but it is not so easy to make sure whether the air supply suffices and when and how much it gradually (perhaps owing to displaced chambers) decreases. The practical man, who daily observes his furnace, knows well when a deficit of it begins; nevertheless he would gratefully welcome an aid which informed him with safety the amount of air which his furnace continually received. On the basis of such specification, it would be safely possible to catch it up at proper times with a fan and considerably increase the production capacity of so many furnaces, and to lengthen their duration of life.

PART II

THE CHEMISTRY OF THE BASIC OPEN-HEARTH PROCESS

CHAPTER XVII

REDUCTION AND OXIDISATION PROCESSES

For technical purposes, iron must be produced entirely by artificial means. As direct raw materials for this purpose, only the compounds of iron with oxygen, the so-called iron ores, which exist in nature in large amounts, come into consideration. In order to produce metallic iron from ores, these must have their oxygen removed. This is brought about by means of their being brought into contact with materials which possess a greater affinity for oxygen than iron, which, therefore, take up the oxygen, whereby the iron is brought into the metallic condition, or, as it is technically expressed, it is reduced. The materials which bring about the operation named, which are capable of bringing about reduction, are called reducing agents; but inasmuch as these remove the oxygen from the iron ore they are themselves changed in form, since they now form with the oxygen chemical compounds: they become oxidised or undergo an oxidisation process. Thus a reduction process for an iron ore simultaneously appears as an oxidisation process for the reducing agent employed.

Iron evolves on combination with oxygen a large amount of heat energy which has been determined to be per kilogramme oxygen

4,326 calories on formation of Fe_3O_4.
4,377 ,, ,, ,, Fe_2O_3.
4,662 ,, ,, ,, FeO.

In order to remove O from the iron again, there must per kilogramme of the latter be employed equal amounts of energy. It follows from this that all those materials appear suitable to serve as reducing agents for iron oxide which, by their combination with oxygen, evolve a greater amount of energy than the iron itself. Now 1 kilogramme of oxygen yields

with Al to form	Al_2O_3 .	. 8,162	calories.
,, Si ,,	SiO_2 .	. 6,850	,,
,, Mn ,,	MnO .	. 6,247	,,

and thus it appears as if all the materials named are capable of achieving the removal of the oxygen from iron oxides, and therefore as if they were employable for the winning of metallic iron.

It is not sufficient simply to bring these materials in contact with iron oxide in order to produce metallic iron. Each and every one of the minutest pieces of ore consists of a great quantity of molecules, from each of which its oxygen must be split off. Each individual molecule must thus be brought into direct contact with the reducing agent. That does not generally occur so long as the materials are present in the solid form. Only if they go over into the fluid or gaseous form of aggregation, by which the molecules are freely mobile and can actually reach each other, are the conditions for the mutual inter-reaction given.

One can, therefore, mix finely divided iron ore with equally finely powdered aluminium, without the occurrence of any change whatever in the two materials, but if one produces in any desired point of this mixture an increase of temperature which brings a little of the substance to the melting point, the reaction takes place forthwith. The amounts of heat set free bring further portions of the mixture to the melting point and thereby the reaction and the decomposition of the entire mass results, and by employment of different reducing agents with greater velocity, the greater the amount of heat set free.

The materials referred to, however, likewise occur in nature only as compounds of oxygen, and their recovery in the pure condition is obviously brought about with greater difficulty than that of iron.

They are, therefore, only regarded as and utilised as suitable reducing agents, in quite definite proportions in rare cases, and in small extent. One must much more often make use of other reduction materials, which are at our disposal in large quantities.

Of these the first place is taken by carbon, which likewise easily combines with oxygen, and thereby produces heat. The amount of this is nevertheless considerably smaller than that from the substances before-mentioned, since 1 kilogramme O gives with carbon 3,030 calories on combustion to CO_2 and 1,855 calories on combustion to CO.

One sees that carbon is not able by itself to remove oxygen from iron oxides and combine with it; it only then can be capable of doing this if it is enabled to increase its energy content. This can be brought about by the addition of heat which can be produced in different ways, amongst others, by means of combustion of further amounts of carbon, by means of gaseous oxygen externally, or internally, to the mixture of oxygen and carbon manipulated. But thereby the heat will be shared by the oxides, and as in general the affinity of all substances for combination with oxygen increases with rise of temperature, with which the difficulty of removal of the oxygen from its compounds is usually increased under such circumstances, the consequence of such influence on the energy content of the carbon does not without more ado admit of reduction. The results of practice, however, demonstrate that the individual substances in their relation to oxygen at high temperatures exhibit differences, and Ledebur first propounded that the law for the process of reduction with carbon is valid, *that the combustibility of carbon with rising temperatures grows more than that of remaining substances.* By employment of sufficiently high temperatures carbon then actually attains the capacity of removing oxygen from all remaining materials and thus making it a reducing agent which finally no oxide can longer withstand.

The reduction processes of practice are mostly of a very involved nature. Simple pure materials never attain mutual reaction, but those with various impurities, whereby the picture of the process is clouded, and is often rendered quite imperceptible. In order to learn the characteristics of the reduction process, it is desirable to consider next reduction of the pure oxide of each individual substance.

Pure iron oxide mixed with carbon and heated in such a manner that the carbon has not other more easily accessible sources of oxygen at disposal, gives up its oxygen to the carbon already at a little more than 400°, and is converted into metallic iron. The action proceeds according to the formulæ

$$Fe_2O_3+3C=2Fe+3CO,$$

or

$$FeO+C=Fe+CO.$$

The reduction, nevertheless, could not in this manner embrace the entire amount of the iron oxide employed, if the resultant oxidisation product of the carbon did not essentially support the process. Carbon monoxide CO is likewise a reducing agent, it is as a gas capable of forcing its way into the iron oxide, and therefore of attacking all the molecules thereof, which otherwise would not be able to come in direct contact with the carbon ; the action proceeds according to the equation

$$Fe_2O_3+3CO=2Fe+3CO_2.$$

The CO_2 formed and the excess of CO escape out of the reaction zone. If the temperature rises high enough, so the reduced iron fuses together into an adherent mass. In this case, however, it dissolves a considerable amount of carbon and chemically combines itself with it, so that this carbon cannot be again removed from the iron.

In addition, all oxides practically employed for reduction, as well as also the carbon, contain impurities of which silicic acid, phosphoric acid, and manganese oxide take a share in reactions. The substances named are the products of oxidisation of silicon, phosphorus and manganese, and they likewise give off their oxygen under the circumstances to the reducing agent. If one allows in the presence of carbon at incipient white heat, and an absence of oxygen, pure phosphoric acid to make its appearance, carbon will remove the oxygen from this and phosphorus escape in its pure condition, in the form of vapour, together with carbon monoxide.

Pure silicic acid and pure manganese oxide also are able to be reduced by means of carbon, and to be changed into silicon and manganese, but this requires such high temperature that they cannot be produced in furnaces heated with ordinary fuels. In spite of this the reduction of both the substances described is achieved also in these furnaces, if one is satisfied to obtain them (instead of in the pure condition) in combination with iron. In the presence of metallic iron, silica and manganese oxides are reduced by carbon so long as neither the reducing agent employed nor the solubility of the iron for the substances reduced is exhausted.

Should, nevertheless, the reduction be undertaken by solid or liquid reducing agents of a mixture of several of the substances named, the procedure becomes more complicated. Silicic acid and phosphoric acid are at high temperatures powerful acids which unite themselves in combination with bases which are stable at that heat, to which class iron and manganese oxides belong. The combination results generally under the temperature at which iron oxide and phosphoric acid are reduced. The resultant substances are easily fusible and pass into the molten condition. They oppose thus another resistance to the reduction, than that of each of their constituents by itself, since a chemical compound only then admits of being reduced without the aid of another substance, if the conditions for the reduction of its entire individual constituents are fulfilled.

Thus pure iron oxide in pure iron silicate can only be converted into the metallic state if also it is possible to convert the silicic acid into silicon, and from pure manganese phosphate, phosphorus only can be reduced by a reducing agent if the temperature is high enough in order to also be able to produce metallic manganese.

The conditions of reduction become, therefore, in general more difficult if substances reach the reaction zone in the form of chemical compounds.

But one can vary the conditions of reduction if one adds to the substances which should react on one another further substances which determine chemical change. If to pure iron or manganese silicate, or phosphate, one adds lime which is a stronger base than manganese or iron oxide, so the latter at correspondingly high temperatures will be displaced by the lime from combination with the acid, and will be converted into the free state in which the action of the reducing agent is more readily active. Similarly silicic acid, as the more powerful acid, displaces phosphoric acid, and makes the latter qualified for reduction. One can thus by lime additions much favour the conditions for the reduction of iron and manganese from their compounds, whereby at the same time the silicic acid and the phosphoric acid will be brought into a form in which they are no more reducible in our usual furnaces, inasmuch as the lime is not attackable in these. Whilst, however, the silicic acid is now for ever shielded from reduction, the phosphorus can be again reduced if one sets free the phosphoric acid from the phosphate of lime by the addition of free silicic acid.

Although one is thus able by means of lime additions to considerably facilitate the reduction of iron and manganese from their chemical compounds, yet one is not able to completely set on one side the difficulties thereof. This depends on the compounds of iron and manganese oxides being easily fusible, the lime salts corresponding thereto on the contrary being very infusible. With the removal of the oxygen contents, the melting point of the melted substance is increased, and the moment at which they are transformed from the fluid into the solid condition the reaction must cease, as now the contact between the solid or melted reducing agent and the individual molecules of the substances to be reduced will not be longer possible. In consequence one cannot by the medium of lime attain complete reduction of the entire iron and manganese from their compounds. Nevertheless the amounts which they remove by reduction are smaller the higher the temperature reached in employment.

It is thus shown that the employment of lime for reduction should be cut off *to those amounts of silicic and phosphoric acids which are combined with lime, as well as so much oxide of manganese and iron as are necessary for the melted substance technically called slag, to maintain the fluid condition at reaction temperature.*

From the circumstances—

(*a*) That in the reduction processes in practice only materials are able to be used which, in addition to iron oxide and pure carbon, always contain silicic acid, phosphoric acid, manganese oxide, and sulphur compounds;

(*b*) That carbon, in addition to iron oxide, also reduces all remaining oxides;

(*c*) That, lastly, carbon and also sulphur and oxygen are soluble in iron and are taken up by it; it shows the impossibility of winning iron in its pure state from iron ores and carbon in technical working. The metal, on the contrary, always contains carbon, manganese, silicon, phosphorus, sulphur, and oxygen. All these substances, however, influence the properties of the metal considerably, and, indeed, each in different ways.

Now, oxygen and sulphur act always quite harmfully, and one is, therefore, constrained to reduce their amount to the smallest possible extent. Each of the remaining substances bestows on the iron in practice valuable properties, which generally make it only useful for specified purposes. By means of varying the relative proportions of the individual impurities one is able to produce the most manifold qualities of iron, which in their properties frequently exhibit greater variations than the different elements themselves. Each special property is, however, settled by quite definite proportions of the substances, and if these cannot be contained in the metal produced from the ore, it must undergo further treatment, which renders it possible to regulate the relative amounts of the impurities, be it by the removal of an excess of or by the addition of the deficient amounts of the individual substances.

In the process for the regulation of the composition of the metallic iron, the refinement processes, both methods are employed, but the removal process predominates. It never achieves it completely, for even the softest irons always still contain small quantities of carbon; generally also of manganese and phosphorus.

Most methods of manufacture of iron have the peculiarity that, in addition to carbon, other substances also, such as silicon, manganese, phosphorus and aluminium are used in small amounts as reducing agents. Owing to this the properties of these substances, as well as the properties of their products of oxidisation, are decisive of the course of the process.

Silicon, for example, is able to react on iron or manganese oxide, but this cannot happen according to the formulæ

$$Si+2FeO=SiO_2+2Fe$$

or

$$Si+2MnO=SiO_2+2Mn,$$

since by the reaction conditions present silicic acid cannot originate in the free condition, and must generally appear in the form of chemical compounds, and it finds the necessary base for these in a most convenient manner in the agent itself, from which it removes a portion. The reaction occurs according to the formulæ

$$Si+4FeO=SiO_4Fe_2+2Fe$$

or

$$Si+3FeO=SiO_3Fe+2Fe.$$

The iron protoxide (or manganese protoxide), which is still contained in the last-named iron or manganese bi-silicate, is now protected against further change by means of silicon, so long as chemical influence from other materials is absent. If it be transformed into the free state in the way described, it can again be attacked by silicon.

Phosphorus can likewise become a reducing agent for metallic oxides, notwithstanding that its oxidisation product as phosphoric acid cannot occur in the free condition. It must generally, like the silicic acid, seize a portion of the metallic oxide and be converted into metallic phosphate.

Manganese is able to remove the oxygen from iron protoxide and is converted thereby into the strongly basic manganese protoxide, which in the presence of acids seeks to attain possession of them. If no free acids are present, the manganese is able to displace iron from iron silicate, and in this act, as is apparent from the formula

$$Mn+SiFeO_3=MnSiO_3+Fe.$$

CHAPTER XVIII

THE CHEMICAL ACTION OF THE FLAME

(*a*) Formation of Scale.

Metallic iron has great attraction to unite with oxygen, and this affinity grows with rise in temperature. As stated at the commencement, there originates from the combination of 1 kilogramme O with iron, free heat in amounts of 4,300 to 4,600 calories, whilst its union with hydrogen to form steam yields 3,645 calories, and with carbon monoxide to form carbon dioxide yields 4,205 calories. On heating metallic iron in an atmosphere which contains oxygen, water-vapour, or carbonic acid, there always results a change in the iron, which takes up oxygen and damages its metallic surface. The strongest reaction would naturally take place with oxygen in its free state, but should this nevertheless not be at disposal, oxygen will be taken from water-vapour and carbonic acid. Now carbonic acid and water-vapour form substantial constituents of every flame, one and the same if its qualities constitute it an oxidising or a so-called reducing flame. Therefore it is impossible to subject iron to direct action of any such flame without the outer surface receiving a covering of iron-oxygen compounds. The resulting substance is termed "scale." By continual attack its amount grows, and there originates on the iron a crust, which, by shattering or by change of the form of the metal, can be made to fall off; for example, in forging or rolling. The scale then is called hammer scale or roll scale. Its composition, according to Wedding, lies between the limits $Fe_2O_3 + 4FeO$ and Fe_2O_3 (or pure iron-oxide), and is on the average $Fe_2O_3 + FeO = Fe_3O_4$.

It it substantially independent of the composition of the heated iron, and scale originates equally well on the softest wrought iron, as on steel and pig iron, no matter whether the same is in a solid or liquid condition. If one frees molten iron from the usual slag covering swimming thereon and exposes the bare upper surface to the action of the air or a gas flame, one sees forthwith black points originate thereon, which magnify and soon unite themselves into a connected layer. The black newly-formed substance is again scale. Pure scale is infusible in all cases coming into consideration, even at the highest temperatures of the open-hearth process.

(*b*) FORMATION OF SLAG.

Scale has, like all iron-oxides, the property of going into combination with silicic acid, and also with lime and small amounts of silicic acid, which at moderately high temperatures are fluid. But now silica and lime are the substances which form the chief constituents of the materials which serve for lining of all our furnaces and apparatuses for the heating of iron and for handling of the same in the fluid state. If, therefore, iron is heated in such apparatuses and the scale formed comes in contact with the walls of the same, mutual reaction must take place. A liquid is formed with the scale. This liquid is called slag, and it endeavours to change its composition so long as it has not become neutral to its surroundings.

Slag is thus an additional or by-product, which must be taken off. Therefore, already on technical working grounds, its degree of fluidity must be so great that it admits of being withdrawn without trouble from the apparatus. The degree of fluidity depends again now on the temperature and composition of the slag, and, therefore, the composition of the same must at all times be governed by the corresponding temperature.

The chief constituents observed in freshly-formed slags are the iron silicates, and these are Fe_2SiO_4, with 29·4 per cent., SiO_2 and 70·6 per cent. of FeO, which contains 2·4 units of weights of FeO per unit of weight of SiO_2 . . . (28), and $FeSiO_3$, with 45·5 per cent., SiO_2 and 54·5 per cent. FeO, in which for one unit of weight of SiO_2 there are 1·2 units of weight of FeO . . . (29). These substances are easily fusible, and they are able to dissolve silica and also protoxide of iron, and in addition a quantity of other substances in varying amounts which depend on the temperature. Each new substance taken up alters the melting point, the degree of fusibility and the solubility of the slag for other substances, and owing to this originates such an abundance of compounds that the survey of this province is rendered difficult, if not almost impossible.

The easy receptivity of iron silicates for other substances fixes the character which the slag takes under the influence of the furnace structure. With acid linings the furnace must produce a slag with an excess of acids, whilst with basic linings bases must predominate.

The plainest example of the formation of slag is furnished by heating or soaking furnaces for charges for rolling or forging. Ingots in rolling-mill furnaces, by way of example, cover themselves soon after being charged with a film of scale, from which pieces fall off and reach the hearth of the furnace, which consists of sand. On turning over the ingots, at sufficiently high temperature there thus results the union of iron scale and sand into a liquid iron silicate, which dissolves further scale, and with this spreads out on to the bottom of the furnace. Hence the slag comes into contact with fresh silica, which it takes up, whereby it acquires the capability of dissolving further scale. In this manner the slagging by scale is in progress on the entire bottom of the furnace in zones in which it is not too cold in order to allow the combination of solid scale with solid silicic acid to take place direct. Thus the entire scale which reaches the bottom is dissolved, and the fluid slag at temperatures under 1,200° is able to be drawn off from the furnace almost like water, whilst the ingots are not far removed from their melting point. The heating- or soaking-furnace slag is in the main iron silicate. It contains 28 to 35 per cent. SiO_2, in addition to 48 to 50 per cent. Fe in combination with oxygen and small amounts of other substances, such as MnO from the charge or such as Al_2O_3, CaO and MgO, which come from the furnace structure. The complete analysis of such a slag showed 33 per cent SiO_2 + 57 per cent. FeO + 9·5 per cent. Fe_2O_3 + 0·5 per cent. MnO.

Per unit of weight of SiO_2 in it, there are 1·7 units by weight of FeO, from which it appears as a mixture of $FeSiO_3$ (with 1·2 units by weight FeO) with Fe_2SiO_4 (with 2·4 units by weight of FeO), whilst its content of Fe_2O_3 renders it apparent that it also contains dissolved free scale. This slag at the ruling temperature is to be regarded as approximately in equilibrium with the acid furnace structure. In open-hearth furnaces with acid structure considerably higher temperatures rule, whereby the conditions of the equilibrium become different. In addition to the before-considered predominating constituents, FeO and SiO_2, there comes in addition a third, the MnO; nevertheless, FeO and MnO are in their chemical character very similar to one another and exhibit very little difference in their molecular weight, so that one can judge the chemical character of the slag very well from its silica content. $FeSiO_3$ contains, as stated, 45·4 per cent. SiO_2, and the final slag of acid open-hearth working shows, with its silica content of approximately 45 per cent., that in this furnace the endeavour rules for the attainment of the siliciousness of the bi-silicates, and that, nevertheless, the strongly-increased temperature which makes its appearance at the end of the process is in a position to render the bi-silicate capable of taking up further quantities of silica, in that the SiO_2 content can rise up to 59 per cent. (Ledebur, "Eisenhuttenkunde," Vol. III., p. 369).

In the basic open-hearth furnace, the conditions for the composition of the slag are more complicated, because now in addition, lime and magnesia appear as substantial constituents of the slag. Iron protoxide forms with lime not so sharply precise compounds as with silicic acid. For all that, however, the two substances combine into fusible compounds, the formation of which are considerably favoured by the inter-reaction of small amounts of silicic acid. Schmidthammer gives (*vide* Stahl und Eisen 1902, pp. 651 *et seq.*) examples of the formation of the slags from iron oxides and lime on basic hearths, which were obtained by the Gorainoff process in the Bogoslovsk forge in the Ural. In this process, iron ore and limestone are brought into the furnace and fused together, whereupon then only the metallic charge is introduced. The iron ore possessed the following composition :—

SiO_2	Al_2O_3.	Fe.	CaO.	MgO.	MnO.
Per cent. 3·24	Per cent. 1·43	Per cent. 64·76	Per cent. 1·52	Per cent. 0·28	Per cent. 0·39
3·50	1·45	64·50	1·33	0·31	0·36

The ore-lime slag formed contained :—

SiO_2	Al_3O_3.	Fe.	CaO.	MgO.	MnO.
Per cent. 4·18	Per cent. 4·08	Per cent. 50·36	Per cent. 20·39	Per cent. 1·53	Per cent. 0·39
5·10	2·47	55·30	13·46	0·71	0·69
4·68	2·13	56·47	13·75	2·59	0·95
5·87	1·01	56·22	15·30	0·83	1·01

The oxides of iron appear as the chief constituents of this slag ; lime takes the second place, and silica the third. The relatively high magnesia content shows that the basic structure had been attacked. The tests which were taken and investigated during the formation of the slag are interesting.

Slag I.—Fused Together 55 Minutes after Completion of Charging.

Time Taken Test.	Fe_2O_3.	FeO.	Total—Fe.
8·10	49·62 per cent.	26·65 per cent.	55·31 per cent.
8·30	37·01 ,,	38·22 ,,	55·63 ,,
8·45	36·04 ,,	39·27 ,,	55·78 ,,
9·10	27·07 ,,	56·98 ,,	56·94 ,,

Slag II.—Fused Together 35 Minutes After Completion of Charging.

Time Taken Test.	Fe_2O_3.	FeO.	Total—Fe.
2·0	51·33 per cent.	18·98 per cent.	50·79 per cent.
2·30	39·10 ,,	30·99 ,,	51·47 ,,
2·50	21·78 ,,	46·47 ,,	51·37 ,,
3·35	2·91 ,,	63·08 ,,	51·14 ,,

It shows that the iron oxide under the influence of lime has a disposition to go over into the form of protoxide, and that in slag II. also, nearly all iron could be reduced to protoxide. The results further show that iron protoxide also is dissolved by ferro-lime slag.

(c) SLAG-FORMING SUBSTANCES.

Silica and lime may be regarded, as shown, as the most important slag-forming substances in open-hearth furnaces, and it is evident that one can facilitate the formation of slag and conserve the furnace structure if one adds corresponding amounts of these substances to the charge. It is nevertheless in rare cases necessary to make a special addition of silica, since this material comes generally in desired and often, unfortunately, even in too large amounts into the furnace. The causes thereof are the following:—

(1.) The metallic charge is always uncleansed from sand, clay, or similarly highly siliceous materials, as pig iron is often cast in sand, which adheres in not inconsiderable quantities to the pieces. The absolute amount of SiO_2 which in this way reaches the furnace, is naturally very varied, and must be in each case specially appraised and correspondingly ascertained . . . (30A).

(2.) The metallic addition always contains silicon also, which is combined with the iron. During the process the silicon will be oxidised and go over into silica, and from 1 per cent. silicon there results 2·14 per cent. SiO_2 . . . (30B).

(3.) Silica reaches the bath from the acid furnace structure, since the best run furnace wears out by use, and comes finally to a stop, even if during the entire run of the furnace a so-called burning of the furnace should not occur. The main roof and a portion of the port block consist of materials which are made from silica with small additions of other materials, and these portions must naturally be so arranged that their material by wearing out, reaches the combustion chamber and must be taken up by the slag. The extent of the quantity of silica which in this way reaches the combustion chamber admits of being estimated on the basis of the working data, which for each furnace is ascertainable in particular. If one knows, for example, that the roof and the before-named portions of the port block last out 600 charges of 30 tons, that is to say in the run of the furnace 18,000 tons of charge are able to be worked, whilst in the manufacture of this portion about 52,000 kilogrammes of gannister are necessary, of which after shutting off the furnace there still is present one-half, one finds that during the run of the furnace 26,000 kilogrammes of SiO_2 must have reached the bath, or per 100 kilogrammes of charge, 0·15 kilogrammes of SiO_2, or in general 0·15 per cent. of SiO_2 on the weight of metallic charge . . . (30c).

(4.) Usually, the before-mentioned amounts of silica are sufficient to more than cover the requirement of this material by the slag ; but there will be added to the bath still further silica from the bottom and the walls of the furnace, with which the metal and the slag come into direct contact. Especially the latter gives rise in the so-called slag zone to a not small wear of the banks, which must be renovated after each charge by means of fresh materials. Since, however, there is generally not enough time to admit of adequately burning fast the renovating material, this will also be nearly completely dissolved by each new charge.

The hearth of the basic furnace is generally made out of burnt dolomite, and if this material possesses the composition SiO_2 6 per cent.+CaO 55 per cent.+MgO 34 per cent.+ Balance (Al_2O_3 and Fe_2O_3) and the dolomite requirement amounts to about 5 per cent., then of this material about $6\times{}\cdot05=0\cdot3$ per cent. of SiO_2 on the weight of the metallic charge, taken at 30 tons, comes into the bath . . . (30D). In basic furnaces of this capacity, and in which the dolomite requirements amount to the above, the entire addition of SiO_2 of the furnace structure will be $0\cdot15+0\cdot30=0\cdot45$ per cent. of the weight of metallic charge (taken at 30 tons) . . . (30E).

In the basic open-hearth furnace, a portion of the amounts of lime for the formation of slag come partly from the same source as the amounts of silica last considered. In addition to lime, the magnesia also in the dolomite is enabled to satisfy the acids which make their appearance, and if a burnt dolomite is employed, of the composition given, in which 55+34=89 per cent. of the alkaline earths are present, so a dolomite consumption, from the furnace structure by the slag, of 5 per cent. is attained, *i.e.*, $89 \times 0{\cdot}5 = 4{\cdot}45$ of alkaline earths (taken on the weight of the metallic charge) . . . (31A). In general, this amount does not suffice, and one must make additions of lime in order to prevent further wearing of the banks. Formerly, generally, one used burnt lime, but since, however, this rapidly takes up water and then forms large amounts of fine lime dust, which are carried by the furnace gases through the ports into the chambers, and which damage these portions of its structure, one has turned more from the use of burnt lime and gone over to the employment of raw limestone. Limestone should, for open-hearth working, contain at the most 2 per cent. SiO_2, and this amount of silica requires for its satisfaction approximately 5 per cent. of lime, so that in such materials about 50 per cent. of free CaO remain for the satisfaction of free acids. From this for each 1 per cent. of necessary CaO, about 2 per cent. of limestone should be employed . . . (31B).

(*d*) METAL AND SLAG IN THE OPEN-HEARTH FURNACE.

The free iron protoxide dissolved in the slag reacts, however, not only on the furnace structure, but also on the metal in the furnace. It is enabled to penetrate into the same, since iron protoxide is soluble in liquid iron. Hereby, however, the iron receives very undesirable properties; it becomes red-short and its melting point is increased, and finally also the highest heating capacity of the furnace does not suffice to give the metal the necessary degree of fluidity for casting. Therefore, the entrance of iron protoxide into the iron must be profited by, which can only be achieved by adding to the latter substances which do not permit protoxide of iron in their presence, but convert it into metallic iron. For fulfilment of this proviso, only reducing agents are suitable, of which some are always present in all classes of iron technically employed.

They are dissolved in the melted metal and have a disposition to an equalisation of their division in the entire mass of iron, and therefore also present at the place from which the permeation by the protoxide of iron takes place, namely the contact surface of metal and slag. Here, the reducing agents and free iron protoxide in the fluid state come into contact with each other at a temperature which produces mutual reaction.

The latter, therefore, favours the slag covering, keeping aloof the oxygen of the gases of combustion from the reducing agents in the iron, or indeed only permits it reaching it in quite inconsiderable quantities. It enables, therefore, their effort at combustion only to be satisfied if they can take out oxygen from the different oxides present in the slag. On these grounds forces must enter into the furnace which admit of oxidation processes for the reducing agents in the metal and reduction processes for the dissolved oxide content in the slag taking place, and thus also an effort at arriving at a state of equilibrium between the metal and slag.

The reducing agents which are capable of hindering the entry of protoxide of iron into the metal are again carbon, silicon, phosphorus and manganese. Their products of oxidisation, as already remarked, are carbon monoxide (which simultaneously with its formation escapes from the bath), further silicic acid, phosphoric acid, and manganese protoxide, which are taken up by the slag. From the mutual interreaction of the elements named on the oxides present in the slag entirely, all processes which take place in the open-hearth furnace, and render possible the production of steel, are explained.

(*e*) THE ELIMINATION OF IMPURITIES FROM IRON AND RETENTION OF THEIR PRODUCTS OF OXIDISATION IN THE SLAG.

The elimination of the four impurities of the iron, Si, Mn, P and C, is brought about by means of oxygen combined with iron, and it occurs in acid as well as in basic furnaces, giving rise to the appearance of the same products, namely the silicates and phosphates of iron and manganese, and carbon monoxide. The first-named products of elimination remain exposed to treatment in the furnace. Their further control will be determined by the influences which the character of the furnace structure exercises on the composition of the slag.

1. Silicon.

According to the equation $Si+2O=SiO_2$, 1 per cent. Si requires for its oxidation 1·14 per cent. O resulting in the formation of 2·14 per cent. SiO_2 . . . (32).

In the open-hearth furnace, however, the requisite oxygen can only be derived from iron oxides, the decomposition of which, as already mentioned on p. 146, takes place according to the formula

$$Si+3FeO=SiO_3Fe+2Fe.$$

The resultant iron silicate is liquid and much lighter than metallic iron; therefore, on formation it floats to the slag. On formation of this iron silicate, the ferrous oxide contained in it has become inactive on the reducing agents. In acid open-hearth furnaces it is, therefore, cut off from further reaction. It is, however, in contact with the furnace structure and is capable of taking up silica therefrom, up to the maximum content, which is attained at about 59 per cent.[1] In acid Bessemer convertors, where the conditions are similar, the SiO_2 content of the slag rises to as much as 69 per cent., according to H. H. Campbell.

With increased silica content, the degree of fluidity of the slag varies; it becomes always thicker, in spite of rise of temperature. If the latter be high enough a new phenomenon makes its appearance, which is always observed in crucible steel manufacture, and at times in acid open-hearth furnaces. The carbon has become able to remove the free silica from the slag, and reduce it to silicon, which is dissolved by the metal. The reaction occurs according to the formula

$$2C+SiO_2=Si+2CO.^2$$

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[1] The translator does not agree at all with this view; he regards the increased silica content in the slag due to greater reducibility of FeO in the slag the higher the temperature, as one of several causes of the higher SiO_2 percentage.

[2] This is certainly not the case; even at 1,000° above steel-making heats it does not occur, and were the statement given true, ordinary plumbago crucibles would be self-smelting. The action is largely due to catalysis, iron being essential to the reaction taking place.—(Translator.)

Researches as to the reducibility of silica from the slag have been undertaken by McWilliam and Hatfield, from which the following examples have been taken :—

Example 1.—Stahl und Eisen, 1902, p. 639.

(Taken from paper read before the Iron and Steel Institute.)

Time.	Composition of the Metal.			Composition of the Slag.			Remarks.
	C per cent.	Mn per cent.	Si per cent.	SiO_2 per cent.	FeO per cent.	Fe_2O_3 per cent.	
1·30	0·86	0·018	0·018	—	—	—	Slag thin.
2·0	0·73	—	0·022	—	—	—	Becoming thicker.
2·30	0·65	0·056	0·034	—	—	—	Fairly thick.
3·0	0·55	0·068	0·061	—	—	—	Thick.
3·30	0·40	0·08	0·078	—	—	—	Thick.
3·50	0·38	0·095	0·088	56·8	20·8	1·1	Thickest.

Example 2.—Stahl und Eisen, 1902, p. 640.

Time.	Composition of the Metal.			Composition of the Slag.			Remarks.
	C per cent.	Mn per cent.	Si per cent.	SiO_2 per cent.	FeO per cent.	Fe_2O_3 per cent.	
12·20	0·64	0·053	0·017	53·0	20·5	2·1	Slag thinnest.
12·55	0·47	0·059	0·035	—	—	—	Becoming thicker.
1·25	0·39	0·065	0·066	—	—	—	Fairly thick.
2·0	0·33	0·071	0·058	54·6	18·1	0·6	Thickest.

Example 3.—(McWilliam and W. H. Hatfield.)

Time.	Composition of the Bath.			Composition of the Slag.			Remarks.
	C per cent.	Mn per cent.	Si per cent.	SiO_2 per cent.	FeO per cent.	Fe_2O_3 per cent.	
6·0	0·31	0·039	0·034	—	—	—	Slag moderately thin.
6·2 to 6·5	—	—	—	—	—	—	Addition of red brick (8 cwts.).
6·15	0·22	0·037	0·034	—	—	—	Slag thickening.
6·25	0·20	0·039	0·049	—	—	—	Slag thickening.
6·35	0·17	0·039	0·049	55·64	21·38	1·27	Slag thick.

In discussing example 3, p. 157 (Stahl und Eisen, 1904, p. 1,396), these investigators maintain that the percentage of silica in the slag is the factor on which depends the increase or decrease of the silicon content of the molten metal. They added a large quantity (8 cwts.) of highly siliceous material to a bath of steel, and proved that in spite of the violent cooling of the bath, that although only slowly, a really marked increase of silicon content of the metal occurred.

The examples cited, however, show that the reduction of silica from the slag in acid open-hearth furnaces is of very small extent.

In the basic open-hearth furnace, this is quite impossible, since the large quantities of alkaline earths present do not admit of the occurrence of a concentrated solution of silica, and absolutely all Si which is eliminated from the iron must remain in the slag.

The bases employed alter the structure of the slag completely. Lime and magnesia are at high temperatures more powerful than the remainder of the bases, and they set the latter free and take up the silica themselves. According to the equation: $FeSiO_3+CaO=SiO_3Ca+FeO$, there results from $FeSiO_3$ and lime, silicate of lime and ferrous oxide, which latter is soluble in a mixture of lime silicate and iron silicate. The higher the temperature the more iron silicate can be decomposed; the reaction, however, cannot take place completely, inasmuch as the slag would lose its fluidity. The alkaline earths, owing to removing the metallic oxides from combination (with acids) cause manganese protoxide as well as iron protoxide to be more easily and to a greater extent used up by the reducing agents in basic than in acid furnaces. The reduction can be driven to the limit which is fixed by the condition that the lime silicate must remain in the fluid state. But certain amounts of metallic oxides are necessary for this.

2. Phosphorus.

This requires for its oxidation, according to the equation, $2P+5O=P_2O_5$ for 1 per cent. P, 1·29 per cent. O, and yields 2·29 per cent. P_2O_5 . . . (33).

This oxygen can only be derived from the metallic oxides, but not from lime, as was formerly supposed. The elimination from the iron takes place possibly according to the formula $2P+9FeO=P_2O_9Fe_4+5Fe$.

The resultant phosphate of iron is, however, not able to withstand the action of the reducing agents, since both its components are able to be very easily reduced. It is, therefore, only stable so long as it is in such highly oxygenous surroundings that all reducing agents present are more easily able to satisfy their affinity for oxygen from these than from the phosphate of iron itself, and therefore are not compelled to have recourse to attacking this.

In the acid open-hearth furnace, the removal of phosphorus is prevented because any iron phosphate is decomposed by the excess of the silica present, whereby the free phosphoric acid is again reduced back into the iron. On the contrary, the removal of the phosphorus from the iron easily takes place in the basic open-hearth furnace, in the presence of large amounts of oxides, but in order that the phosphorus may be combined in the slag and prevented from re-entering into the metal, it is necessary that it should be transformed into the stable form of lime phosphate, and indeed earlier than the excess of these oxides is used up by the reducing agents. Lime phosphate arrests the action of reducing agents, but the amount of silica in the slag may only be such that the phosphoric acid will not be again converted into the free state, since in this case it will again be reduced, as in the acid furnace.

H. H. Campbell states, that in so-called recarburisation, that is to say, in a process in which the reducing agents in the iron are suddenly increased in amount, the following amounts of phosphorus are returned to the metal from slags containing the following respective amounts of P_2O_5 and SiO_2 :—

Acids contained in slag.				P returned from the slag.		
				Maximum.		Mean.
	Per cent.		Per cent.	Per cent.		Per cent.
Under	5	not above	20	0·01	not above	0·00
,,	5—10	,,	19	0·025	,,	0·005
,,	10—15	,,	17	0·02	,,	0·005
,,	15—20	,,	12	0·02	,,	0·01

Source.	Time Test taken.	Metal.				Slag.					
		P	C	Mn	Si	Fe	Mn	SiO_2	P_2O_5	CaO	MgO
		Percent.	Percent.	Percent.	Percent.	Percent.	Percent.	Percent.	Percent.	Percent.	Percent.
Ledebur, "St. und E." 1903, p. 40, Bertrand-Thiel, 1st Furnace	12·4	0·043	2·80	0·058	0·04	12·00	n.o.	14·66	20·30	n.o.	n.o.
	12·22	0·087	2·50	0·10	0·04	6·00	n.o.	19·16	18·88	n.o.	n.o.
Ditto ditto	11·40	0·092	3·40	0·05	0·01	14·15	n.o.	18·00	16·04	n.o.	n.o.
	12·0	0·125	2·90	0·05	0·01	7·20	n.o.	21·00	16·94	n.o.	n.o.
	12·8	0·174	2·70	0·06	0·01	6·00	n.o.	24·33	15·83	n.o.	n.o.
Author's Notes, Charge 997 of 14/X/1904	5·55	0·01	0·79	0·42	0·03	9·94	11·28	24·80	1·41	n.o.	n.o.
	6·10	0·04	0·55	0·45	0·02	8·78	11·07	24·90	1·27	n.o.	n.o.
Ditto, Charge 9375	10·15	0·02	0·40	0·48	trace	8·78	12·94	23·62	0·69	36·3	7·17
	10·45	0·04	0·09	0·50	,,	8·18	11·70	23·76	0·70	38·03	7·54
Dr. Naske "St. und E." 1907, p. 231, Charge 975	6·55	0·01	1·91	0·35	0·05	13·64	13·06	22·20	1·73	n.o.	n.o.
	7·20	0·03	1·25	0·42	0·04	12·10	12·74	23·75	1·67	n.o.	n.o.
	7·40	0·05	0·71	0·42	0·02	10·67	12·43	24·30	1·53	n.o.	n.o.
Ditto, p. 232, Table 8	6·50	0·01	0·98	0·42	0·04	7·49	11·41	21·25	n.o.	n.o.	n.o.
	7·45	0·02	0·07	0·53	0·04	5·01	10·31	21·45	n.o.	n.o.	n.o.
	8·0	0·03	0·07	0·71	0·02	3·95	13·33	21·60	n.o.	n.o.	n.o.

Some indications as to reduction of phosphoric acid from the slag are given by the analyses on p. 160.

It is apparent that the re-entry of phosphorus into the metal accompanies an increase in the silica content of the slag, or carrying too far the removal of iron-oxide from the same, thereby creating more than normal efforts on the part of the reducing agents to satisfy their affinity for oxygen.

3. MANGANESE.

Manganese is oxidised according to the formula $Mn+O=MnO$. From this one derives that each 1 per cent. Mn requires 0·29 per cent. O, and produces 1·29 per cent. MnO . . . (34).

Manganese is generally eliminated as manganese silicate, as stated on p. 146. Lime is able in this case (as in that of the analogous iron-silicate) to replace the metallic oxide, and the manganese protoxide thus freed is in like manner soluble in the iron-lime silicate slag.

Free manganese protoxide is produced from $SiMnO_3$ according to the equation $SiMnO_3+CaO=SiCaO_3+MnO$, and under the influence of the reducing agents is converted into the metallic state and returned to the metal.

One therefore frequently finds a sudden increase in the manganese content of the bath, which is only explainable by a reduction of manganese from the slag.

Thus Ledebur (St. und E., 1903, p. 40) gives the following examples from the Bertrand-Thiel process :—

			Per cent.		Per cent.
1st Furnace—Test,	12·4	Mn in metal,	0·058 ;	Fe in slag,	12·0
,, ,, ,,	12·22	,, ,, ,,	0·100	,, ,, ,,	6·0
2nd ,, ,,	1·40	,, ,, ,,	0·050	,, ,, ,,	13·5
,, ,, ,,	2·0	,, ,, ,,	0·230	,, ,, ,,	13·5

Dr. Naske has (*vide* St. und E., 1907, pp. 158 *et seq.*) set out a series of analyses of the maganese in metal and slag, and arrived at the conclusion that it is determined by the relative ratios of MnO and FeO in the slag. With a ratio of MnO to FeO=unity a state of equilibrium can exist, but with $MnO>FeO$ manganese goes over from slag to metal, and with $MnO<FeO$, manganese goes over to the slag from the metal.

In support of the accuracy of his views, he gives the following table:—

Table O.

Number.	Interval: Minutes.	Metal.				Slag.		Fe% on Mn	Remarks.
		C	Si	P	Mn	Mn	Fe		
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent	Per cent.	Per cent.	
1	10	3·36 3·10	0·05 0·05	0·07 0·07	0·45 0·63	— 16·87	— 7·12	42	Charge 19,232 kg. pig iron; very hot; manganese reduced from slag.
2	13	3·05 3·00	0·03 0·03	0·07 0·08	0·77 0·84	— 14·08	— 6·04	42	Charge 19,232 kg. pig iron; very hot; manganese reduced from slag.
3	15	2·34 2·04	0·02 0·02	0·08 0·01	0·49 0·59	— 11·80	— 11·06	92	Charge 19,232 kg. pig iron; very hot; manganese reduced from slag.
4	30	0·56 0·39	0·01 0·01	0·01 0·01	0·36 0·41	— 10·09	— 9·51	94	Charge 19,300 kg.; hot; slag watery; Mn reduced.
5	25	1·56 1·47	0·05 0·05	0·03 0·03	0·52 0·63	— 12·67	— 10·32	81	Charge 20,303 kg. pig iron; charge hot, slag thin; Mn reduced from slag.
6	55	0·42 0·08	0·05 0·05	0·03 0·03	0·49 0·86	— 11·80	— 9·25	78	Charge 20,303 kg. pig iron; very hot; slag boiling; Mn reduced from slag.
7	25	1·91 1·25	0·05 0·05	0·01 0·03	0·38 0·42	— 12·74	— 12·10	95	Charge 20,860 kg. pig iron; very hot; Mn was reduced.
8	80	0·71 0·05	0·04 0·04	0·05 0·05	0·38 0·56	— 11·00	— 9·55	86	Charge 20,100 kg. pig iron; slag boiling, gas evolution small; Mn reduced.
9	80	2·94 1·74	0·05 0·05	trace 0·02	0·28 0·42	— 12·46	— 9·90	79	Charge 21,520 kg. pig iron; very hot; Mn reduced.
10	15	1·74 1·64	trace ,,	0·02 0·02	0·40 0·42	— 12·05	— 11·03	91	Charge 21,520 kg. pig iron; very hot; Mn reduced.
11	25	0·93 0·79	,, ,,	0·01 0·04	0·35 0·38	— 11·28	— 9·49	84	Charge 21,520 kg. pig iron; warm; slag watery; Mn reduced.
12	15	0·79 0·55	,, ,,	0·04 0·04	0·38 0·45	— 11·07	— 8·78	80	Charge 21, 520 kg. pig iron; warm; Mn reduced.
13	65	0·55 0·06	,, ,,	0·04 0·03	0·45 0·52	— 10·30	— 7·21	74	Charge 21,520 kg. pig iron; Mn reduced.
14	—	0·09 0·07	0·02 0·02	0·01 0·01	0·35 0·49	— 10·74	— 7·58	70	Charge 15,984 kg. pig iron; hot; Mn reduced before the addition of ferro-manganese.
15	70	3·38 1·63	0·04 0·04	0·01 0·01	0·21 0·39	— 12·16	— 9·60	78	Charge 19,248 kg. pig iron; bath very hot; Mn reduced.
16	50	1·63 0·98	0·04 0·04	0·01 0·01	0·39 0·42	— 11·41	— 7·49	65	Charge 19,248 kg. pig iron; intense reaction, Mn reduced.
17	115	0·98 0·07	0·04 0·04	0·01 0·02	0·42 0·53	— 10·31	— 5·01	50	Charge 19,248 kg. pig iron; very hot; Mn reduced.
18	30	1·55 0·55	0·02 0·01	0·01 0·01	0·11 0·25	— 10·57	— 6·78	64	Charge 20,176 kg. pig iron; hot; Mn reduced.
19	40	1·09 0·55	0·01 0·01	0·01 0·02	0·25 0·37	— 9·26	— 4·60	50	Charge 20,176 kg. pig iron; hot; Mn reduced.
20	40	0·55 0·07	0·01 0·01	0·02 0·02	0·37 0·40	— 8·63	— 4·13	48	Charge 20,176 kg. pig iron; hot; Mn reduced.

TABLE O—*continued.*

Number.	Interval: Minutes.	Metal.				Slag.		Fe % on Mn	Remarks.
		C	Si	P	Mn	Mn	Fe		
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	
21	65	2 10	0·01	trace	0·27	—	—	75	Charge 15,360 kg. pig iron and 3,840 kg. scrap; hot; Mn reduced.
		0·96	0·01	,,	0·48	6·61	4·96		
22	30	0·55	0·04	0·03	0·34	—	—	78	Charge 23,152 kg. pig iron; hot; Mn reduced.
		0·25	0·04	0·02	0·45	9·37	7·45		
23	35	0·16	trace	trace	0·41	15·50	15·61	100	Charge 9,600 scrap and briquettes, consisting of manganese ore, coke and tar; very hot; Mn in equilibrium.
		0·06	,,	,,	0·41				
24	30	1·88	0·02	0·02	0·42	—	—	150	Charge 19,232 kg. pig iron; hot; Mn oxidised out of bath.
		0·56	0·02	0·01	0·36	10·44	15·65		
25	10	4·01	0·28	0·87	0·87	—	—	169	Charge 20,592 kg. pig iron; furnace without gas, refined only by ore; temperature low; Mn oxidised.
		3·68	0·09	0·38	0·38	17·67	30·00		
26	25	3·84	0·14	0·07	0·56	—	—	101	20 080 kg. pig iron; warm; Mn oxidised.
		3·74	0·07	0·02	0·35	18·43	18·62		
27	20	3·79	0 34	0·03	0·66	—	—	112	Charge 21,520 kg. pig iron; warmed a little; Mn oxidised.
		3·57	0·09	0·02	0·35	15·92	17·79		
28	55	3·35	0·05	0·01	0·28	—	—	300	Charge 17,408 kg. pig iron; bath warm; Mn oxidised.
		2·51	0·05	0·01	0·24	8·82	26·49		
29	25	3·33	0·09	0·02	0·31	—	—	166	Charge 19,248 kg. pig iron; cool; Mn oxidised.
		2·83	0·04	0·01	0·21	11·81	19·65		
30	30	3·33	0·02	0·01	0·34	—	—	220	Charge 23,152 kg. pig iron; hot; Mn oxidised.
		2·83	0·02	0·01	0·27	6·82	15·04		
31	55	1·94	trace	0·01	0·52	—	—	145	Charge 9,600 kg. scrap and briquettes of manganese ore, coke, and tar; warm; Mn oxidised.
		1·36	,,	0·01	0·34	16·02	23·19		
32	35	1·55	0·02	0·02	0·61	—	—	133	Bath cool; Mn oxidised.
		1·00	0·02	0·01	0·50	11·12	14·82		

This table indicates, however, at least equally clearly another condition which favours the reduction of manganese from the slag.

This condition is mainly the exhaustion of metallic oxides in the slag, and therefore of oxygen.

A reduction of Mn from the slag took place in all cases in which percentage of iron in the slag was 12 per cent. or below, which slags thus were low in oxygen.

In all cases in which maganese had gone over from bath to the slag, the iron content of the latter exceeded 15·6 per cent.

Thus the reducing agents had at their disposal large amounts of oxygen in the form of iron protoxide, and were not constrained to decompose manganese protoxide.

All the reactions reviewed up to the present yield products which, like the reagents themselves, preserve the fluid state of aggregation. They thus manifest themselves only in an increase in the amount and change in appearance of the slag, but do not alter the quiet state of the entire bath.

In the elimination of carbon it is otherwise. This gives rise to a gaseous product, which cannot be held back by either the metal or slag. It must escape, on the contrary, and is forced through the slag, giving rise to very apparent and characteristic phenomena.

4. CARBON.

According to the formula $C+O=CO$, 1 per cent. carbon requires 1·33 per cent. O, and produces 2·33 per cent. CO . . . (35).

Its removal admits of being compared very well with the removal of a gas from a liquid, which has been formed therein by the reaction of some corresponding reagent. The further course is different from the concentration of the agents reacting on one another. A concentrated solution of carbonate of soda, for example, sets up from small drops of a concentrated acid an extremely powerful reaction. The reaction takes place at the point of contact with effervescence, and a somewhat too rich addition of acid produces losses by splashes or overflowing of the solution; but if by means of gradual addition of the acid to the carbonate salt it has become poorer, so each molecule of acid does not longer come into contact with the upper surface of the salt, and the acid is capable of penetrating into the solution, and its action only takes place in the deeper layers, and after being spread out over a large space. It thus gives rise to bubbles of gas in the interior of the fluid, which rise up in it and thereby give it the appearance of boiling. With progressive exhaustion of the carbonate salt, the apparent boil becomes feebler, the size of the gas bubbles produced becomes diminished so far that the individual bubbles are not able to ascend, but require time in order to unite into larger gas bubbles. Finally, in general there are no more bubbles formed, but there still remains suspended in the liquid an amount of gas in the form of minute gas bells. By powerful disturbance, one can drive out a great proportion of the gas, because hereby the resistance of the liquid against the escape of the gases is diminished, and the minute particles of gas are given the possibility of more quickly reaching each other.

The removal of carbon from iron as carbon-monoxide takes place in quite similar manner.

Pig iron with its carbon content of 3 to 4 per cent. may be regarded as a concentrated solution of carbon; and slag with an iron content of 30 per cent. or more, as a concentrated solution of active oxygen. At the contact surface, there results a formation of carbon monoxide in the state of bubbles of gas which seek to ascend, in which they are hindered by the viscosity of the slag. This is thereby forced from the contact surface of the metal. Soon, however, the gas bubbles are able to force their way through the slag, and this finally thereby closes under them and again comes in contact with the metal, whereby the process begins anew. The passage of the bulk of the resulting gas bubbles through the slag is, however, owing to the consistency of the same, considerably delayed, and this is the cause of the slag becoming frothed up and its volume considerably increased. In this connection, H. H. Campbell states on p. 211, "From the time that the metal is thoroughly melted, when it may contain about 3 per cent. of carbon, until the proportion is reduced to about 1½ per cent., the bath resembles soda water more than pig iron, and it tries to flow out of the doors and to occupy about twice the room it should."

The previously described course of the removal of the carbon is nowadays to be seen only in few works, since it is not frequently that molten metal with such high carbon content is worked in open-hearth furnaces.

On the other hand, one can observe the second quieter period of the carbon removal, which begins with a carbon content of about 1·5 per cent. and less, in the normal course in all open-hearth furnace charges.

The oxygen-containing slag at the surface contact of the bath, does not come into contact with sufficient amount of molecules of carbon, and the free iron oxide of the slag now penetrates into the interior of the metal until it comes into contact with carbon. Thus gas bubbles originate in the interior of the metal. This, however, offers greater resistance to the gas than the lighter slag covering. Therefore, the gas-bubbles must assemble themselves together into large gas-bubbles before their buoyancy suffices for their overcoming the cohesion of the bath of iron. Then only are they able to throw the particles of iron on one side and to rise through the metal. Thus only large gas bubbles and in small multitude reach the slag, through which they pass undivided, whilst they carry with them the small gas bubbles contained in the latter. The slag thereby soon loses its frothy appearance and sinks down, but still gas bubbles rise up from the bath in regular streams and invest it with a deceptive similarity to a boiling fluid—the bath " boils."

A regular boil is of the greatest importance for the open-hearth furnace process. Firstly, the bath is thereby more intensely mixed throughout, and can react better than ever could possibly happen by the action of any kind of mechanical mixing devices whatever. Secondly, the heat exchanged between the flame and the bath takes place in a more active manner, in that the colder bottom layers of the bath are always again brought to the top and exposed to the action of the flame. Lastly, owing to the boil, the direct chemical action of the flame is strengthened which is essentially only interpolated, since the ascending gas bubbles lift particles of the metal above the slag covering and bring them, if only for a moment, in direct contact with the flame. But the rôle repeats itself uninterruptedly; thus in spite of the apparently protective slag covering there takes place during the whole period of the lively boil a direct transference of oxygen from the gases of the flame to the metal. It thus in consequence forms scale which, by sinking back of the particles of iron through the slag covering, is washed off and dissolved in it, and in consequence becomes active on the carbon as dissolved iron oxide.

With lessened carbon content the boil diminishes, and presuming that there are, up to then, at all times sufficient amounts of oxygen present in the slag, at about 0·1 per cent. C becomes quite feeble, in that only isolated gas bubbles rise up out of the bath.

Inseparably accompanying the removal of the carbon is another weighty occurrence, the raising of the melting point of the metal. The lower the metal is in carbon, the less fusible it is. Therefore, during the entire period of the removal of carbon, a large quantity of heat must be introduced into the metal. When the decarbonisation is ended, the metal then lies quietly again, and the transference of heat to the lower layers can only occur by conduction, and this takes place more slowly than the radiation of heat through the hearth. The lower layers of metal cool down, therefore, and bring the bath into a condition which does not longer allow of smooth casting. Therefore, the charge must be tapped as soon as the carbon content has been brought down to the desired extent.

5. SULPHUR (IN BASIC OPEN-HEARTH FURNACES).

In addition to the substances Si, P, Mn and C, considered, there are other substances which are never entirely absent in iron, and the properties of the same in all cases act wholly unfavourably. These substances are sulphur and oxygen. Both, even in extremely small amounts, give rise to red-shortness and since iron in all working in forge fires has an opportunity at least to take up sulphur, so is one obliged to see the smallest possible content of the same in the products of the open-hearth furnace, if one intends to make only really first-class metal. Iron combines easily with sulphur, and it is capable of taking this up from otherwise stable sulphur compounds. Amongst others, also, it decomposes sulphate of lime (according to Finkener, "St. u. E.," 1908, p. 1021, and 1893, p. 50), according to the equation $CaSO_4 + 4Fe = FeS + CaO + 3FeO$ and the sulphur goes over into the iron as iron sulphide.

The author has in remembrance an instance in practice where, by inadvertence, some 100 kilogrammes of old boiler tubes which contained large amounts of boiler scale were put into an otherwise faultless charge. The sulphur content of the metal was thereby so highly increased that it caused great trouble to overcome the red-shortness and make the material to some extent usable. Nearly all fuels for producer working contain sulphur, which goes over into the gas as sulphurous acid, and then in the flame comes into most intimate contact with the charge. In the combustion chamber, a portion of the sulphurous acid is oxidised to sulphuric acid, which combines with the lime into lime sulphate. The latter can then be reduced by the iron, whereby the sulphur must go over into the metal.

Fortunately, there are generally forces at work in the furnace which oppose the taking up of sulphur from the gases of the flame, so that such can only seldom happen. This opposition is supplied by the manganese in the iron, which takes up the sulphur, and with it and iron forms a substance which is soluble in the slag as well as in the metal. Owing to this, the sulphur content divides itself between the two media, but MnS further has the property, in contact with free oxygen, of giving off the sulphur as SO_2, which escapes from the furnace, so that the slag is robbed of its sulphur content, and thus new amounts of sulphur are able to reach it from the metal. Thus manganese acts in removal of sulphur from the iron, and this property is utilised partly in the mixer and also in the transfer ladle, and in the basic open-hearth furnace. In this connection, Dr. Kintzlé, of Aachen, has given examples in "Stahl und Eisen" of 1897, pp. 386 and 388, of which some are given in the table on p. 169.

One sees that owing to the manganese, large amounts of sulphur had already been removed in the transfer ladle, and the further removal of the same down to about one one-hundredth of 1 per cent. easily took place in the mixer. Complete removal of sulphur cannot be obtained in this way, as, according to Professor Osann, "with progressive desulphurisation such an increased inactivity in the course of reaction must follow that finally it requires such a large amount of time as is never practically at disposal."

In the basic open-hearth furnace, desulphurisation proceeds

Pig Iron taken from Blast Furnace.				On being poured into the mixer, the metal contained		On being poured into the convertor, the metal contained	
Time.	Pig iron, Kg.	Mn.	S.	Mn.	S.	Mn	S.
2·0	31,350	1·03	0·19	0·85	0·10	—	—
2·45	33,050	1·17	0·17	0·92	0·09	—	—
3·30	32,350	1·97	0·08	1·42	0·06	—	—
4·30	10,400	1·13	0·20	0·86	0·10	—	—
5·03	—	—	—	—	—	0·90	0·04
5·32	—	—	—	—	—	0·90	0·06
5·30	44,700	1·08	0·19	0·98	0·14	—	—
5·54	—	—	—	—	—	0·89	0·04
6·18	—	—	—	—	—	0·84	0·04
6·37	—	—	—	—	—	0·89	0·05
6·45	22,800	1·55	0·12	1·08	0·09	—	—
6·50	—	—	—	—	—	0·84	0·04
7·00	21,700	1·22	0·17	0·97	0·11	—	—
7·10	—	—	—	—	—	0·84	0·05
7·30	—	—	—	—	—	0·84	0·05

slowly, and is accompanied by considerable expense in manganese. In a South Russian iron works, for example, a charge of 20 tons which contained 0·50 per cent. S and 0·40 per cent. Mn, required additions of a total of 1,100 kilogrammes of 20 per cent. Spiegeleisen and 2,100 kilogrammes of 80 per cent. ferro-manganese in successive instalments in the course of three hours, reckoned from the end of the decarbonisation. The final product contained 0·05 per cent. S and 0·71 per cent. Mn.

Manganese ore acts similarly to metallic manganese, and after its solution in the slag and its being reduced by carbon small amounts of manganese are always brought into the metallic iron, which then react on the sulphur in it. A. Riemer gives an example thereof in "St. u. E.," 1902, p. 1361, in which 16,400 kilogrammes pig iron with 0·84 to 0·92 per cent. S and 0·42 Mn was worked. The metal was charged with an addition of 2,100 kilogrammes iron ore and 2,300 kilogrammes manganese ore, and showed directly after melting down a content of 0·22 per cent. S, 0·13 per cent. Mn and 0·04 per cent. C. An ordinary charge would have now at most demanded an hour to be ready for tapping; this charge, however, required for its high sulphur content to remain in the furnace four hours, and received total additions of 660 kilogrammes pig iron, 900 kilogrammes 26 per cent. Spiegeleisen, and 250 kilogrammes of ferro-manganese, and yielded a finished product which contained 0·120 per cent. S, 0·56 Mn, and 0·08 C. There was thus necessary three hours longer furnace working and a considerable expense in materials in order to bring down the sulphur content of 0·22 per cent. (after melting down) to 0·12 per cent., thus only to remove 0·10 per cent. from it.

It has been sought to remove sulphur by other means; thus Saniter has proposed calcium chloride in conjunction with a very limey slag, which is rendered thin by means of fluorspar. This process shares with desulphurisation by manganese the like disadvantages of great expense in material and time, and is as a result unsafe. It has not, therefore, been possible in practice to adopt it.

In the most recent times, experience with the production of steel in the electric furnace has apparently furnished full explanation as to the problem of complete removal of sulphur from iron. According to Dr. Ing. Geilenkirchen and Professor B. Osann ("St. u. E.," 1908, pp. 873 and 1071), sulphur can only be completely removed from the iron if it is converted into a form in which it is soluble in the slag, but not in the metal. This form is calcium sulphide. In order, however, that CaS can be produced, the slag must be free from metallic oxides, since otherwise (according to Professor B. Osann, "St. u. E.," 1908, pp. 1501 and 1507) iron sulphide will be continually reformed according to the equation $FeO + CaS = FeS + CaO$, and thereby any sulphur removed must be returned to the metal.

In order that the slag should maintain freedom from oxides, reducing agents such as calcium carbide or ferro-silicon must be added, and for possibility of its existence free from metallic oxides, enormously high temperatures must be employed. The latter condition the open-hearth furnace is not able to fulfil, and therefore a very complete desulphurisation is not possible therein. The difficulties of desulphurisation in the basic open-hearth furnace have above all led to the conviction that it is more profitable in general to waive desulphurisation in this apparatus, and only to employ as much as possible sulphur-free materials for the charges.

6. Oxygen in Iron.

Oxygen is contained in all classes of iron, but only in very minute amounts. In larger amounts, it is only contained in iron by the treatment of the same in the open-hearth furnace itself, inasmuch as the free ferrous-oxide contained in the slag is soluble in the molten metal. The estimation of oxygen in iron by analysis is accompanied by very great difficulties, whence one does not know exactly how much the amounts are which can be taken up by iron under changing conditions.

According to Ledebur, iron contains carbon and oxygen as under :—

By overblowing in Basic Bessemer Convertor	Horde	0·024 C	0·07 O
	Not given	0·037 C	0·244 O
	Konigshutte	0·04 C	0·07 O
	Not given	0·05 C	0·171 O
	Not given	0·123 C	0·187 O
Siemens-Martin Steel	Riesa	0·10 C	0·03 O
	Oberhausen	0·14 C	0·03 O
	Bochum	0·19 C	0·07 O

One assumes that the oxygen is combined with iron as FeO.

There is in FeO per unit Fe $\frac{16}{56}=0{\cdot}29$ unit O . . . (36)

In spite of the amounts of oxygen which go over into the iron being in small ratio to the weight of iron, one can daily observe that iron takes up oxygen; that by themselves large amounts of reducing agents are not capable of completely hindering its entry, as well as that the resistance which they oppose to this entry, is of different amount. Carbon, phosphorus and silicon, for example, act very imperfectly, which possibly indicates that the velocity with which they are capable of keeping in motion and endeavouring to attain uniform distribution in the iron is relatively small, and that, therefore, oxygen is capable of removing these reducing agents in the portions where it has penetrated more rapidly than they can make compensation for by replacing themselves from further removed portions.

The first token of the penetration of oxygen is red-shortness, which, according to Wedding, begins already at 0·01 per cent. O, whilst with a content of 0·05 per cent. iron will be made in a state of being totally unusable. The phenomenon of red-shortness is not able to be got rid of by the presence of even large amounts of the three reducing agents named; this can only occur by means of manganese, which, in spite of its not being capable of bringing about complete removal of the oxygen, must nevertheless be regarded as the best destructive agent for the ferrous oxide dissolved in iron. One can, therefore, use manganese also as a preventive agent against red-shortness, by means of large additions thereof to the charge. This takes place nowadays in all cases where metal of the highest quality is to be manufactured. So long as the manganese content remains sufficiently high (about 0·3 per cent. may be regarded as the lowest limit), oxygen cannot be present in the metal in noteworthy quantity. The grounds for this are as follows:—

(*a*) Manganese has great affinity for iron, and small amounts thereof are retentively held from splitting away. There further takes place a state of equilibrium between the manganese in the metal and the manganese in the slag, and the more the manganese contained in the metal, the quicker this state of equilibrium will be attained. The slag can further only take up a specified maximum content of metallic oxides, and the more manganese oxide contained in it, the less must its content of ferrous oxide become. It is, however, clear that a slag rich in manganese oxide, notwithstanding its possibly very high oxygen content, cannot react so powerfully on the manganese in the charge, as would be the case, if its entire oxygen content were combined with iron. Therefore on the one hand the manganese content of the metal is less diminished, and on the other hand, by exhaustion of ferrous-oxide in the slag, the carbon suffices to reduce manganese-oxide and return it to the metal, in which it is enabled to more energetically attack the traces of ferrous-oxide which have penetrated it than the remaining reducing agents are capable of doing.

(*b*) If one makes the manganese content of the charge not under 3 per cent. it is possible to blow a metal in a basic Bessemer convertor, which without further additions is not red-short, and which works well.

(*c*) The same is able to be achieved in the basic open-hearth furnace. Here, however, one can also add the metallic manganese by means of the oxygen compounds of the same. But in this case, one must specially take care that at the end of the decarbonisation the slag is so poor in oxygen that reduction of manganese from the slag must be compelled to result.

(*d*) Oxygen penetrates into the iron from a slag rich in oxides in the greater amounts, the more the content of reducing agents in the same is lowered. The metal will thereby become unfit for any working, and must then be regenerated by means of deoxidation, to be discussed later.

(*f*) COMPOSITION AND PROPERTIES OF THE SLAG.

(1) *Content of Metallic Oxides in the Slag.*

The composition of the slag under the influence of the metal is other than that which is determined by the action of iron oxide on the furnace structure.

Unfortunately, very little has been written about the first slags which originate on the melting down of iron in basic open-hearth furnaces; the only communication which the author has at disposal is due to F. W. Harbord of Bilston ("St. u. E.," 1886, p. 812). He employed a charge of 67 per cent. pig iron and 30 per cent. steel scrap and 3 per cent. spiegeloisen, and investigated the slag I. which had formed itself before the melting down of the metal, and the slag II. which was given rise to after about one-third of the charge was melted down.

He obtained the following figures :—

	Slag I.	Slag II.
SiO_2	8·5 per cent	Not given.
Fe_2O_3	4·3 ,,	4·2 per cent.
FeO	63·0 ,,	52 47 ,,

One sees that the chief constituent of the slag is ferrous oxide which is derived from scale, and is dissolved in iron silicate.

For slags in basic open-hearth furnaces which are deliberately created from natural iron oxides brought into contact with metallic iron, recently more examples have been brought forth, derived from the pig-ore process with molten charges.

Dr. Ing. Th. Naske gives in " St. u. E.," 1907, p. 231, Table 6, the analysis of a slag prepared from iron oxide and limestone, which had made its appearance thirty minutes after pouring molten pig iron into a furnace.

The slag contained :—

FeO 47·88 per cent., Fe_2O_3 6·10 per cent., Mn 15·22 per cent., SiO_2 17·68 per cent., P_2O_5 2·36 per cent.

A slag similarly produced, in which the content of lime and magnesia is also given (*ibid.*, p. 267), contained :—

Fe 36·05 per cent., Mn 15·01 per cent., SiO_2 20·85 per cent., CaO 11·50 per cent., MgO 1·20 per cent., P_2O_5 1·49 per cent.

Here also the chief constituent is ferrous oxide, which, with iron peroxide, is dissolved in an iron silicate.

The slag formed at the commencement of the process does not retain its high iron content long, since the metallic oxides are gradually reduced down to small amounts by the reducing agents in the iron, whereby the fluidity of the slag is not substantially lowered. On the attainment of a state of equilibrium between metal and slag, the metallic oxide content of the latter will manifestly be the smaller, the more reducing agents are present in the metal.

It is doubtless of great interest to know the conditions for such an equilibrium ; unfortunately, however, no scientific investigations thereon have been presented. One can nevertheless obtain data from the available examples from open-hearth furnace practice, which are able to render good service as approximations.

On p. 175, Table P, are set out analyses of slags, which have been a long time in contact with metal and have no longer exercised specially perceptible influence thereon. In all cases the reaction had thrived so far that it had been found necessary to interrupt the process, or to make further attack. The slags have occurred in basic furnaces of the most different systems, and in the most different parts of the world, and one

	Temperature.	Metal.				Slag.					
		C	Si	Mn	P	Fe	Mn	SiO_2	CaO	MgO	P_2O_5
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Action of Pig Iron on Slags low in Iron.											
South Russian Works:—											
1. "St. & E.," 1907, p. 230, Dr. Naske	high	3·76	0·18	2·48	0·14	1·72	2·94	35·80	n.o.	n.o.	0·05
2. " " 1905, p. 1339, Author	"	3·87	0·56	2·38	0·14	1·19	1·46	38·60	n.o.	n.o.	0·04
Kladno-Bertrand-Thiel process.											
3. "St. & E.," 1903, p. 40, Ledebur, 1st F'ce	"	2·50	0·04	0·10	0·087	6·00	n.o.	19·16	n.o.	n.o.	18·88
4. " " " " " " "	"	2·70	0·01	0·06	0·174	6·00	n.o.	24·33	n.o.	n.o.	15·83
Action of low Carbon Metal on Slag.											
Bogoslowsky Iron Works, Ural:—											
5. "St. & E.," 1902, p. 652, "Schmidthammer"	Tapping	0·42	0·11	0·90	0·01	6·1	7·4	29·44	41·53	11·91	n.o.
6. " " " " "	"	0·43	0·015	0·68	0·027	4·85	5·2	30·66	27·63	8·57	n.o.
Polish Works:—											
7. Author's Notes	"	0·40	n.o.	n.o.	n.o.	7·1	17·6	24·4	32·5	9·2	2·0
8. " "	"	0·30	n.o.	n.o.	n.o.	9·4	15·4	22·0	33·7	8·9	0·9
Campbell, "Manufacture of Iron and Steel."											
9. Pencoyd (Pennsylvania) Talbot process, Ch. 254	"	0·16	n.o.	0·50	0·036	11·81	6·06	11·55	n.o.	n.o.	12·03
10. " " " " " 306	"	0·14	n.o.	0·45	0·038	18·39	4·21	10·94	n.o.	n.o.	12·26
Kladno-Bertrand-Thiel process.											
11. "St. & E.," p. 40, 1903, Ledebur, 2nd F'ce	"	0·15	0·018	0·32	0·01	13·5	n.o.	13·0	n.o.	n.o.	4·99
12. " " " " " "	"	0·16	trace	n.o.	0·02	15·75	n.o.	11·43	n.o.	n.o.	5·67
Campbell-Steelton.											
13. Mean of 17 charges (Test C)	"	0·12	0·01	0·22	0·013	15·82	6·98	15·08	42·16	8·45	3·85
14 " 27 " before tapping	"	n.o.	n.o.	n.o.	n.o.	9·80	n.o.	12·4	45·4	n.o.	13·73
Polish Works:—											
15. Author's Notes	"	0·01	n.o.	n.o.	n.o.	15·7	11·6	18·0	34·5	7·5	5·6
16 " "	"	0·01	n.o.	n.o.	n.o.	14·4	4·0	17·7	39·8	11·4	2·8
17 " "	"	n.o.	n.o.	n.o.	n.o.	10·3	10·1	30·5	30·7	11·3	2·2
Pencoyd-Talbot process.											
18. "St. & E.," 1900, pp. 264, 265	"	0·07	n.o.	0·17	0·038	10·29	5·8	15·39	n.o.	n.o.	8·68
19. " " " " " "	"	0·10	n.o.	0·21	0·021	15·52	8·3	12·97	n.o.	n.o.	6·58
Witkowitz Duplex process. E. Holz.											
20. "St. & E.," 1902, p. 5	"	not given, but about 0·1 per cent.				18·03	7·33	15·10	37·1	7·5	4·05
Pencoyd-Talbot process.											
21. "St. & E.," 1902	"	"	"	"	"	14·2	9·7	15·68	38·6	8·4	7·55
South Russian Works:—											
22. Magnesite Hearth, Author's Notes	"	0·07	trace	0·55	0·02	9·06	11·32	25·1	24·8	18·0	n.o.

can therefore assume that a large portion of the possible working contingencies had received consideration. For comparison, the composition of the correspondingly belonging metals is given, and the analyses are arranged according to the carbon contents of the metals.

One sees that with a fall in the carbon content of the metal, the content of metallic oxides in the slag rises as under :—

Per cent. C in Metal.	Metals contained in Slag.	
	Fe per cent.	Mn per cent.
About 3·75	1·5	1·5
,, 2·7	6·0	Not given
,, 0·4 to 0·1	4·85 to 18·39	4·85 to 17·6

The field in the case of complete decarburisation is very great. If one, however, looks into the individual analyses more closely, one finds that all the works cited exhibit values lying much nearer one another.

The Ural Works, viz.	4·85 and 6·1	per cent. Fe
The Polish Works, Ex. 7	7·1	,, ,,
Talbot process in America, Ex. 18	10·29	,, ,,
Steelton Works in America, Ex. 14	9·7	,, ,,
South Russian Works, Ex. 22	9·06	,, ,,

The metallic oxide appears therefrom as a constituent of the slag whose amount evidently admits without difficulty of being lowered to at least 10 per cent. Fe. One must further assume that, with an iron content in the slag of the height given, it is at least approximately in equilibrium with the bath of metal, and that at least the cases show that with somewhat higher iron contents, such does no longer permit a specially great action on the metal, since notwithstanding this condition it was possible to produce a good final product.

One can thus for practical purposes regard the state of equilibrium in respect of the slag and reducing agents in the iron as being reached if the content of iron in the slag has been lowered to 10 per cent., corresponding to 13 per cent. FeO . . . (37).

On the grounds already laid down in the discussion on the proportions of manganese oxide in the slag and oxygen in the iron, it appears desirable, for the production of a faultless final product, to have the manganese content of the slag at least as great, so that 10 per cent. manganese corresponding to 13 per cent. MnO also should be present in the slag.

Thereby the amounts of metallic oxides in a good final slag are fixed at about 26 per cent. of its weight.

(2) *Relative Proportions between Acids and Alkaline Earths in Final Slags.*

For the estimation of the relative ratios between acids and alkaline earths in good final slag, the chemical constitution of the same will furnish the best basis. Unfortunately, this question has not as yet received its theoretical answer, and thus there remains nothing left but to utilise as a basis and investigate the slag analyses from practice, and to derive in purely empirical manner from a great number of these, data which are able to be of value in practice.

The most essential property of the slag is its fluidity. As fluxes for the final slag, since the major portion of it consists of bases, only the two acids, silicic acid and phosphoric acid, are able to be taken into consideration. H. H. Campbell takes evidently the same view, if he desires for a good final slag a content of 26 to 27 per cent. $SiO_2+P_2O_5$. These figures pass however, only seldom to other proportions.

Nowadays one generally assumes that the phosphoric acid in the final slag is always present in a form of phosphate of lime, and it is quite defined. There must thus be P_2O_5 and CaO always united in quite definitely relative ratios to each other.

If one further assumes that this lime phosphate consists of the tetrabasic phosphate $Ca_4P_2O_9$, there is thus in it per unit of weight P_2O_5; 1·58 weight units CaO, which yields 2·58 weight units of $Ca_4P_2O_9$.

Since the phosphoric acid almost always is only derived from the P in the charge, there originates from 1 per cent. P, 2·29 per cent. P_2O_5, which requires 3·61 per cent. CaO and yields 5·9 per cent. $Ca_4P_2O_8$ . . . (38).

One can thus accordingly deduct the phosphoric acid in the form of lime phosphate in slag, and thereby make the latter more easily reviewable in respect of its remaining ingredients.

TABLE Q.—SLAGS ON DECARBURISATION OF METAL DOWN TO 2 TO 3 PER CENT.

Source.	P_2O_5.	Fe.	SiO_2.	$Ca_4P_2O_9$.	Silicate Slag.	Ratio of SiO_2 to P_2O_5.	Ratio of Silicate Slag to SiO_2.	Silicate Slag contains	
								SiO_2.	Fe.
Bertrand-Thiel, 1st F'ce.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.			Per cent.	Per cent.
"St. & E." 1897, p. 412	23·38	7·68	16·02	60·3	39·7	0·68	2·5	40	12·4
,, 1898, p. 751	21·88	6·34	19·60	56·6	43·5	0·9	2·2	45	14·6
,, 1897, p. 411	19·84	5·24	20·18	51·2	48·8	1·02	2·4	41	10·7
,, ,, ,,	19·20	4·68	19·77	49·5	50·5	1·03	2·5	40	9·2
,, ,, p. 412	18·73	7·02	20·32	48·3	51·7	1·08	2·5	39	13·7
,, 1903, p. 40	18·18	6·00	19·16	47·6	52·1	1·05	2·7	37	11·5
,, 1897, p. 412	17·02	7·95	22·64	43·9	56·1	1·33	2·5	40	14·2
,, ,, p. 411	16·32	5·05	19·42	42·3	57·7	1·2	3·0	34	8·8
,, 1905, p. 40	15·83	6·00	24·33	40·8	59·2	1·53	2·4	41	10·1
,, 1898, p. 755	15·79	6·00	25·30	40·6	59·4	1·6	2·3	43	10·0
,, ,, p. 750	15·61	5·93	23·18	40·3	59·7	1·5	2·6	39	10·0
,, ,, p. 755	15·48	7·55	23·41	39·9	60·1	1·5	2·5	39	12·2
,, ,, ,,	14·84	5·67	24·25	38·3	61·7	1·64	2·6	39	9·2
,, ,, ,,	14·46	4·59	25·92	37·3	62·7	1·8	2·4	41	7·3
,, 1897, p. 412	14·08	11·91	26·60	36·3	63·7	1·9	2·4	41	18·7
,, 1898, p. 755	13·84	5·80	20·80	36·0	64·0	1·5	3·1	33	9·0
,, 1897, p. 412	13·82	6·93	24·41	35·6	64·4	1·8	2·6	38	10·8
,, 1898, p. 755	13·80	3·60	20·9	35·6	64·4	1·5	3·1	32	5·6
,, ,, ,,	13·56	6·48	25·56	35·0	65·0	1·9	2·1	39	10·0
,, ,, ,,	13·37	7·96	25·36	34·5	65·5	1·9	2·6	39	12·2

„ 1897, p. 412	13·18	8·24	25·2	34·0	66·0	1·9	2·6	38	12·5
„ „ p. 411	13·05	5·99	25·24	33·7	66·3	1·9	2·6	38	9·0
„ 1898, p. 751	12·51	7·15	25·00	32·3	67·7	2·0	2·7	37	10·5
„ 1897, p. 412	12·41	7·68	24·93	32·0	68·0	2·0	2·7	37	11·3
H. H. Campbell . .	12·23	7·30	26·3	31·6	68·4	2·1	2·6	38	10·7
"St. & E." 1897, p. 411	12·13	5·99	26·92	31·3	68·7	2·2	2·5	40	8·7
„ „ „	12·03	5·99	25·7	31·0	69·0	2·1	2·7	37	8·7
„ 1898, p 753	11·96	11·23	20·60	30·8	69·2	1·7	3·3	30	16·2
„ 1897, p. 411	11·26	5·62	29·0	29·0	71·0	2·6	2·5	40	8·0
„ 1898, „	11·26	5·72	32·56	29·0	71·0	2·9	2·2	46	8·0
„ 1897, p. 412	10·36	8·26	19·44	26·7	73·3	1·8	3·8	26	12·9
„ 1897, p. 411	8·32	5·62	30·96	21·5	78·5	3·7	2·5	39	7·2
Author's Notes, Charge No. 1271 . . .	2·60	4·72	24·2	6·7	93·3	9·3	3·8	26	5·1
Dr. Naske. "St. & E." 1907, p. 232	abt. 2·5	9·60	20·5	abt. 6·0	abt. 94·0	8·0	abt. 4·6	abt. 21·8	abt. 10·2
„ „ p. 231	2·44	14·71	21·66	6·3	93·7	9·0	4·3	23·1	15·9
Author's Notes, Charge No. 846 . . .	1·88	11·15	22·4	4·8	95·2	12·0	4·3	23·5	11·7
"St. & E." 1907, p. 233	1·74	14·88	22·8	4·5	95·5	13·0	4·2	23·9	14·8
„ „ p. 231	1·73	13·64	22·2	4·5	95·5	13·0	4·3	23·2	14·3
Author's Notes, Charge No. 997 . . .	1·34	9·96	27·4	3·4	96·6	20·0	3·5	28·4	10·3
Author's Notes, Charge No. 3468 . . .	abt. 1·3	10·93	34·8	abt. 3·5	abt. 96·5	abt. 30·0	abt. 2·8	abt. 36·1	abt. 11·3
Author's Notes, Charge No. 1093 . . .	0·66	16·32	30·0	1·7	98·3	44·0	3·3	30·5	16·6
Average . . .							2·9		

TABLE R.—FINAL SLAGS AFTER COMPLETE DECARBURISATION.

Source.	P_2O_5.	Fe.	SiO_2.	$Ca_4P_2O_9$.	Silicate Slag.	Ratio of SiO_2 to P_2O_5.	Ratio of Silicate Slag to SiO_2.	Silicate Slag contains	
								SiO_2.	Fe.
H. H. Campbell, "Mfr. I and S."	Per cent	Per cent	Per cent	Per cent	Per cent			Per cent	Per cent
,, Talbot process	17·05	8·0	12·62	40·0	56·0	0·74	4·4	22·5	14·3
,, ,, ,,	16·43	9·2	12·1	42·4	57·6	0·74	4·8	21·0	16·0
,, Steelton	15·53	6·93	14·35	44·0	60·0	0·92	4·2	23·9	11·5
,, Talbot	15·56	8·25	12·32	40·0	60·0	0·79	4·9	20·5	13·7
,, Steelton	13·73	9·7	12·4	35·4	64·6	0·9	5·2	19·2	15·0
,, Talbot	13·26	8·1	11·68	34·2	65·8	0·88	5·7	17·8	12·3
,, ,,	12·45	14·0	12·08	32·0	68·0	0·97	5·6	17·7	20·6
,, ,,	12·26	14·2	10·94	31·6	68·4	0·82	6·2	16·0	20·7
,, ,,	12·03	9·10	11·55	31·0	69·0	0·96	5·0	16·7	13·2
,, ,,	12·03	11·0	11·7	31·0	69·0	0·97	5·9	17·0	16·0
Bertrand-Thiel	11·78	11·0	13·23	30·0	70·0	1·1	5·3	18·9	15·7
St. & E., 1903, p. 40	10·53	15·00	12·3	27·0	73·0	1·17	5·1	16·8	20·5
H. H. Campbell	9·70	18·00	14·66	25·0	75·0	1·5	5·1	19·6	20·4
,,	4·99	13·5	13·0	12·9	87·1	2·7	6·7	14·9	15·5
,, Steelton	3·85	15·65	15·08	10·0	90·0	4·0	6·0	16·9	17·4
,, ,,	2·96	12·8	15·75	7·6	92·4	5·3	6·0	17·0	13·8
Author's Notes, Polish works	1·99	7·15	24·39	5·0	95·0	12·0	4·0	25·2	7·5
,, ,, S. Russian works	1·90	9·63	24·20	4·9	95·1	12·0	4·0	25·4	10·1
,, ,, ,,	1·79	11·68	23·15	4·6	95·4	13·0	4·0	25·5	12·2

Dr. Naske.									
St. &. E., 1907, p. 231	1·72	7·35	22·25	4·4	95·6	13·0	4·3	23·3	7·7
,, ,, p. 233	1·58	13·52	18·70	4·0	96·0	12·0	5·1	19·5	14·1
,, 1905, p. 1,434	1·56	9·93	20·92	4·0	96·0	13·0	4·6	21·8	10·4
,, 1907, p. 231	1·53	10·67	24·3	4·0	96·0	16·0	4·0	25·3	10·5
Author's Notes, Charge p. 1,271	1·53	3·24	23·30	4·0	96·0	15·0	4·1	24·4	3·4
,, ,, ,, p. 1,384	1·53	7·33	25·50	4·0	96·0	17·0	3·8	26·6	7·7
St. & E., 1907, p. 267	1·51	9·00	21·00	4·0	96·0	14·0	4·6	21·9	9·4
,, ,, p. 231	1·50	3·95	21·6	4·0	96·0	14·0	4·4	22·5	4·1
Author's Notes, Charge No. 846	1·44	10·76	22·08	3·7	96·3	15·0	4·4	23·0	11·1
,, ,, ,, ,, 997	1·34	7·71	23·95	3·6	96·4	18·0	4·0	24·8	8·0
,, ,, ,, ,, 9,375	1·24	6·02	23·26	3·2	96·8	17·0	4·0	24·0	6·2
,, ,, ,, ,, 9,070	1·23	11·37	16·80	3·2	96·8	13·0	6·0	17·4	11·7
,, ,, Polish works	0·90	9·43	21·95	2·3	97·7	24·0	4·4	22·5	9·5
,, ,, Charge No. 1,603	0·83	17·74	15·50	2·0	98·0	19·0	6·3	16·0	18·0
,, ,, ,, ,, 1,093 (Foundry Pig Iron)	0·47	4·8	30·4	1·2	98·8	60·0	3·2	30·8	4·9
,, ,, On Magnesible hearth	0·40	9·06	25·14	1·1	98·9	60·0	4·0	25·4	9·1
St. & E., 1902, p. 653	abt.0·40	6·50	28·72	1·0	99·0	70·0	3·4	29·0	6·6
,, ,, Ural works	abt.0·40	7·0	29·26	1·0	99·0	70·0	3·3	29·6	7·1
Average							4·78		

After elimination of the lime phosphate, the slag presents itself as an, of course, hypothetical silicate slag, to which one can ascribe the property of holding in solution the corresponding amount of lime phosphate. One can then further estimate for each example, from practice, how much silicate slag per unit SiO_2 was formed, how much alkaline earth was necessary for its formation, and how much silicic acid was required to form the hypothetical silicate slag, which was capable of dissolving the lime phosphate, due to 1 unit phosphoric acid. In order to obtain better analytical material for these calculations also, such analyses are taken in which only the three principal substances SiO_2, P_2O_5 and Fe are given.

A comparison of the results given shows that the slags may very well be divided into two classes, of which the first is formed by the case of decarburisation to about 2 to 3 per cent., the second the case of complete decarburisation.

Table Q. "Decarburisation of the metal to about 2 to 3 per cent." (p. 178), unfortunately only contains analyses for highly phosphoric materials by the Bertrand-Thiel process, since others are not at disposal. For low phosphorus materials, the material is inadequate on the ground that the ending of a process with such high carbon contents practically never takes place; in order, however, nevertheless to have some approximate data, slags are also taken which occur in the usual pig iron-ore process, notwithstanding that the high iron content of these slags indicates that their oxygen content was not as yet exhausted, owing to which they could not be regarded as intrinsically good final slags.

Table R. "Final slags on complete decarburisation of the metal." (p. 180), contains, on the contrary, slags from all parts of the world, and from furnaces of the most widely different construction.

One sees at once from both tables that lime phosphate appears easily soluble in the hypothetical silicate slag, inasmuch as one unit of weight of P_2O_5 in the form of lime phosphate can be contained in an amount of hypothetical silicate slag, in the formation of which only 0·68 to 0·7 units of weight of SiO_2 were necessary, one and the same whether the decarburisation had only taken place to small extent or had taken place completely. Thus a total quantity of silica sufficed of an amount of 0·7 ÷ 2·29, or 0·3 units of weight, per unit of weight of P in the charge . . . (39).

An astonishing condition is disclosed by the silicate slag; the iron content of which apparently admits without difficulty of being brought down to approximately 10 per cent. in it, even with the highest amounts of calcium phosphate in the total slag. One may therefore very well assume that the before-quoted minimum amounts of metallic oxides, viz., 10 per cent. Fe and 10 per cent. Mn, corresponding to 13 per cent. FeO and 13 per cent. MnO, can be taken possession of by the hypothetical silicate slag alone.

Investigation of the question of how much hypothetical silicate slag can originate from 1 unit of weight of silica, discloses that these amounts are much greater in the case of complete decarburisation than in only partial decarburisation. Whilst on complete decarburisation, there are on an average in the silicate slag 4·78 unit weights of silicate slag per unit of weight of SiO_2, which slag thus contains about 21 per cent. SiO_2, there are formed on an average on decarburisation down to 2 per cent. to 3 per cent. only 2·9 parts (40) of this silicate slag per part of SiO_2, so that this slag shows about 34 per cent. SiO_2.

These estimates are now sufficient in order to fix the demand of the silicate slag for bases, having regard to the condition that other impurities also (some clays) in amounts of approximately 4 per cent. get into the slag. The composition of the slag must then be as under :—

	In the case of complete decarburisation. Per cent.	Decarburisation to 2—3 per cent. Per cent.
SiO_2	21	34
Metallic Oxides FeO+MnO . .	26	26
Impurities	4	4
Total .	51	64
Balance CaO and MgO	49	36
	100	100

The requirement of CaO and MgO per unit SiO_2 in the bath thus is derived as being

$$\frac{49}{21}=2{\cdot}33 \text{ CaO and MgO} \quad . \quad . \quad . \quad (41), \text{ and}$$

$$\frac{36}{34}=1{\cdot}06 \text{ CaO and MgO} \quad . \quad . \quad . \quad (41\text{A}).$$

With the aid of these figures, the composition of any desired charge, which should have a good final slag, admits of being fixed, and likewise admits of the ascertainment of the amounts of all necessary additions.

A good final slag should make its appearance as a quietly flowing mass of creamy consistency. A bar of iron dipped into the slag should, on being taken out of the furnace, be covered with a uniform crust of slag of about 2 to 3 millimetres thickness, which after cooling down should exhibit a dull grey-black tint.

In the test spoon, the slag itself should flow quietly like oil; if it is taken out with fluid metal, it should not be effervescent. It should be easily stripped off the steel test, but admit of being held back, so that the latter can be cast free from slag into the test mould. An effervescent state shows that the action of the slag on the metal is still under full way; excessive fluidity is an evidence of an excess of metallic oxides, but with high carbon metal is at times, also, of an excess of silica.

Viscosity is a sign of an excess of earthy bases, or too high magnesia content. At times, this viscosity suddenly makes its appearance at the end of the charge, after large additions of manganese, and one has sought to explain this phenomenon by manganese sesqui-oxide Mn_3O_4 making its appearance, which may be insoluble in the slag.

One can bring too thin a slag to the proper consistence by means of addition of lime and especially magnesia, whilst too thick a slag can be made more fluid by addition of silica, but the latter means must naturally be employed with caution with highly phosphoric charges. Also, fluorspar rapidly makes the slag fluid, but, however, this material is only employed in rare instances.

(*g*.) THE QUANTITY OF SLAG.

On the basis of the before-going assumptions, the quantity of slag which must occur under good management on any given charge admits of being ascertained. The final slag consists of—

(1) Hypothetical silicate slag which originates from the silicon content of the metallic charge;

(2) Phosphate slag, which is formed from the P content of the charge;

(3) Hypothetical silicate slag, which is produced from the silica of the furnace structure; and also

(4) The silica content of all other materials put into the furnace.

It appears possible to derive the amount of the final slag from the composition of the charge and the quantity of slag which will be formed under the circumstances mentioned under heading (3). In this connection, however, a circumstance arises which will soon be considered, viz., One has always remarked that silicon, phosphorus and manganese are very rapidly removed, whilst carbon removal throughout requires a longer time. In all cases where the carbon content of the charge is increased, the duration of the heat, and therewith also the wear of the furnace structure is increased, and, indeed, approximately proportionally to this increase. It, therefore, appears admissible to regard the removal of carbon, the product of which, CO, has itself nothing to do with the slag, as of influence on the quantity of the slag, and this occurs most simply (if also not quite free of objection), if one allocates the entire amount of silicate slag which grows from the using up of furnace structure, to removal of carbon.

On this hypothesis, in the case of the complete decarburisation, a final slag is originated as under:—

From each 1 per cent. Si in the charge (from formulae 30 and 40) $2{\cdot}14 \times 4{\cdot}78 = 10{\cdot}23$ per cent. . . . (42) and from each 1 per cent. P (from 38) 5·9 per cent. In consequence of the carbon content of the metal there originates (if from the furnace structure according to (30) there is a total of 0·45 per cent. SiO_2 in the slag) $0{\cdot}45 \times 4{\cdot}78 = 2{\cdot}15$ per cent. . . . (43).

Finally, from each unit of weight of SiO_2 which independently reaches the slag, there is, according to (40), 4·78 per cent. of final slag . . . (43A).

The manganese content of the charge does not require to be taken into consideration in the calculation of the quantity of slag, since the manganese protoxide originated from it is already contained in the silicate slag.

(*h.*) CHARGE SHRINKAGE.

The removal of the reducing agents from iron causes naturally a diminution of the weight of metal, or charge shrinkage. The extent of this is, however, not simply equal to the amount of the reducing agents eliminated, but these are accompanied by such quantities of iron as go into the slag in combination with oxygen. The iron oxides in the slag can, of course, partly come from the auxiliary materials, for example, the hearth, but the quantities of iron from these sources are often extremely small, and it appears more useful to regard them in calculations as completely derived from the metallic charge.

From this it is indicated that the quantity of slag is dependent on the kind of reducing agents employed, and, therefore, admits shrinkage being brought into relation with these agents. Were it assumed in the calculation of the quantity of slag that the carbon content in the metal, in consequence of the wear of the furnace structure, yielded 2·15 per cent. slag, it is now further known that this slag must contain 10 per cent. of iron, which thus is $2{\cdot}15 \times 0{\cdot}1 = 0{\cdot}2$ per cent. taken on the metallic weight. The loss which originates owing to the elimination of the carbon content is, therefore $= C + 0{\cdot}2$ per cent. . . . (44). A silicon content of 1 per cent. yields from (42) 10·23 per cent. final slag, in which the Fe is 10 per cent.=about 1·0 per cent. on the charge, and thus loss which must result owing to an impurity of 1 per cent. Si must amount to 1 per cent. Si + 1 per cent. Fe = 2 per cent. . . . (45).

A silica content of the charge, or of the excess materials added, gives rise for each kilogramme of SiO_2 according to (40) to an amount of slag of 4·78 kilogrammes; this contains

$4 \cdot 78 \times 0 \cdot 1 =$ about 0·5 kilogramme Fe; and an amount of silica of 1 per cent. on the weight of charge derived from all auxiliary materials, in addition to the wear of the furnace structure, is thus the cause of a furthur iron loss of 0·5 per cent. of iron . . . (45A).

The loss of charge which is produced owing to the agents Mn and P is equal to the amounts of these materials eliminated, since according to the method of calculation adopted, the resulting quantities of slags do not contain iron. (The manganese protoxide is calculated as silicate slag, and the phosphate of lime is assumed to be dissolved in the silicate slag.)

(*i*.) The Result of the Chemical Action of the Flame.

The chemical action of the furnace gases manifests itself in the transfer of oxygen to the metallic charge. The primary action is scale formation, which in turn gives rise to slag formation; the oxides in the slag act now, under the influence of the heat liberated by the furnace gases, on the reducing agents in the metal, whereby the composition of the metal as well as that of the slag is changed.

If, however, the composition of the materials charged and of the finished metal, and the composition of the final slag are known, so the means are given of measuring the oxidising action of the flame.

The amount of oxygen liberated by the flame is contained in the oxidation products of the agents attacked. From the loss of Si, P, Mn and C by the metal, one can ascertain by use of the values given by (32) to (35) the quantities of oxygen which have been absorbed by these agents; whilst the balance is present in the amount of ferrous oxide, which is contained in the final slag.

The oxidising action of the furnace gases is naturally very varied; nevertheless one can in general assert that most of the large furnaces at present employed are able by means of the oxidising action alone, to work charges of steel, which consist of about 30 per cent. pig iron of a composition of about 4 per cent. C, 2 per cent. Mn, 1 per cent. Si, 0·5 per cent. P and 70 per cent. scrap. The mean composition of such a charge is about as follows:—

30 kg. Pig Iron with	1·2 kg. C	+0·3 kg. Si	+0·60 kg. Mn	+0·15 kg. P
70 ,, Scrap ,,	0·07 ,, C	+	+0·35 ,, Mn	+0·07 ,, P
100 kg. Charge	1·27 kg. C	+0·3 kg. Si	+0·95 ,, Mn	+0·22 kg. P
Contained in final metal	0·10 ,, C		+0·30 ,, Mn	+0·05 ,, P
Thus have been eliminated	1·17 kg. C	+0·3 kg. Si	+0·65 kg. Mn	+0·17 kg. P

The amounts of oxygen required for elimination of the above are:—

1·17 kilogrammes	$C \times 1 \cdot 33$	(from 35)	$=1 \cdot 54$	per cent.	O
0·30 ,,	$Si \times 1 \cdot 14$	(,, 32)	$=0 \cdot 34$	,,	O
0·65 ,,	$Mn \times 0 \cdot 29$	(,, 34)	$=0 \cdot 19$	,,	O
0·17 ,,	$P \times 1 \cdot 29$	(,, 33)	$=0 \cdot 22$	,,	O
		Total	2·29	per cent.	O

For the estimation of the oxygen combined with iron and remaining in the slag, the weight of the slag must be fixed. Let it be assumed that the charge is contaminated with 1 per cent. of sand. The amounts of phosphoric acid and silica which must go into the slag can be estimated as follows:—

	P_2O_5	SiO_2
From charge .	$0 \cdot 17 \times 2 \cdot 29 = 0 \cdot 39$ per cent.	$0 \cdot 3 \times 2 \cdot 14 = 0 \cdot 64$ per cent.
,, sand in charge		1·00 ,,
,, furnace structure (from 30c)		0·45 ,,
Total	P_2O_5 0·39 per cent.	SiO_2 2·09 per cent.

Lime required is ascertained thus:—

$0 \cdot 39\ P_2O_5 \times 1 \cdot 58 = 0 \cdot 62$ per cent. CaO.
$2 \cdot 09\ SiO_2 \times 2 \cdot 33 = 4 \cdot 87$,,
Total 5·49 per cent. CaO

Of which there will come from the basic structure

(*vide* 31A) 4·45 per cent.
Leaving 1·04 per cent. CaO

which must be added in the form of $2 \times 1 \cdot 04 = 2 \cdot 08$ per cent. limestone (*vide* 31B).

This limestone brings again 2 per cent. SiO_2 or $2 \cdot 08 \times 0 \cdot 02 = 0 \cdot 04$ per cent. SiO_2 into the slag, so that there is present a total of $2 \cdot 09 + 0 \cdot 04 = 2 \cdot 13$ per cent. SiO_2.

Herefrom the quantity of slag may be ascertained thus:—

Hypothetical silicate slag (*vide* 40)	2·13×4·78=10·18 per cent.
Phosphate slag (*vide* 35)	0·39×2·58= 1·00 ,,
Total slag (on weight of charge)	11·18 per cent.

A good final slag should (*vide* 37) contain 10 per cent. iron; thus in the final slag under consideration, there must be contained 1·118 per cent. Fe, with which there must be combined (*vide* 36) 1·118×0·29=0·32 per cent. O (taken on weight of charge).

Thus the total amount of oxygen given up by the furnace gases is

In eliminating impurities . . .	2·29 per cent.
In oxidation of iron itself . . .	0·32 ,,
Total (based on weight of charge) .	2·61 per cent.

One sees that the furnace action is quite considerable. Of the same 2·29 per cent., or 88 per cent. of the total action of the furnace gases, is devoted to changing the composition of the metal, and only 0·29 per cent., or 12 per cent. of the total action, was not used for the essentially refining process. If one takes the "chargedure" as abscissa, and the amounts of oxygen taken up as ordinates in a system of co-ordinates, one obtains the diagram below:—

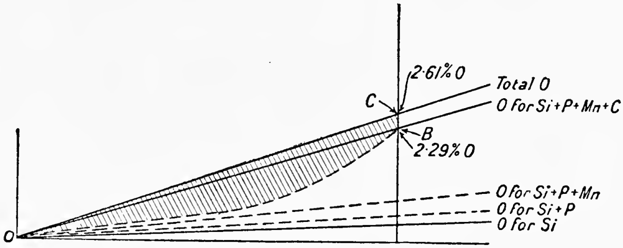

FIG. 11.

The upper line *OC* gives the total amount of oxygen transferred, whilst the under line *OB* shows how much oxygen has been brought into use in changing the composition of the metal. The latter line will actually probably have taken the course of the dotted line. From the space between the lines *OC* and *OB* one can derive the amounts of oxygen which at each moment have been contained in the slag. The values are not quite exact, because the changes which the weight of the metal has undergone during the process have not been taken into account. The same is, however, very small and cannot essentially influence the result.

An example, from which the oxidising action of the furnace is apparent for a special case, is cited in "Stahl und Eisen," 1905, p. 1338, as follows :—

HEAT 3215.

				Per cent.		Per cent.		Per cent.		Per cent.
Charge,	6,560 kilogrammes	pig	iron	3·44 C	+	2·66 Si.	+	0 07 P	+	0·78 Mn
,,	13,120 ,,	scrap	,,	0·09 C	+	—	+	0·03 P	+	0·50 Mn

Time test taken. Charging from.	Minutes from commencement of charging.	Metal.				Slag.						Remarks.
		C. Per cent.	Si. Per cent.	P. Per cent.	Mn. Per cent.	Fe. Per cent.	Mn. Per cent.	SiO_2. Per cent.	Al_2O_3. Per cent.	CaO. Per cent.	Mg.O. Per cent.	
6·0 to 8·0		1·2	0·89	0 04	0·59	—	—	—	—	—	—	Calculated.
9·40		0·17	—	0·01	0·20	—	—	—	—	—	—	Seedy boil.
10·0	240	0·09	—	0·91	0·25	9·23	8 56	28·00	2·25	37·89	6·48	After test addition of 160 kilogrammes 16 per cent. spiegel and 32 kilogrammes 80 per cent. ferro-manganese.
10·20		0·08	—	0·01	0·65	7·52	9·46	24·70	4·66	38·83	8·29	After addition of 160 kilogrammes FeMn.
10·37	277	0·07	—	0·02	0·60	7·39	12·01	22·50	5·89	37·25	8·24	Test of Finished Steel.

The furnace action for the melting down period, as well as for the finishing period, admits of being calculated from this example; taking into consideration the quantities of slag for the intermediate stages,[1] it shows that oxygen was transferred from the flame gases which, calculated from commencement of charging to end of melting down period, amounted to 2·61 per cent. for changes wrought in the steel and to 0·22 per cent. for the production of FeO in the slag, *i.e.*, to a total of 2·83 per cent. O, whilst for the entire heat 2·86 per cent. was required for the metal and 0·22 per cent. for the slag, or a total of 3·11 per cent. The figures yield the following diagram.

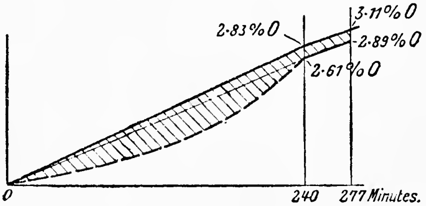

FIG. 12.

From this one sees that oxidising action of the flame during the fusion period is more powerful than on already fused metal. An example of the action of the flame on molten metal containing large amounts of reducing agents is given from the same source (p. 1339).

CHARGE 846.—Charge 19,705 kilogrammes molten pig-iron, heated without additions in the furnace.

Time Test taken.	Minutes from start.	Metal.				Slag.					Remarks.
		C.	Si.	P.	Mn.	Fe.	FeO.	Mn.	P_2O_5.	SiO_2.	
12·35 12·53	Charged	4·44	1·10	0·15	2·03	—	—	—	—	—	Pig-iron from both ladles.
1·5		—	0·65	0·15	2·10	6·04	7·76	8·20	0·87	30·95	Bath quiet. Light slag covering.
1·20		—	0·65	0·15	2·20	2·49	3 20	4·26	0·43	38·18	Reaction moderate.
1·40		—	0·65	0·15	2·24	1·66	2·13	2·61	0·23	39·34	Bath warm.
2·0		—	0·63	0·13	2·34	1·54	1·98	1·81	0·11	39·76	,, ,,
2·20	105	3·87	0·56	0·14	2·38	1·19	1·53	1·46	0·04	38·60	,, hot.

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[1] Herein the using up of furnace structure has been taken correspondingly to the "chargedure" as an addition of silica of 1·2 kilogramme per minute.

Here the quantity of oxygen amounted to 1·28 per cent. for the changes in the metal, and to 0·02 per cent. for the iron in the slag, or to a total of 1·30 per cent.

There was evidently some slag remaining in the furnace from the previous charge. One sees that the oxygen content of the slag had been considerably lowered and that iron and manganese had been reduced from it.

The covering of the oxygen requirements of the reducing agents in the iron, and metallic oxides in the slag by the gases forming the flame, is still more clearly perceptible in the example given by F. W. Harbord, at Bilston, which has been already referred to.

As no working data are given as to this furnace, the quantity of the slag may be approximately estimated from its phosphorus content and that of the charge, as follows:—

	When melted.		Four hours after melting down.	
		Per cent.		Per cent.
P eliminated . . .		1·08		2·184
P_2O_5 due thereto	$1·08 \times 2·29 =$	2·47	$2·114 \times 2·29 =$	4·851
P_2O_5 per cent. in slag .		12·5		16·19
Weight of slag	$\frac{247}{12·5} =$ about 20		$\frac{485·1}{16·19} =$ about 31	

If we assume that this increase of slag from 20 per cent. when charge melted down, to 30 per cent. in the course of four hours thereafter took place at uniform rate, we can calculate the quantities of slag and oxygen combined with iron therein for the intermediate periods. The values derived in this manner are added to the table taken from Mr. Harbord's paper, and are used in setting out the diagram Fig. 13.

As the iron content of the slag is small, the faults which originate from the method of calculation can scarcely be so large as to efface the character of the phenomena.

Such small furnaces are seldom employed nowadays, likewise such very impure charges are worked by other methods. Apparently, on this occasion, the furnace had furnished an amount of oxygen equal to some 8·17 per cent. of the weight of the charge, the major portion, *i.e.*, 5·80 per cent. being in the four hours' duration of melting down, whilst in the further four hours only 2·37 per cent. oxygen was introduced into the bath by action on the molten metal. It further shows (as was apparent in the large furnace) that the reducing agents in the metal, beginning with final melting down, and continuing up to a certain limit, possess the faculty of using up more

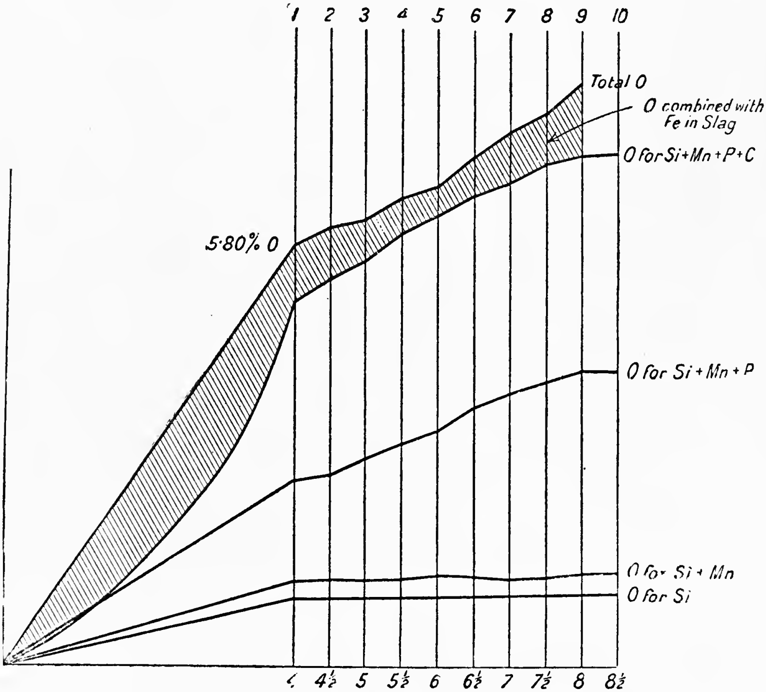

FIG. 13.

oxygen than is introduced by the working of the furnace They removed this oxygen from the slag which, up to the end of the two hours after melting down, became poorer in oxygen. At this time the carbon content of the metal reached 0·075 and the phosphorus content 0·70 per cent., whilst the Fe content of the slag still only amounted to 5·47 per cent. From this it is manifest that a state of equilibrium was attained, since from this period onwards the carbon content

EXPERIMENT WITH 5-TON BATHO FURNACE AT BILSTON.

F. W. HARBORD, *Journal Iron and Steel Institute*, Vol. II., 1886, pp. 701, 704.

		Before Melting. —	When Melted. 1	½ hour. 2	1 hour. 3	1½ hours. 4	2 hours. 5	2½ hours. 6	3 hours. 7	3½ hours. 8	4 hours. 9	4½ hours. 10	After re-carburising.
Metal.	C	2·300	0·42	0·23	0·178	0·094	0·075	0·070	0·060	0·050	0·045	0·050	0·13
	Si	0·87	0·06	0·070	0·070	0·050	0 040	0·050	0·050	0·045	0·025	0·010	trace
	P	2·300	1·22	1·180	1·000	0·840	0 700	0·480	0·330	0·192	0·116	0·085	0·065
	Mn	0·96	0·08	0·060	0·088	0·062	0·064	0·060	0·085	0·065	0·080	0·050	0·51
	S	0·23	0·23	0·213	0·206	0·183	0·170	0·165	0·157	0·160	0·137	0·130	0·125
Slag	SiO_2	—	22·90	—	—	—	—	—	—	—	17·20	—	—
	Fe_2O_3 *	—	1·17	1·03	1·85	1·90	1·23	1·75	2·20	1·40	2·31	—	—
	FeO *	—	14·90	10·40	7·20	5·94	5·91	6·61	9·09	9·91	13·30	—	—
	Al_2O_3	—	14·20	—	—	—	—	—	—	—	12·20	—	—
	MnO	—	3·69	—	—	—	—	—	—	—	2·64	—	—
	CaO	—	28·00	—	—	—	—	—	—	—	33·60	—	—
	MgO	—	1·70	—	—	—	—	—	—	—	2·27	—	—
	P_2O_5	—	12·50	—	—	—	—	—	—	—	16·19	—	—
	Fe *	—	12·40	8·81	6·89	5·95	5·46	6·37	8·61	8·69	11·96	—	—
Quantity of slag per cent.		—	20·00	21·37	22·75	24·12	25·5	26·87	28·25	29·62	31·00	—	—
O combined with Fe in slag per cent.		—	0·73	0·66	0·49	0·45	0·43	0 53	0·76	0·78	1·13	—	—
O per cent. producing change in metal		—	5·07	5·37	5·67	6·00	6·23	6·53	6·70	6·92	7·04	—	—
Total O from Flame		—	5·80	6·03	6·16	6·45	6·66	7·06	7·46	7·70	8·17	—	—

* Charge, 67 per cent. pig, 30 per cent. scrap, and 3 per cent. spiegeleisen.

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[1] The translator noticed some discrepancies between the figures for total Fe and the oxides thereof, and on comparing these with the figures given in "Stahl und Eisen" and Mr. Harbord's original paper, he communicated with that gentleman. Mr. Harbord went into the matter and found that in some inexplicable manner the figures in the bottom column of the tables had been altered by the printers after the final proof had been passed, and Mr. Harbord has now furnished the translator with corrected figures. The errors, which were small, only apply to the equivalent of metallic iron present in the form of oxides in the slag, and consequently do not affect the value of the argument deduced from the oxides present or the purposes for which the tables are quoted, as one of the very earliest and most interesting investigations of the basic open-hearth process.

of the metal did not perceptibly decrease. The iron content of the slag, however, considerably increased.

One sees that carbon exercises its reducing power up to what may be regarded as its complete elimination from the iron, and that it is the most powerful of all the reducing agents present, whilst phosphorus itself, in amounts of 0·7 per cent., is not able to hinder an increased oxidation of iron, which is apparent in the rise of the Fe content of the slag.

The preceding example shows further (equally with charge 846 in the large furnace) how slowly the elimination of large amounts of reducing agents results from the oxidising action of the furnace alone. In order to remove 0·7 per cent. of P, two hours' furnace working were necessary.

The oxidising action of the flame is, on the one hand, the cause that one must add reducing agents to the charge; on the other hand, however, the slowness with which the furnace action removes an excess of these reducing agents is a ground for the adaptation of the composition of the charge exactly to the oxidising action of the furnace gases, if one wishes to avoid loss of time, and to obtain the largest output from a given plant. For a long time, therefore, a pride was taken in fixing the charges accordingly to take the most direct possible course.

CHAPTER XIX

THE HEAT WORK IN OPEN-HEARTH FURNACES

(*a*) THE ABSOLUTE HEAT CONTENT OF STEEL AND SLAG.

THE materials are generally brought cold into the furnace. They must be heated to their melting point, melted down, and be brought to the temperature which permits of clean casting of the finished product. The definition of the absolute quantities of heat necessary therefor is quite a complicated problem, the solution of which, however, must be investigated, since only by figures is the possibility presented to appraise the influence of the different factors on the course of the open-hearth process.

The industry has had placed at its disposal apparatuses which permit of ascertainment with sufficient exactitude of all the temperatures coming into question. Thereby the temperature of castable steel has been fixed at 1,465—1,585° C., and 1,780—1,788° has been found to be the highest attainable temperature of the flame in open-hearth furnaces. But in order to be able to ascertain from these temperatures the absolute heat content which the substances possess at known temperatures, their specific heats must be known, and here our knowledge exhibits great deficiency. Dipl. Eng. P. Oberhoffer ("Metallurgie," 1907, p. 495) has ascertained the specific heat of pure iron at high temperatures (the metal investigated contained 0·06 per cent. C, 0·005 per cent. P, 0·019 per cent. S, and 0·05 per cent. Mn), and found that it is constant between 750° and 1,500° and amounted to 0·1667. A kilogramme of this iron has thus, at a temperature of 1,500° (at which steel is easily cast), a heat content of 250 calories. The metal investigated, however, was still in the solid condition, but would at this temperature go over into the fluid condition, so this heat content must be increased by the latent heat, of fusion, which according to Wedding amounts to

25—30 calories, but according to H. H. Campbell amounts to 69 calories. The heat content of molten iron at 1,500° would thus amount to 275—280, or correspondingly 310 calories.

Practically, however, such a pure iron is not manufactured and, therefore, also the above values (having regard to the great difference which is caused by the questionable latent heats) do not appear quite usable.

But at various times it has been sought to ascertain the values experimentally, and Professors F. Wüst and L. Laval found from the increase of temperature which weighed quantities of water underwent, from ascertained amounts of molten materials, that the heat content of—

1 kilogramme molten pig iron amounted to a mean of 277 calories
1 ,, ,, steel ,, ,, ,, 336 ,,
1 ,, ,, slag ,, ,, ,, 536 ,,

Wedding furnishes values for pig iron which are ascertained in similar manner and varied between 258 and 337 calories.

In January, 1902, and later, the author conducted some similar experiments, the mention of which will possibly possess some interest, because we can perceive therefrom that the discrepancies in preliminary researches are able to be very small; but in spite of this the results make no pretension to any kind of absolute exactitude whatever, because the thermometer is inexact and the method generally could not be further worked out. Wooden buckets were used for the reception of the water, and indeed these were chosen because the metal under research in consequence of the Leidenfrostschen phenomenon remains at a white heat for a time under water, and buckets of other materials would be destroyed, whilst wood was only slightly singed; but owing to this, as well as to the quite powerful decomposition of the water, which allows a quantity of gas to originate, sources of error are introduced, which could not be further investigated. Indeed, a research was made as to the gas, which consisted of

78·5 per cent. H, 1·1 per cent. CO_2, 9·6 per cent. CO, and 9·5 per cent. N,

but its amount could not be ascertained, since the apparatus failed and the experiments could not be further pursued.

The following series of experiments had the object of fixing the increase of temperature, which molten pig iron undergoes during its change into steel. The tests were taken from the furnace with the test spoon, and poured into the water, the quantity of water employed amounting to nine litres. The weight of the metal poured in varied between 144 and 160 grammes. Two to three parallel experiments were made for all determinations.

Carbon—Content of Metal.	Test I.	Test II.	Test III.	Mean.
	Cals.	Cals.	Cals.	Cals.
(*a*) 4·28 per cent. Ladle I . .	270	271	—	270·5
(*b*) 4·28 ,, Ladle II . .	251	253	—	252
(*c*) 3·44 ,, from furnace .	259	255	279	264
(*d*) 2·68 ,, ,, .	269	272	267	269
(*e*) 2·04 ,, ,, .	272	275	277	275
(*f*) 1·57 ,, ,, .	281	275	283	280
(*g*) 0·73 ,, ,, .	279	278	275	277
(*h*) 0·30 ,, ,, .	293	298	288	290
(*i*) 0·08 ,, ,, .	295	291	291	292

The agreement is really good, if one disregards the results of the Test III., in series *c* and *h*. One sees also clearly the growth of the heat content with diminishing carbon content. Between *f* and *g* there had been made an addition of ore which has as a consequence the fall of the heat content of the series *g*. Other tests which, during the casting of the finished steel in the moulds, were directly cast from the casting ladle into the water buckets (in which case the quantities of water amounted to 39 litres) gave results as under:—

First Series.

	Water Bucket I.	Water Bucket II.
Quantity of water employed	39 litres.	39 litres.
Temperature at end of experiment . .	31·1° C.	31·0° C.
Temperature before the experiment . .	19·2° C.	19·8° C.
Increase of temperature	11·9° C.	11·2° C.
Quantity of metal used	1.527 g.	1,435 g.
Corresponding cals. per kg. steel . .	303·9 cals.	304·4 cals.

SECOND SERIES.

	Water Bucket I.	Water Bucket II.
Quantity of water employed	39 litres.	39 litres.
Temperature at end of experiment	26·4° C.	33·5° C.
Temperature before the experiment	17·8° C.	17·6° C.
Increase of temperature	8·6° C.	15·9° C.
Quantity of metal used	1,064 g.	2,072 g.
Corresponding cals. per kg. steel	315 cals.	299 cals.

In this later experiment, the temperature of the metal streaming into the moulds was ascertained by Wanner's pyrometer to be 1,465° C. The metal was "ingot iron" and cast well, in spite of the relatively low temperature.

The slag floating on the metal had a higher specific heat and, therefore, at an equal temperature, a higher heat content per unit of weight. Professor Wedding gives the specific heat of ingot iron in the molten state as being 0·207 and to the slag belonging to it 0·33, wherefrom it follows that the heat content of the latter is equal to 1·59 times that of the metal. The author found it in the experiments quoted 1·41, 1·56 and 1·52, wherefrom as a mean one can take 1·5 times as approximately correct. Professor B. Neumann calculates on 400 to 500 calories; Stassano 600 calories; Professor Wüst found, as above quoted, 536 calories.

On the basis of the before-going materials, it may be well assumed that one will not use too low values if one fixes the heat contents of the following as under :—

1 kg. molten pig iron, not overheated,	250 cals.	. . .	(46)
1 ,, slag from same ,, ,,	375 ,,	. . .	(47)
1 ,, castable steel	350 ,,	. . .	(48)
1 ,, slag from same	525 ,,	. . .	(49)

(b) INFLUENCE OF THE IMPURITIES IN THE IRON ON THE HEAT REQUIRED IN THE PRODUCTION OF STEEL.

The demands which are established on the output of heat of the furnace admit of being ascertained from the sum of the heat contents of all products which issue from the furnace, if one deducts the sum of the heat contents of all materials brought into the furnace, and in addition takes into account all energy changes, by which the reactions taking place during the course of the process are accompanied.

The main products are steel and slag, which carry away from the furnace on tapping 350 and 525 calories per kilogramme respectively. But in addition, by-products make their appearance namely carbon dioxide from the decomposed limestone (if this material is used as an addition), and carbon monoxide gas from the eliminated carbon content. The quantities of heat carried away from these materials are dependent on the temperature at which the respective reactions proceed.

The limestone will be completely decomposed already by about 1,200°. The carbonic acid set free possesses at this temperature a heat content of about $1{,}200 \times 0{\cdot}3475 = 418$ calories per kilogramme, and since the limestone which is employed contains about 98 per cent. $CaCO_3$, there is contained in the same about 0·43 kilogramme CO_2. The carbonic acid from 1 kilogramme limestone carries off therefore

$$418 \times 0{\cdot}43 = \backsim 180 \text{ calories} \quad . \quad . \quad . \quad (50)$$

The elimination of the carbon from the iron begins at the moment at which the metal is melted down and continues up to the end of the "heat." It occurs, therefore, between temperature limits of approximately 1,200—1,600°, and thus takes place at a mean temperature of approximately 1,400° C. From this 1 kilogramme CO possesses a heat content of $1{,}200 \times 0{\cdot}2849 = 342$ calories, and since 1 kilogramme C gives rise to 2·33 kilogrammes CO, so the carbon monoxide from 1 kilogramme C removes from the furnace $2{\cdot}33 \times 342 =$ about 800 calories. . . . (51).

The carbonic acid issuing from the bath and the carbon monoxide are forthwith brought to high temperature by the flame gases; the carbon monoxide is burnt thereby and the heat developed comes to the bath profitably, in the same way as the heat from the flame of the producer gas. The issuing gases further go through the chambers and leave behind in the same a portion of their available heat, of which later a portion is again made useful. Since the last-named portion nevertheless does not admit of being exactly determined, let the combustible value of the carbon monoxide as well as the utilisable available heat of both gases be neglected, and let it be taken that there are removed from the furnace

By the carbonic acid from 1 kilogramme limestone, 180 calories . (50)
,, carbon monoxide from 1 kilogramme C . 800 ,, . (51)

Further, let it be assumed that the entire materials are put into the furnace at a temperature of 0°, thereby fixing the first two starting points for the heat balance-sheet.

The determination of the energy changes accompanying the reactions presents great difficulties, and one can only obtain approximate values, since the bases at hand are still very unreliable.

In the decomposition of limestone heat is absorbed, and this amounts per unit limestone to 425 calories . . . (52).

Then the materials, Si, Mn, P and C must be set free from their combination with iron, whereby likewise heat is absorbed. According to E. D. Campbell (*Journal I.S.I.*, May, 1901) there is necessary for this per kilogramme C, 705 calories; for 1 kilogramme Si, 931 calories; for P and Mn there appear to be no data at hand. One cannot disregard these, and it appears thus to answer the purpose also to neglect the heat of combination of carbon and Si with iron.

Further, the reducing agents and likewise iron become oxidised, and hereby quite considerable quantities of heat are set free.

						Calories.	
1 kilogramme	Si	gives on its	oxidisation	to		$SiO_2[+7,830]$	
1	,,	P	,,	,,	,,	$P_2O_5[+5,965]$	
1	,,	Mn	,,	,,	,,	$MnO[+1,784]$	
1	,,	C	,,	,,	,,	$CO[+2,387]$	
1	,,	Fe	,,	,,	,,	$FeO[+1,350]$	. . (53)

Finally, the resulting products of oxidisation go into combination, whereby again heat is developed. For these there has been given:

1 kilogramme SiO_2 with FeO to form $FeSiO_3$ (F. Fischer, St. u. E., 1903, p. 75)=583 calories ($FeO+SiO_2=FeSiO_3+[35]$ calories).

Against this, Pawloff (Communications to the St. Petersburg Polytechnic Institute, 1906, Vol. VI.) gives the formula

$$FeO+SiO_2=FeSiO_3\ [+\ 10{\cdot}08\ \text{calories}].$$

Whereby for 1 kilogramme SiO_2, only 168 calories would be set free.

Further, one obtains, according to Pawloff (*ibid.*),

For 1 kilogramme	SiO_2	with CaO	to form	SiO_3Ca	254 calories . .	(54)
,, 1 ,,	SiO_2	,, MnO	,,	$(MnO)_3(SiO_2)_2$	134 calories	(55)
,, 1 ,,	SiO_2	,, CaO	,,	SiO_4Ca_2	384 ,, ,,	(56)
,, 1 ,,	P_2O_5	,, CaO	,,	$P_2O_9Ca_4$	1,131 ,,	

For the foregoing object, only the final slag will come into consideration in which silicic and phosphoric acids are regarded as combined with the lime, and therefore heats of combination will be settled as under:

1 kilogramme	SiO_2	with lime at 384 calories . . .	(56)
1 ,,	P_2O_5	,, ,, 1,131 ,, . . .	(57)

1. *Influence of Silicon on the Heat Requirement.*

Were it possible to produce in the open-hearth furnace pure iron from a charge which contained 99 kilogrammes iron and 1 kilogramme Si, so there would be 2 per cent. loss of charge (*vide* 43), and thus there would be obtained 98 kilogrammes iron, and from (42) 10·23 kilogrammes final slag. For satisfying the silica from 1 kilogramme Si, there would be necessary $2{\cdot}14 \times 2{\cdot}33 = 5$ kilogrammes CaO or 10 kilogrammes limestone (from formulæ (32) and (41).

The quantity of heat which would be derived from the furnace by the entire products would thus be

		Calories.
98 kilogrammes steel × 350 calories (from 48) . .		34,300
10·23 ,, slag × 525 ,, (from 49) . .		5,370
Carbonic acid set free from 10 kilogrammes limestone 10 × 180 calories (from 50)		1,800
Total heat in products		41,470
Setting free Si from Fe		unknown
Decomposition of limestone 10 × 425 from (52) . .		4,250
Total heat requirement		45,720
Against this there would be developed by the reaction: 1 kilogramme Si yielding (from 53)	7,830 calories	
On combination of 2·14 SiO_2 with lime there would be set free $2{\cdot}14 \times 384$ (from 56) $=$	822 calories	
1 kilogramme Fe would be burnt liberating	1,353 ,,	
	10,005 calories	10,005
Balance to be supplied by furnace		35,715

Thus the heat requirement for the production of 1 kilogramme steel would be $\frac{35,715}{98} = 365$ calories.

Since 1 kilogramme molten steel possesses a heat content of 350 calories, there is effected by an impurity of 1 per cent. Si in the charge an increase of heat requirement of 15 calories . . . (58).

2. *Influence of Silica from Impurity of the Metallic Charge and Additions.*

Could one produce a charge of steel from a charge of 99 kilogrammes pure iron and 1 kilogramme silica, so there would originate from the latter (from 40) 4·78 kilogrammes slag, in which would be contained 0·5 kilogramme iron. One would then obtain 98·5 kilogrammes metal, and from (41), 2·33 kilogrammes CaO or 4·66 kilogrammes limestone must be utilised in the formation of slag.

The products therefore take up heat as under:

		Cals.
98·5 kilogrammes steel × 350 . . . . . . =		34,475
4·78 kilogrammes slag × 525 . . . . . . =		2,509
Carbonic acid from the limestone		839
Total heat in the products . .		37,823
Decomposition of limestone requires . . .		1,980
Total heat requirement . . .		39,803
Heat set free:		
Combination of 1 kilogramme SiO_2 with CaO	384 cals.	
Combustion of 0·5 kilogramme Fe=1,351×0·5 . . . . =	676 ,,	
	1,060 ,,	1,060
Thus heat requirement . . . . =		38,743
Or 393 calories per kilogramme of steel.		

One per cent. silica in the charge thus increases the heat demand for the production of 1 kilogramme steel by 393—350 = 43 calories . . . (59).

3. *Influence of Phosphorus.*

From a charge consisting of 99 kilogrammes iron and 1 kilogramme phosphorus, there must (from 38 and p. 187) originate 99 kilogrammes steel and 5·9 kilogrammes slag, and further the charge would require 2 × 3·61 = 7·22 kilogrammes limestone (*vide* 38).

The available heat of the products is as follows:—

		Cals.
99 kilogrammes of steel × 350	=	34,650
5·9 kilogrammes slag × 525	=	3,097
CO_2 from 7·22 kilogrammes limestone 7·22 × 180 .	=	1,300
Total heat in products . . .		39,047
The heat demand of the reactions is:		
(Separation of P from Fe not taken into account) .		n. t.
Decomposition of limestone 7·22 × 425	=	3,068
Total heat requirement . . .		42,115

		Cals.
Against this heat liberated by reactions:		
From 1 kilogramme P yielding P_2O_5	5,965 cals.	
2·29 kilogrammes P_2O_5 on combination with CaO, 2·29 × 1,131 (from 57) . . . . =	2,590 ,,	
	8,555	8,555
Thus furnace must supply . . .		33,560

Or per kilogramme steel $\frac{33,560}{99}$=339 cals.

One per cent. P in the charge thus diminishes the heat demand for the production of 1 kilogramme steel by 350—339 = 11 calories . . . (60).

4. *Influence of Manganese.*

From a charge of 99 kilogrammes iron and 1 kilogramme Mn is produced (*vide* pp. 186 and 187) 99 kilogrammes steel. For the foregoing calculation, slag does not come into account. In reality SiO_2 and carbon are always present, and the manganese protoxide produced from the manganese is received by the slag, which is stipulated for by the substance, named.

The heat content of the products is:

		Cals.
99 kilogrammes steel × 350	=	34,650
The heat of union of Mn with Fe is unknown.		
Thus the heat demand is		34,650
Of which the combustion of 1 kilogramme Mn liberates		1,724
Thus furnace must furnish . . .		32,926

Or per kilogramme steel $\frac{32,926}{99}$=333 cals.

One per cent. Mn in the charge thus diminishes the heat demand for the production of 1 kilogramme steel by 350—333 = 17 calories . . . (61).

5. *Influence of Carbon.*

The exact numerical determination of the influence of carbon on the heat requirement presents great difficulty, since the quantity of slag which proceeds from elimination of carbon and therewith also the loss of charge do not admit of being determined.

The figures found are herein based on the wear of the furnace, and the total carbon content is taken into account without regard to the effective amount. Actually the wear and tear of the furnace increases with the rise of carbon content. The values given for this wear and tear by the formulæ 30C, 30D and 31A are founded, however, on a carbon content of the charge of 4 per cent, and are thus able to be regarded as maximum values for charges regularly used.

If, therefore, from (43) the total carbon content, which now assume at 4 per cent., gives rise to 2·15 per cent. slag and 0·2 per cent. iron loss, so there will result due to 1 per cent. C, $\frac{2{\cdot}15}{4} = \backsim 0{\cdot}5$ per cent. slag with 0·05 per cent. Fe (always taken on the weight of the metallic charge).

According to this, from a charge of 99 kilogrammes Fe and 1 kilogramme C, one must obtain 98·95 kilogrammes metal and 0·5 kilogramme slag. For the production of the latter no limestone is necessary, since the base is derived from material of the bottom.

The available heat of the products is then:

98·95 kilogrammes steel × 350 . . . . . . =		34,632
0·5 kilogrammes slag × 525 . . . . . =		263
CO from 1 kilogramme C		800
Total heat of products . . .		35,695
By the reactions are liberated		
from 1 kilogramme C . .	2,387	
0·05 kilogramme Fe × 1,353 . =	67	
By combination of SiO_2 with CaO		
(from 56) $\frac{0{\cdot}45}{4} \times 384$ . . =	42	
	2,496	2,496
Therefore to be supplied by furnace . . .		33,199

Or per kilogramme steel $\frac{33{,}199}{98{\cdot}95} = 336$ calories.

One per cent. C in the charge thus diminishes the heat demand for the production of 1 kilogramme steel by 350 − 336 = 14 calories . . . (62).

Practically, the production of steel in open-hearth furnaces from charges of the composition considered is not possible, even if they appeared feasible for the last considered case of the pure iron-carbon alloy. But here also the auxiliary action of large amounts of silica is necessary, as under normal circumstances it will be supplied by the furnace structure, and therewith gives rise to slag in an amount which ensures an advantageous course of the process.

Nevertheless should the charge contain silicon, manganese and phosphorus, without carbon, so these reducing agents employed individually or collectively are not able to allow the carrying out of the process. In the metal, there must always be so much carbon present that a boil and a reaction throughout of the bath takes place. In practical working there are, therefore, always several of the five substances, if not all, simultaneously present in the charge, and therefore one obtains from the figures ascertained explanation of the influence of the composition of the materials employed on the process.

Silica increases the heat demand (1 per cent. SiO_2 by 43 calories per kilogramme steel); silicon (15 calories) acts likewise unfavourably. On the other hand, phosphorus (11 calories), manganese (17 calories) and carbon (14 calories) diminish the heat requirement a little and thereby act favourably, nevertheless only so long as their amount does not exceed the extent which is prescribed through the oxidising action of the flame.

CHAPTER XX

THE ENHANCEMENT OF THE OXIDISING ACTION OF THE FLAME

In practical working, it often appears impossible to avoid an excess of reducing agents in the charge, and in such cases the resultant lengthening of the "chargedure" makes itself felt in the most sensible manner. One is bound to look about for an aid which permits of the rapid performance of the elimination of the excess mentioned. The experiments, according to the example of the Bessemer process, of blowing air in or upon the impure metal, brought so many disadvantages that one was obliged to employ an alternative. There remained only the possibility of employing oxygen in the form of chemical compounds and this means (in the form of hammer slag, or natural iron ores) has been used since the earliest stages of the open-hearth process. One was, however, for a long time in the dark as to the action of such kinds of additions. The cause may well be sought in the assumption so generally circulated in a peculiar way, that the iron protoxide present in all final slags must owe its origin entirely to iron ore. Thereby is overlooked that flame action must always produce iron oxide and the slag cannot exist without it. In all determinations of the useful effect of iron oxide added, one always found them of varied and generally very small values. H. H. Campbell says as to this on p. 184 of his treatise:—

"This quantity (of iron ore necessary for conferring fluidity on a viscous slag) will be a constant under given conditions, no matter how much ore is afterwards needed, it might be 90 per cent. of a small addition and only 10 per cent. of a large one."

It is obvious that it appears more economical to create the iron content of the slag by means of cheap ore, instead of by combustion of the costly metallic charge. On this ground, iron ore additions are often made (also experimentally in

Bessemer converters), and H. H. Campbell remarks as to the acid open-hearth process (p. 14):—

" . . . Whenever iron ore is not added to the bath . . . it may be necessary for the slag to have more oxide of iron, and there is no place for this to come from except the bath. Therefore, when there is need of oxide of iron, the iron of the bath unites with the oxygen of the flame and goes into the slag. Therefore it is clear that if no iron ore is used, a certain equivalent amount of stock must be oxidised, and that if iron ore is used, the weight of the metal tapped will be greater than if it had not been added."

The same author explains the action of ore additions in the following manner: (p. 13) "If iron ore is added, this is the easiest way for the slag to get the oxide, since it simply appropriates it to its own use." (The peroxide ore is referred to.) He continues . . . "If the slag contains too high a percentage of silica and needs more iron oxide, and if under these conditions iron ore is added, then only one of these atoms of oxygen goes towards oxidising the silicon and carbon of the bath . . . and the rest of the oxide stays with the slag, and (the operation) may be expressed by the following simple chemical formula:—

$$Fe_2O_3 + C = 2FeO + CO."$$

This sort of mode of action of the ore additions has for a long time been regarded as the only one possible; it caused (since the entire FeO remained in the slag) the employment of ores in basic open-hearth furnaces also to appear as direct extravagance in valuable materials which could be utilised in the blast furnace with great advantage.

On this ground, one deemed the assistance of the oxidising action of the flame by means of iron ore additions as a necessary evil, and sought to suitably reduce it to the smallest possible extent. Later, one learnt, of course, that the utilisation nevertheless can be larger under the circumstances than would be stipulated through the course of the reactions according to the above equation, but as to the actual extent of the same, nevertheless, scarcely precise statements are placed before one. In his "Eisenhuttenkunde," 1908, Vol. III.,

p. 344, Ledebur says:—"With the amount of the added ore, the difficulty increases of preserving a durable furnace lining. . . . Only a part of their iron content is reduced from the ores, in all processes for the production of soft iron from ores; the other part goes into the slag; finally also the productive capacity of the furnace diminishes whilst the fuel consumption and the wages increase."

H. H. Campbell investigates the problem exhaustively and says (p. 14):—"Sometimes the slag has a sufficient supply of oxide of iron and needs no more. In this case, when ore is added, all the oxygen goes to the carbon of the bath so that there are three atoms of oxygen calling for three atoms of carbon. This leaves the iron alone in its metallic state and is instantly dissolved in the bath and the weight of the charge is just increased by so much. The chemical symbol expressing this is as follows:—$Fe_2O_3+3C=2Fe+3CO$. Generally it will happen that the truth lies between these two conditions; that the slag keeps part of the oxide and the rest is reduced, part of the oxygen uniting with the carbon and part of the iron being dissolved in the bath, the remainder of the oxide of iron entering the slag."

But how much is this balance which must remain in the slag? From the fact that the ferrous oxide is the active agent in the slag, which again cannot otherwise act on the reducing agents in the iron, as, if it does, it is itself thereby re-transformed, that further, thanks to the conditions naturally existing in the open-hearth process, owing to which iron oxide can be reduced to metal from the slag down to the point that the iron content of the latter has reached 10 per cent., it follows that if this necessary amount of 10 per cent. of iron is present in the slag, additions of iron are reduced and indeed must be completely reduced, as their amounts correspond to the amounts of the reducing agents present.

The reduction then can only be incomplete if also the necessary ferrous oxide content for the existence of the slag should be covered by the ore, or if the addition of ore is greater than corresponds to the amount of reducing agents present, or, lastly, if the ore contains impurities like silica, which create an increase in the quantity of slag, and therefore in the necessary quantity of ferrous oxide.

As a means of making the largest possible use of ore in the basic open-hearth furnace, that of correctly gauging the amount of the additions and freedom of the ore from slag-forming ingredients, especially silica, is indicated.

The extent of the oxygen demand from ore additions will be dependent upon the amount of the total oxygen demand of all the reducing agents in the metal, less that which is furnished by the oxidising action of the flame. The extent of the ore additions again is derived from the above oxygen demand, in addition to those amounts of iron which must remain in the slag.

The oxygen of the ore can naturally only be eliminated if the necessary heat is supplied, which is per kilogramme 0 as follows:—

For Fe_3O_4, 4,326 cals.
,, Fe_2O_3, 4,377 ,,
,, FeO, 4,662 ,,

If a charge contains reducing agents in such quantities that their elimination to the requisite degree requires 1 per cent. more oxygen than the furnace action is capable of supplying in the time which is required for the heating of the charge to the casting temperature, then the heat demand per 100 kilogrammes charge is increased to the extent of the above amounts, or approximately 43 to 46 calories per kilogramme steel. This is a really considerable growth of the already large heat demand, and it further serves as an explanation of the antipathy of steel makers to large ore additions.

On the other hand, however, proper utilisation of the oxygen of the ore brings about an increase in the yield of metal, owing to the reduction of the iron contained in the ore.

For each kilogramme of oxygen from the ore there can be won nearly

2·33 kg. Fe from Fe_2O_3 $\left(i.e.\ \frac{112}{48}\right)$
2·62 ,, Fe ,, Fe_3O_4 $\left(i.e.\ \frac{168}{64}\right)$
3·5 ,, Fe ,, FeO $\left(i.e.\ \frac{56}{16}\right)$

and in recent times due attention has begun to be devoted to this condition, since it can be of great influence on the manufacturing costs.

The foregoing remarks exhaust in principle the phenomena which are involved in the employment of oxygen from ores. The peculiarities in the reduction of iron ores, under the conditions ruling in the open-hearth furnace make, nevertheless, necessary a closer investigation of the details of the reactions taking place.

When compelled to resort mainly to regular employment of additions of ore, the requisite quantity of ore becomes so large that one is never in the position to cover it by means of the artificially produced oxides, such as hammer scale. One must always resort to natural iron ores. Further, since the greatest purity (especially freedom from silica) is a necessity, and this condition is usually fulfilled only by those iron ores which consist in the main of iron peroxide, in what follows iron peroxide Fe_2O_3 will be the subject of discussion as the reagent.

(*a*) Reactions Between Iron Peroxide and the Reducing Agents in Iron, and Iron Peroxide Requirement for Elimination of the Same.

1. *Iron Peroxide and Silicon.*

If iron peroxide acts on silicon in molten iron, the resultant silica, exactly as by the action of iron protoxide, takes up a portion of the reagent, and the reaction can take place according to the formulæ

(*a*) $Fe_2O_3+Si=SiO_3Fe+Fe.$
(*b*) $4Fe_2O_3+3Si=3SiO_4Fe_2+2Fe.$

then according to *b*

1 per cent. Si requires 7·62 per cent. Fe_2O_3 . . . (63).

2. *Iron Peroxide and Phosphorus.*

Phosphoric acid can only be formed if the conditions admit of its combining with FeO, and therefore the equation of the reaction must run thus :—

(*c*) $3Fe_2O_3+2P=P_2O_9Fe_4+2Fe$;
or (*d*) $8Fe_2O_3+6P=3(PO_4)_2Fe_3+7Fe.$

And according to *c* there would be required:

for 1 per cent. P, 7·80 per cent. Fe_2O_3 . . (64).

3. *Iron Peroxide and Manganese.*

Manganese usually requires no oxygen from Fe_2O_3, since it is capable of setting free the iron from the silicate and phosphate of iron formed from the silicon and phosphorus of the iron, as has already been shown on page 146. A chance excess of manganese must be eliminated according to the formula:—

(*e*) $Fe_2O_3+3Mn=3MnO+2Fe$, wherefrom
1 per cent. Mn requires 0·97 per cent. Fe_2O_3 . . (65).

4. *Iron Peroxide and Carbon.*

The estimation of the iron peroxide demand for carbon elimination is difficult, owing to Si, P and Mn being present in the iron simultaneously with and in addition to carbon, and they can likewise be attacked, and that iron and manganese protoxides which are present in the products of their elimination may be partly employed in the oxidation of the carbon. The amount of iron protoxide referred to is naturally dependent on the Si, P and Mn content of the metal, and therefore does not generally admit of being estimated. Nevertheless, an excess of carbon must be removed according to the formula:—

(*f*) $Fe_2O_3+3C=3CO+2Fe$, whence
1 per cent. C requires 4·44 per cent. Fe_2O_3 . . (66).

(*b*.) ENERGY CHANGES ACCOMPANYING THE ACTION OF IRON PEROXIDE ON THE REDUCING AGENTS IN IRON.

All chemical reactions are accompanied by energy changes, which are characteristic of their course. For knowledge of the events accompanying the action of iron peroxide on the reducing agents in iron it is, therefore, necessary to ascertain the energy changes accompanying them. In order to render this possible, the temperatures must be taken into account at which the action occurs, as also the specific heats of the reagents, and the products of the reactions as well as their

TABLE S.—ENERGY CHANGES DUE TO REACTIONS BETWEEN Fe_2O_3 AND REDUCING AGENTS IN IRON AT 1,300° C.

	1 Kg. Si.		1 Kg. P.		1 Kg. Mn.		1 Kg. C.	
Energy-content of reagent		Cals.		Cals.		Cals.		Cals.
1 kg. agent on combustion with O	—	7,830	—	5,965	—	1,724	—	2,387
1 kg. agent—available heat at 1,300°	0·20×1,300=	260	0·18×1,300=	234	0·20×1,300=	260	0·45×1,300=	585
Product of oxidation	2·14 kg. SiO_2		2·29 kg. P_2O_5		1·29 kg. MnO		2·33 kg. CO	
Heat of combination of ditto with FeO. (Note.—Fe_2O_3 taken at 0°)	2·14×168=	360	2·29×700= *Vide* below[1]	1,600	—		—	
Total energy content of reagent		8,450		7,799		1,984		2,972
Energy absorbed in reaction								
Reduction of Fe_2O_3 to Fe	$\frac{56}{28}=2$ kg. Fe		$\frac{56}{31}=1·81$ kg. Fe		$\frac{2\times56}{3\times55}=0·7$ kg. Fe		$\frac{112}{36}=3·11$ kg. Fe	
	2×1,796=	3,592	1·81×1,796=	3,251	0·7×1,796=	1,257	3·11×1,796=	5,585
Reduction of Fe_2O_3 to FeO	2×450=	900	2×1·81×450=	1,620	—		—	
Reaction product	$\frac{132}{28}=4·8$ kg. $FeSiO_3$		$\frac{430}{62}=7$ kg. $Ca_4P_2O_9$		$\frac{71}{55}=1·29$ kg. MnO		$\frac{28}{12}=2·33$ kg. CO	
							0·29×1,300×3·11= 3·11 kg. Fe	808
Heating reaction to 1,300°	0·33×1,300×4·8= *Vide* note[2]	2,059	0·33×1300×7=	3,003	0·2×1,300×1·29=	335	0·20×1,300×3·11=	808
	2 kg. Fe×325=	650	1·81 kg. Fe×325=	588	0·7 kg. Fe×325=	227		
Total energy absorbed		7,201		8,462		1,819		7,241
Energy change		+ 1,249		— 663		+ 165		— 4,269

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[1] Assumed to be 700 cals., since according to Pawloff 1 kg. P_2O_5 with MnO yielded 616 cals., and obviously somewhat more will be given with FeO, inasmuch as 1 kg. SiO_2 yields 134 cals. with MnO and 168 cals. with FeO.

[2] 0·33=specific heat of Bessemer slag according to Wedding, Vol. I., p. 932. The calculations are based according to the equations—

$Si+Fe_2O_3=SiFeO_3+Fe$. $3Mn+Fe_2O_3=3MnO+2Fe$. $2P+3Fe_2O_3=P_2Fe_4O_9+2Fe$. $3C+Fe_2O_3=\ CO+2Fe$.

amounts (*vide* the investigations of Ledebur "Eisenhuttenkunde," Vol. III., p. 285, and others). If one assumes 1,300° as the reaction temperature, and uses the same figures for the specific heats as Ledebur, as well as the values previously given for the heats of combination of acids with bases, one obtains the summary given on p. 213.

By the oxidation of the reducing agents by iron peroxide at 0°, one thus obtains with Si a not inconsiderable and with Mn a minute heat gain, and with phosphorus a heat loss, but on endowing the Fe_2O_3 with a small stock of available heat, this becomes a heat gain. Carbon, however, causes a quite considerable heat absorption. One obtains the same results by whatever method one carries out the calculations. Silicon and manganese always exhibit strongly exothermic reactions, phosphorus a feeble exothermic reaction, that is to say, they develop heat, whilst the reaction with carbon is strongly endothermic, that is to say, absorbs much heat. From this the reagents divide themselves into two sharply characterised groups.

From the law of conservation of energy it follows that heat absorbing or endothermic reactions can only take place if the energy absorbed by them is replaced, and that they must cease if the supply of energy is absent, and a certain stock of energy which has been present is cut off. Inversely, it is possible that heat evolving or exothermic reactions, once instituted continue, and if the energy set free does not hinder their progress, or if in this case it is carried away, their end only occurs if inter-reacting reagents are brought to an end.

Intimate contact of the reagents is necessary to render possible the action of iron peroxide on the reducing agents in the iron, and this condition is fulfilled by the aid of the slag, since the same dissolves iron peroxide.

The initiation of the reaction is thus provided by the slag, and the heat set free by the reaction is able with difficulty to exercise a restricted influence on the continuation of the reaction, since it is carried away by radiation and conduction, or, however, may be used up by the carbon reaction. Thus the removal of silicon, phosphorus, and manganese from molten iron must be able to result without further ado by means of iron peroxide introduced with the aid of a basic slag.

The foregoing conclusions are nevertheless placed in question owing to the fact that the combustion effort of the agents depends on the influence of change of temperature, and that it becomes more powerful with rising temperature for carbon than for all the remaining agents. Through high temperature it becomes possible for the carbon to exercise its affinity for oxygen, and be removed from the iron before or simultaneously with the remaining agents.

Conclusion as to the behaviour of the reducing agents under the circumstances described is therefore only able to be furnished by experiment.

(*c*.) ACTION OF IRON PEROXIDE ON THE REDUCING AGENTS IN MOLTEN IRON, WITHOUT THE AID OF EXTRANEOUS HEAT.

For experimental proof of the behaviour of iron peroxide on the reducing agents present in molten iron, practical experiments were made on a large scale in the year 1902 and later in the south Russian works of the Donetz-Jurjewka Company. Pure iron ore (nearly chemically pure iron peroxide, which was well dried, but nevertheless not further preheated), was introduced into the transport ladle, and molten pig iron from the blast furnace, or from the mixer or cupola, was allowed to flow on to the same. It demonstrated that a reaction actually always ensued. It began as soon as it was in the ladle, and, indeed, mostly in the place on which the falling stream of pig iron impinged a little slag formed, which apparently brought some iron oxide into solution. The dissolved iron peroxide, however, acted forthwith on the silicon in the iron, it produced fresh melted iron silicate, whereby the quantity of slag rapidly increased. It acted on the iron ore in the ladle, and rapidly changed it into an effervescent liquid. This was powerfully whirled about with the iron by the stream of pig iron, and evidently also by the influence of the resultant reactions, whereby spontaneously a quite intimate mixture of the reagents was set up, which considerably assisted the reaction. The experiments were conducted with pig irons at very varied temperatures, and of very varied compositions, and it demonstrated that the further course of the same was to a certain extent influenced by variation of both conditions mentioned. With high temperature, or high silicon content of the metal, the action was more intense, and was able to become so violent with a rapid stream of iron, that the metal in the ladle boiled so violently that one must fear losses owing to ejection of materials. In such cases the instreaming of pig iron was brought down to moderation, or to a total stoppage for a moment, whereby the lighter slag forthwith rose to the upper surface, so that mutual contact with larger quantities of materials ceased, and thus the action came to an end. By renewal of the stream of iron one could again restart the reaction. After the filling of the ladle the metal and slag separated, so that the latter solidified rapidly on the upper surface, and was thus rendered inactive on the metal.

The following results of analyses furnish information as to the mutual reactions:—

Table T.

Source.	Pig Iron from	Metal.				Slag.						Ore per cent. on Pig Iron.
		Si	Mn	P	C	SiO_2	Fe_2O_3	FeO	Fe	Mn	P_2O_5	
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
1. St. & E.,	Blast F'ce	1·30	2·19	0·17	4·23							
1907,p.229	Ladle . .	0·37	0·81	0·14	4·21	35·35	—	—	16·2	19·62	0·43	7·0
2.	Blast F'ce	1·75	2·79	0·16	3·82							
”	Ladle . .	0·14	0·42	0·11	3·80	31·60	—	—	31·44	18·91	0·64	12·0
3.	Blast F'ce	3·27	1·52	0·06	3·79							
”	Ladle . .	0·49	0·38	0·03	3·71	36·10	—	—	41·52	6·29	0·11	20·0
4. St. & E.,	Blast F'ce	3·50	0·88	0·46	3·93							
'05, p.1345	Ladle . .	0·42	0·33	0·36	3·74	34·00	2·37	54·36	43·94	3·39	0·62	20·5

Similar results were obtained in all experiments, wherein the temperatures of the molten iron employed lay between 1,198° and 1,389° estimated by the Wanner pyrometer. One perceives that within these temperatures the exothermic reactions had decidedly the precedence of the endothermic reactions, in that especially silicon and manganese were eliminated from the iron in large amounts, whilst the endothermic carbon reaction had only resulted to a small extent. Further it showed that the slag with its silica content in amounts of 31 per cent. to 36 per cent. lay between the monosilicate (29·4 per cent. SiO_2) and the bisilicate (45·4 per cent. SiO_2).

Example 4 is investigated in more detail in the article mentioned, from which it showed that of the ore used only about 3 per cent. remained inactive, whilst of about 60 per cent. of the total quantum of ore, the Fe_2O_3 was reduced to FeO, and about 37 per cent. was reduced to Fe.

Incidentally it is to be remarked that it was possible by means of sufficiently large additions of ore, to remove the silicon down to under 0·1 per cent., and the manganese down to 0·5 per cent., as to which the following example is cited :—

	Si per cent.	Mn per cent.
Pig iron from blast furnace	0·75	2·46
Pig iron after action of iron ore . . .	0·09	0·41

The elimination of phosphorus was on the contrary not considerable.

(*d.*) ACTION OF IRON PEROXIDE ON THE REDUCING AGENTS IN IRON, AIDED BY FURNACE HEAT.

Long previously to the energy changes due to the mutual action of iron oxide on the reducing agents in molten iron being known, the different behaviour of Si, Mn, and P on the one hand, and C on the other, in regard to iron ore had been understood. In the year 1877, Alfred Krupp took out a patent in Germany and England for a process for dephosphorisation of iron, which he also protected by patent in the United States of America in 1880.

As apparatus in which the process is conducted, an open-hearth furnace of any desired system should serve which fulfils the condition of permitting the attainment of the melting point of the pig iron. The hearth of this furnace is (after heating up the latter) lined with iron and manganese oxide, which is introduced tentatively and heated to sintering. Then further iron ore is introduced into the furnace in amounts which are dependent on the composition of the iron to be purified, and heated until the material is baked fast to the walls of the same, whereupon the iron in the molten state is as rapidly as possible run in thereon. In the American patent specification it says:

"When the charge has been run at once into the furnace, it remains generally almost quiet for about three to eight and even more minutes. This is the first period of reaction in my process where phosphorus, sulphur, silicon and manganese are oxidised."

"This oxidation forms liquid products, viz.: phosphates and silicates of protoxide of iron and silicate of protoxide of manganese. Sulphur only, if present, is oxidised partly to gaseous sulphurous acid, but partly it combines with iron and manganese, as a liquid product, sulphide of iron or manganese. Therefore, the bath remains almost untroubled and only little froth and bubbles are formed; but as soon as the above substances have been oxidised (phosphorus and sulphur, for the most part, silicon and manganese throughout, or at least except minimal traces) the oxygen of the oxides acts with all its power upon the carbon. It forms with the carbon a gaseous product—carbonic oxide—causing thus a revolution in the whole bath. The molten mass commences to rise, and froth and foam are formed or bubbles thrown out, which burn upon the surface of the bath to carbonic acid with bluish flames. All these signs are very conspicuous, so that every intelligent workman may recognise the moment for tapping. A short delay in tapping presents no inconvenience. On the contrary, it gives the guarantee that almost all phosphorus has been removed, especially if the pig iron treated contained some manganese."

The specification states that with pig irons containing about 0·6 to 2·5 per cent. of phosphorus, the consumption of ore for repairs of lining is about 6 per cent. on the weight of the metal charge after each charge, and in addition about 12 to 24 per cent. for the production of chemical reactions, that is to say a total of 18 to 30 per cent. on to the weight of the charge. With a Pernot furnace, about sixteen charges of 5 to 6 tons may be produced in twenty-four hours. It further says:—

"I never melt the pig-iron which is to be cleaned in the cleaning-furnace itself as is done generally in the puddling process. The reason why I proceed in another way lies in the quickness with which the reactions of the oxides upon phosphorus, etc., are performed, so that if I should melt the pig iron in the cleaning furnace itself, the first molten part would be refined and already decarbonised to a high degree before the last part of the pig iron is melted."

After describing the manner in which the hearth is prepared and the charging of the ores required for reaction and causing these to adhere to the bottom walls of the hearth, and that the charge is then run upon them into the hearth, the specification goes on to say:—

"In proceeding thus there is not much ore torn off mechanically from bottom and walls, but the cast-iron charge dissolves for itself as much of the oxides as it needs for its purification, the oxides being obliged to pass gradually as they melt through the cast iron. By these means I cause the reaction not to develop in a too rapid and explosive manner, so that the metal does not run over the walls of the hearth or is not thrown out. All these inconveniences would take place if I introduced the oxides in the molten state at the same time as or before the cast iron, and by proceeding in the latter manner, it would not be possible to treat large quantities at once, neither to maintain a regular and economic working."

The process has been employed with success for several years in America, and large quantities of low phosphorous iron (washed metal) manufactured thereby. It has furnished proof that phosphorus also, as well as Si and Mn, that is to say, the agents with exothermic reactions, can be eliminated before carbon. Of course, in the Krupp process, temperatures rule which may not be allowed to considerably exceed 1200°.

Recently estimates have become available as to the behaviour of the agents at higher temperatures.

Ledebur gives in "Stahl und Eisen," 1903, p. 40, examples from the Bertrand-Thiel process, which is carried out in the basic open-hearth furnace. Pig iron was introduced into the furnace in the molten state, and refined by means of iron ore additions, whereby the entire heat action of the furnace gases was exercised unexposed to the charge.

The composition of the pig iron was:

1st ladle at 10·0: 3·60 per cent. C, 0·47 per cent. Mn, 0·56 per cent. Si: 1·33 per cent. P.

2nd ladle at 10·11: 3·45 per cent. C, 0·42 per cent. Mn, 0·46 per cent. Si, 1·39 per cent. P.

After repeated additions of ore and lime the metal contained at 12·22, 2·50 per cent. C, 0·10 per cent. Mn, 0·04 per cent. Si. 0·087 per cent. P.

Therefore, in somewhat over two hours, manganese, silicon and phosphorus were nearly completely eliminated, whilst the carbon was only lowered by something more than 1 per cent.

Beyond doubt, in the course of the two hours duration of the furnace reaction, the bath was brought to a much higher temperature than was possible with the Krupp process, and in spite of that, the exothermic reactions took precedence.

In "Stahl und Eisen," 1905, p. 1343, a further example of the action at high temperatures is furnished. Pig iron was melted down in a basic open-hearth furnace and brought to a very high temperature. Thereupon an iron ore addition to an extent of 12·4 per cent. on the weight of the metal was introduced, and after forty minutes' action, a test was taken of the metal.

The molten metal had the following composition:—

Si 1·33 per cent.; Mn 2·71 per cent; P 0·12 per cent.; C 3·66 per cent.

After forty minutes' action of ore, it contained:

Si 0·02 per cent.; Mn 0·33 per cent.; P 0·01 per cent.; C 3·14 per cent.

Dr. Ing. Th. Naske furnishes in "Stahl und Eisen," 1907, p. 233, Table 10, another similar experiment in which 20,018 kilogrammes molten pig iron was exposed during ninety minutes to the full heat of the furnace, and brought to the highest temperature attainable. Then an ore addition of 820 kilogrammes or only 4·1 per cent. was made. The composition of the metal and slag changed as follows :—

	Metal.				Slag.					
	C	Mn	Si	P	Fe	FeO	Fe_2O_3	P_2O_5	Mn	SiO_2
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Without ore added	3·76	2·48	0·18	0·14	1·72	2·21	—	0 05	2·94	35·80
After 25 minutes' action of 4·1 per cent. ore . .	2·98	0·87	0·05	0·06	10·85	12·05	2·11	2·29	18·97	22·90

One sees clearly from both examples that the action on the agents Si, Mn and P is much more powerful than the action on the carbon.

Dr. Ing. Th. Naske gives in the foregoing, p. 232, Table IX., an example of the action of molten pig iron on such strongly preheated ore that the same was fused into iron-lime slag. In the reaction there were employed 17,843 kilogrammes molten pig iron, and 3,280 kilogrammes = 19 per cent. ore, and 820 kilogrammes limestone. The reaction was very lively; the pouring in of the pig iron was obliged to be very slowly performed.

The pig iron contained at 1·20 on being poured in—

C 3·90 per cent., Si 1·03 per cent., Mn 1·56 per cent., P 0·14 per cent.

and after fifteen minutes action at 1·35—

C 3·35 per cent., Si 0·05 per cent., Mn 0·28 per cent., P 0·01 per cent.

Here again the removal of carbon is small, in spite of which one would conclude that an energetic action on the carbon occurred from the very violent evolution of gas during the pouring in of the iron.

A number of similar experiments yield a like result and demonstrate that *with the means at disposal in the open-hearth* *furnace process, it is not possible to raise the combustion effort of the carbon so high that the same is able to hinder the removal of the agents whose reactions are exothermic.* On the contrary, these reactions remain under all circumstances ensured of precedence over the endothermic carbon removal, except where deficiency of oxygen is present. So long as the entire reducing agents are able to obtain oxygen with ease, they do not disturb themselves in their general and mutual reactions. So soon, however, as oxygen commences to be deficient in amount, the power of the greater combustion effort of carbon manifests itself, and this now attacks the oxidation products of the remaining agents, and decomposes them to the extent that they are made accessible to it by the conditions of reaction.

Owing to the presence of larger quantities of oxygen, however, the elimination of the substances Si, Mn and P is quite extraordinarily favoured, and it is already expressed in the Krupp patent that the elimination of large amounts of these agents can be ended in the short space of time of six to eight minutes. Similar results were obtained in the ladle experiments before quoted, and likewise by the pouring of molten pig iron on ore placed in the open-hearth furnace, whether or no it was cold or melted, as to which the following experiment is furnished from "Stahl und Eisen," 1905, p. 1344. Two ladlefuls of 10 tons of molten pig iron were teemed on to ore (22 per cent. on the weight of metal) already in the furnace. The composition of the metal was

1st ladle. Test from ladle. Time 4·38.
  Si 1·61, Mn 2·73, P 0·27, C 4·06 per cent.
1st ladle. Test from furnace. Time 4·45.
  Si 0·04, Mn 0·24, P 0·08, C 3·42 per cent.
2nd ladle. Test from ladle. Time 5·0.
  Si 1·63, Mn 2·86, P 0·27, C 4·06 per cent.
2nd ladle. Test from furnace. Time 5·8.
  Si 0·04, Mn 0·41, P 0·08, C 3·47 per cent.

Here also the elimination of Si, Mn and P was brought to an end in seven to eight minutes.

But if one takes into consideration that one was only able to approach the furnace after the ladle was removed, and it was not, therefore, possible to take the tests from the furnace, one cannot reject as groundless the assumption that the extensive removal of the substances Si, Mn and P was already completed much earlier, and that it appears to be much more certain that this removal resulted momentarily, and only required as much time as was necessary to bring the reagents into necessarily intimate contact with one another.

If one regards their behaviour in this manner, new points of view are given rise to which render possible further chains of reasoning.

(*e*.) Iron Oxide Demand and Charge—Shrinkage in the Production of Steel from Molten Iron.

If the elimination of the substances Si, P and Mn from the molten charge, by means of iron oxide, can occur in a moment, it is evidently possible by this means to remove the substances named from the oxidising action of the furnace gases, so that carbon remains as the sole reducing agent in the iron which opposes itself to the latter. If one takes care to have the presence of large amounts of carbon in the charge, one is still able to use up from the products of elimination of silicon and phosphorus, *i.e.*, the iron silicate and iron phosphate, the oxygen content of those amounts of the iron protoxide therein contained which, under the influence of the lime, go over into the free state, in so far as they are not demanded for the existence of the slag.

Carbon present to some excess must be removed by further additions of iron oxide, for the prevention of an excessive lengthening of the process. If one proceeds in the manner assumed, and selects therefore the quantity of the oxide additions in such wise that they cover the entire iron protoxide, requirements of the slag, there results a simplification in the calculation of the oxygen required, as well as for the variation which the weight of metal must undergo, by simply allocating to the oxidising action of the flame the combustion of a portion of the carbon content.

It thus admits of ascertaining the oxide required for each individual reducing agent, inasmuch as one deducts from iron oxide the entire quantity of oxygen necessary for its oxidation, and to this adds just as much, but no more, iron oxide than is necessary to cover the iron protoxide content of the slag simultaneously produced which is given rise to by the reducing agent in question. By this mode one finds the oxide required:

1. *For the Silicon.*

One per cent. Si gives rise to 10·23 per cent. final slag (according to formula (42)) with 10 per cent. or 1·023 per cent. Fe. Should this iron be taken from iron peroxide, there must be present in one weight unit of iron peroxide, $\frac{Fe_2}{Fe_2O_3}=\frac{112}{160}$ $= 0·7$ weight units of iron, and $\frac{1·023}{0·7}= 1·46$ per cent. Fe_2O_3 be employed.

Iron is present in the final slag in the form of iron protoxide, and according to the formula

$$Fe_2O_3+Si=SiO_3Fe+Fe$$

there are necessary for the reduction of 1·46 weight units of Fe_2O to FeO, $1·46\times\frac{28}{160}=0·25$ weight units of Si, so that from 1 per cent. Si there now only remain behind 0·75 per cent. Si, the oxygen demand of which from Fe_2O_3 under complete using up of the oxygen content of the latter can be covered according to the formula

$$2Fe_2O_3+3Si=3SiO_2+4Fe.$$

Hence one finds the iron peroxide requirement for 0·75 per cent. Si as being

$$0·75\times\frac{2\times160}{3\times28}=2·86 \text{ per cent.}$$

The demand of iron peroxide for the complete elimination of 1 per cent. Si is therefore $1·46+2·86=4·32$ per cent. . . . (67).

The change which the weight of metal must now undergo owing to the elimination of silicon is, since there is produced from 2·86 per cent. Fe_2O_3 an amount of $2·86\times0·7=2·00$

per cent. Fe against which 1 per cent. Si is burnt off, as a net result a gain of 1 per cent. . . . (68).

2. *For the Phosphorus.*

Should the elimination of the phosphorus take place exclusively by means of iron peroxide with complete utilisation of the oxygen content of the latter, so the formula

$$6P+5Fe_2O_3=3P_2O_5+10Fe$$

must be employed for estimation of the oxygen required, according to which 1 per cent. $P\times\frac{5\times160}{6\times31}=4{\cdot}30$ per cent. Fe_2O_3 is required . . . (69).

Since the hypothetical phosphate slag contains no iron protoxide, an extra addition of iron peroxide is not necessary for the slag.

The change in weight which will be caused by the elimination of 1 per cent. P by means of iron peroxide is calculable as follows:—

1 per cent. P is the cause of the reduction of $\frac{10\times56}{6\times31}=3{\cdot}00$ per cent Fe from Fe_2O_3, and by 1·0 per cent. P the charge is diminished; in consequence the net result is a gain in charge weight of 2·00 per cent. . . . (70).

3. *For the Manganese.*

The iron peroxide requirement for 1 per cent. Mn is calculable in like manner from the formula

$3Mn+Fe_2O_3=3MnO+2Fe$ as being $\frac{160}{165}=0{\cdot}97$ per cent. . . . (71).

Here 1 per cent. Mn separates out from the charge, against which there is reduced $\frac{2\times56}{3\times55}=0{\cdot}68$ per cent. Fe; thus from the removal of 1 per cent. Mn by the agency of Fe_2O_3 a loss of charge of 0·32 per cent. results . . . (72).

4. *For the Carbon.*

The carbon of the charge has now alone to overcome the oxidising action of the flame, and this is not only different for different furnaces, but it exhibits differences for the same furnace, which are dependent on the length of process, the thickness of the layer of slag, and the greater or lesser intensity of boil of the bath. Therefore, the determination of iron peroxide required for the elimination of carbon is only approximately possible. No matter, one can assume on the basis of empirical values for charges with high carbon content and in rapid working furnaces with correctly carried out working, that at the most one-fifth of the carbon content is removed by means of the furnace action, whilst four-fifths or somewhat more, are able to be eliminated by means of the oxygen of ore. Thus of 1 per cent. C about 0·2 per cent. would be removed through the oxidising action of the flame, and 0·8 per cent. by means of iron peroxide.

From 1 per cent. C there would be developed, according to p. 205, 0·5 per cent. slag with 0·05 per cent. Fe. This 0·05 Fe, corresponding to 0·0645 per cent. FeO, must be produced from iron peroxide according to the formula $Fe_2O_3+C=2FeO+CO$, wherefrom $0{\cdot}0645\times\frac{160}{2\times72}=0{\cdot}07$ per cent. Fe_2O_3 would be required.

By the reaction $\frac{12}{160}\times0{\cdot}07=0{\cdot}005$ per cent. C would be removed.

Thus the removal of 1 per cent. carbon occurs in such wise that it may be allocated as under :—

0·200 per cent. through the oxidising action of the flame.
0·005 ,, ,, reduction of Fe_2O_3 to FeO.
0·795 ,, ,, reduction of Fe_2O_3 to Fe.
1·000 per cent.

The iron peroxide required for the last-named reaction amounts according to the equation

$$Fe_2O_3+3C=2Fe+3CO \text{ to } 0{\cdot}795\times\frac{160}{3\times12}=3{\cdot}53 \text{ per cent.}$$

Table U.—Summary. Influence of Elimination of Reducing Agents by Iron Peroxide on Heat Demand in Steel Melting.

—	1 kg. Si+99 kg. Fe.			1 kg. P+99 Fe.			1 kg. Mn+99 kg. Fe.			1 kg. C+99 kg. Fe.			1 kg. SiO_2+100 kg. Fe.		
	—	Cal.	Cal.	—	Cal.	Cal.	—	Cal.	Cal.	—	Cal.	Cal.	—	Cal.	Cal.
Metal produced, kg.	101 kg. (68)	—	—	102 kg. (70)	—	—	99·68 kg. (72)	—	—	101·47 kg. (74)	—	—	100 kg.	—	—
Heat-content of same	101 × 350 =	35,350	—	102 × 350 =	35,700	—	99·68 × 350 =	34,888	—	101·47 × 350 =	35,514	—	100 × 350 =	35,000	—
Slag, kg.	10·23 kg. (42)	—	—	5·9 kg. (38)	—	—	—	—	—	0·5 kg.	—	—	4·78 kg. (40)	—	—
Heat-content of do., *i.e.*, do. × 525	—	5,371	—	—	3,097	—	—	—	—	—	263	—	—	2,510	—
CO_2 from limestone—heat carried off	10 × 180	1,800	—	7·22 × 180	1,300	—	—	—	—	—	—	—	4·66 × 180	839	—
CO from C heat carried off	—	—	—	—	—	—	—	—	—	(51)	800	—	—	—	—
Total heat-content of products	—	—	42,521	—	—	40,097	—	—	34,888	—	—	36,577	—	—	38,349
Necessary for the reactions[1]:—															
Decomposition of limestone	10 × 425 =	4,250	—	7·22 × 425 =	3,068	—	—	—	—	—	—	—	4·66 × 425 =	1,980	—
Reduction of Fe_2O_3 to Fe { Fe produced	2·00 kg. Fe	—	—	3·00 kg. Fe	—	—	0·68 kg. Fe	—	—	2·47 kg. Fe	—	—	—	—	—
heat absorbed	2 × 1,796 =	3,592	—	3 × 1,796	5,388	—	0·68 × 1,796 =	1,221	—	2·47 × 1,796	4,436	—	—	—	—
Reduction of Fe_2O_3 to FeO { Fe involved	1·023 kg. Fe	—	—	—	—	—	—	—	—	0·05 kg. Fe	—	—	0·5 kg. Fe	—	—
heat absorbed	1·023 × 450	460	—	—	—	—	—	—	—	0·05 × 450	23	—	0·5 × 450	225	—
Heat demand for reaction	—	8,302	8,302	—	8,456	8,456	—	1,221	1,221	—	4,459	4,459	—	2,205	2,205
Total heat demand	—	—	50,823	—	—	48,553	—	—	36,109	—	—	41,036	—	—	40,554
Heat produced in reactions[2]:—															
Heat of combustion of reducing agent	1 kg. Si	7,830	—	1 kg. P	5,965	—	1 kg. Mn	1,724	—	1 kg. C	2,387	—	—	—	—
Available heat of do.	0·2 × 1,300	260	—	0·18 × 1,300	234	—	0·2 × 1,300°	260	—	0·45 × 1,300	585	—	—	—	—
Combination heat of SiO_2+CaO	2·14 × 384	822	—	—	—	—	—	—	—	0·11 × 384	42	—	1·0 × 384	384	—
„ „ P_2O_5+CaO	—	—	—	2·29 × 1,131	2,590	—	—	—	—	—	—	—	—	—	—
Total energy content of reagent	—	8,912	8,912	—	8,789	8,789	—	1,984	1,984	—	3,014	3,014	—	384	384
Difference. Heat required	—	—	41,911	—	—	39,764	—	—	34,125	—	—	38,022	—	—	40,170
Required for production of 1 kg. steel	$\frac{41,911}{101}$ =	—	415	$\frac{39,764}{102}$ =	—	390	$\frac{34,125}{99·68}$ =	—	343	$\frac{38,022}{101·47}$ =	—	374	$\frac{40,170}{100}$ =	—	402
1 per cent. reducing agent increases—or reduces + heat required per kg. steel	350 − 414	—	−65	350 − 390	—	−40	350 − 343	—	+7	350 − 374	—	−24	350 − 402	—	−52

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[1] Removal of reducing agents from iron is an unknown quantity in each case.

[2] Available heat of Fe_2O_3 is an unknown quantity. If added cold is of course *nil*.

The total requirement of Fe_2O_3 for the removal of 1 per cent. C is thus, $0{\cdot}07+3{\cdot}53=3{\cdot}60$ per cent. . . . (73).

The change of weight of metal owing to a content of 1 per cent. C in the charge is thus

By reduction of 3·53 kilogrammes $Fe_2O_3 \times 0{\cdot}7=$	2·47 per cent.	
Less C burnt out	1·00 ,,	
Gain of charge for 1 per cent. C . .	1·47 per cent. .	. (74)

(*f.*) INFLUENCE OF THE ELIMINATION OF THE REDUCING AGENTS, BY MEANS OF IRON PEROXIDE ON THE HEAT REQUIREMENT IN STEEL PRODUCTION.

From the preceding figures, the influence exercised by the impurities of the iron on the heat required for production of steel admits of being approximately fixed, for the case that their removal is effected by means of iron peroxide added to already molten charges, and coupled with best possible use of its oxygen, and in consequence also, its iron content.

The calculation is set out in Table U, and renders it apparent that manganese is the only reducing agent which acts favourably under these circumstances, in that the heat demand is reduced about 7 calories per kilogramme steel. All the remaining agents make an increased heat supply necessary, and the increased amounts are as follows:—

For 1 per cent. Si, about 65 calories per kilogramme steel.

For 1 per cent. P, about 40 calories per kilogramme steel;

For 1 per cent. C, about 25 calories per kilogramme steel; and for 1 per cent. SiO_2 from impurities about 50 calories.

By means of these figures, all influences which the composition of the charge exercises on the course of the open-hearth process are approximately established.

CHAPTER XXI

THE OCCURRENCES IN OPEN-HEARTH FURNACES AND THEIR JUDGMENT

The great amounts of heat which are at disposal in the open-hearth furnace allow of a rapid transference of heat to a charge introduced, and if this be in the solid state it soon attains its melting point, and passes over into the molten state. With the first molten mass making its appearance, the actions of the individual constituents of the bath on one another begins, and of these carbon elimination possesses the greatest signification for the result of the process. It begins early, and after complete fusion of the entire charge, takes the course described on p. 166. The regularity of the boil of the bath is an indication that the metal, as well as the slag, has the proper composition; it should have attained its highest point with normal charges about half an hour after melting down, and continue for about a further half-hour. Stoppage of the boil or its diminution is an indication that the metal and slag are in a condition of equilibrium, that is to say, approximate to this condition, and it then must be tapped. As to this, in the first place it must be decided whether the bath possesses the right temperature.

Judging the Temperature of the Metal.

Testing the metal in regard to its degree of heat takes place by a purely empirical method, as corresponding apparatus is not at disposal, and would scarcely be practicable. The method of testing is applicable to all molten substance, and answers equally well for steel as for tin, or even fat. It is based on the circumstance that a molten substance brought into colder surroundings remains fluid the longer, the higher it is heated above its fusion point. In order to test the temperature of the steel, one first covers an iron test spoon with a thin crust of slag by means of turning it over in the slag, which will shield the metal of the spoon from direct contact with the molten metal of the bath, and one thereupon takes a sample of the same from the furnace and observes its behaviour during pouring out. The metal should be completely fluid and admit of being quite slowly poured out, without leaving a film behind in the spoon. One often accelerates the test by means of removing the slag layer, which covers the metal in the spoon and thereby gives it the capability of rapidly radiating heat to the surroundings. If the metal is or becomes viscous or leaves behind it a film in the spoon, it is too cold, and must at once be heated up. The safest means for this purpose is to set up anew a boil, whereby the heat action of the furnace is transferred to the bath in the most powerful manner. This, however, can only happen if the metal still contains enough carbon, and therefore it must, equally as a hot bath before tapping, be now tested also as to its composition.

JUDGING THE DEGREE OF HARDNESS OF THE METAL.

The more reducing agents an iron contains, the more brittle it is in general, and the more easily an article made therefrom is broken. This property of iron furnishes the possibility of rapidly arriving at some conclusion as to the composition of the metal, in the entire process of making ingot-iron or steel.

The peculiarities in the elimination of the reducing agents are accompanied by the fact that most usually only carbon and phosphorus are found in the steel in amounts which exceed the admissible normal.

The investigation of the composition of the metal can be carried out by two-fold methods, by either employing a cast test ingot or forging out the material previous to testing.

The first mode of test requires very little time. About 1 kilogramme steel is poured with the test spoon into a trough-shaped mould, or in a mould of rectangular section (which is made by placing two right-angled elbow-pieces of steel on an iron foundation) and immediately after solidification of the test it is slaked off. Metal with a carbon content of about

1·5 per cent. and above then receives small cracks and thus admits of easily being broken in pieces. With lower carbon content, the test ingot remains whole; it is then laid on a hollow support and broken by means of blows from a hammer. The harder the metal, the more easily fracture results; the softer it is, the more blows are necessary, and the greater bending the test ingot endures.

This test in a few minutes furnishes evidence whether enough carbon is present in order to set up a boil of sufficient intensity after increasing the oxygen content of the slag. With correctly tempered metal, however, it admits of one perceiving whether decarburisation has been sufficiently far advanced for tapping out ingot iron.

This test also indicates whether the phosphorus content is higher than permissible. The texture of the fracture of such a test must be compact and fine-grained, and exhibit a definite, not too glaring, metallic lustre. Phosphorus, however, makes the texture coarsely granular or coarsely striated, and gives it a powerful lustre. These phenomena stand out more markedly the higher the phosphorus content.

With these indications, the capacity of the test is exhausted, and all the remaining properties of the metal do not admit of being perceived thereby.

The results are considerably more extensive if the metal to be investigated is first forged and then further tested. Here again a small test ingot is cast, preferably of rectangular section, and brought at a red heat under a small steam hammer and forged out. With a carbon content of about 1·5 per cent. this usually is not possible—the ingot falls in pieces. With lower carbon content, however, it admits of being drawn out into a bar, to which in practice always the same section is given: viz., about 14 square millimetres. A piece of about 400 millimetres length is cut off from this and placed on one side and allowed to cool down slowly.

The remainder, still bright red, is brought up by heating to the necessary temperature and quenched in cold water. Metal with more than 0·55 per cent. to 0·60 per cent. C develops hardening cracks, or splits up into several pieces if the carbon is very high, whilst metal with low carbon content remains whole. The last-named test-pieces are then broken, and their behaviour under fracture, as well as the appearance of the latter, is used for an approximate determination of the carbon content.

If the water-quenched test breaks at the first light blow, the carbon content amounts to more than 0·4 per cent.; the surface of the fracture shows (presuming that the metal is not brought into the water under a bright red heat) the more lustrous grain the higher the carbon content is.

If the test sustains a bending before fracture, whilst it only breaks at the second blow, or resists still more blows, and the surface of the fracture shows a matt and coarser grain than the previous test, as well as a border of fine sinews at the edges, the metal contains 0·4 to 0·3 per cent. C.

If the test only breaks after a series of blows, and after bending, which can amount to 180°, and the surface of the fracture consists of dull, coarse grain, and a very perceptible border of sinews, the carbon content amounts to 0·3 to 0·2 per cent.

If the test bars admit of being bent together through 180° without exhibiting cracks, the carbon content amounts to less than 0·2 per cent. The carbon content of tests of the last-named category can be determined still more accurately if the bars are nicked by a chisel and fractured by means of a hammer at the nicked point. With a carbon content of about 0·15 per cent. this easily takes place, and only grain is exhibited, and in proportion as the carbon content goes down, the fracture is preceded by more and more bending, and simultaneously the border of sinews which surrounds the fractured surface is still more marked until finally below 0·1 per cent. C all grain has vanished and only sinews appear.

The pieces cut from the forged tests mentioned and slowly cooled down are able at times to perform good service as supplements to the hardened tests. They are bent in the cold state in such wise that they take a U form, whereon the distance between the inner surfaces of both arms is reduced by blows until fracture occurs, which must take place in the apex of the bend. If fracture ensues when the distance between the two surfaces of the arms is equal to about three times the thickness of the test bar, then the carbon content amounts to about 0·55 per cent.; and if when equal to the thickness of the bar, then the carbon is about 0·45 per cent.

Softer materials must endure the U-formed piece being hammered up to contact of its inner surfaces without cracks making their appearance. The test will usually only be employed for the harder kinds of steel, and one can regard it as a practical rule that the hardest kinds of steel must resist bending of the unhardened test to at least 90°. If the material breaks earlier, it is unsuitable for use, and must be further treated, *i.e.*, again melted down.

The forged test admits also of perceiving whether the material exhibits red shortness, and therefore forging should take place at the critical temperature for red shortness.

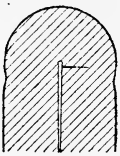


FIG. 14.

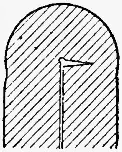


FIG. 15.

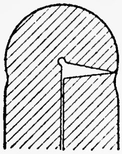


FIG. 16.

According to the degree of the same, the material always either falls in pieces, or the bars develop larger or smaller corner cracks and break if bent at the temperature mentioned. Very small traces of red shortness, of course, do not render themselves apparent in this manner, and therefore the test is aggravated by means of nicking with a chisel another piece of the forged-out metal in the red hot state, and bending it over in the notched place or punching a hole through it, and afterwards stretching it out and bending the piece at this place to 180°, which bending it must resist without receiving any cracks whatever.

Further, the forged tests permit perception of the phosphorus content nearly as well as the cast ones as soon as it exceeds 0·1 per cent. It is most clearly perceptible in the unhardened tests, but in the hardened ones also it is not overlooked by a practised eye. The tests then admit of being actually hammered together from 180° up to contact of the inner surfaces; they possess, however, at the point at which the straight portion of the bar goes into the bend on the inner side a very characteristic crack, which with high phosphorus content, assumes a wedge-like form (*vide* Figs. 14, 15, and 16).

Judging the composition of the metal on the basis of the forged test is a matter of practical experience.

Since it is possible in the basic open-hearth furnace to completely remove the phosphorus before the carbon, it is also possible to interrupt the process at any desired carbon content, and to produce in this manner good, pure material; but likewise on the grounds discussed, care must then be taken that on attainment of this C content, metal and slag have so far approximated to a state of equilibrium that they have become practically inactive on one another.

(*c*) GASES IN IRON.

The molten metal comes in contact with the fire gases CO_2, CO, H, N and O, in addition to which CO originates in its interior. The metal absorbs all these gases and permits a portion thereof to escape during solidification, whilst another portion is retained after solidification.

A. Ruhfuss gives in "Stahl und Eisen," 1897, p. 43, the following analyses of gases, which escaped from the mould during casting:—

No.	CO_2.	O.	CO.	H.	Total.	Behaviour of steel in mould.
1	7·4	1·0	52·8	27·46	88·66	sank
2	7·2	0·01	60·1	21·0	88·31	stood
3	8·2	1·10	63·8	18·0	91·10	sank
4	2·1	0·30	69·4	16·8	88·60	,,
5	3·9	1·0	70·0	19·0	94·00	,,
6	8·3	0·2	73·3	13·3	95·10	stood
7	3·0	0·7	77·0	6·0	86·70	,,
8	5·2	0·5	81·7	5·3	92·70	rose
9	4·0	0·0	82·0	4·8	90·80	stood
10	2·7	0·3	85·2	4·0	92·20	rose

Fr. C. G. Muller ("Zeitschrift d. Ver. Deutsch-Ing.," 1879, p. 493, and also Wedding, p. 476) bored solid metal under water, and found thereby that not inconsiderable quantities of gas escape. Some of the results found are set out here.

Class of iron.	Amount Gas Volume.	Composition.		
		H.	N.	CO.
	Per cent.	Per cent.	Per cent.	Per cent.
Bessemer steel before spiegel addition .	60·0	88·8	10·5	0·7
The same ,, ,, ,, ,, .	44·0	80·0	17·9	1·3
Bessemer rail ingot iron . . .	45·0	77·0	23·0	0·0
The same	51·0	78·1	20·7	0·9
The same forged out	5·0	52·2	48·1	0·0
Open-hearth ingot iron before adding spiegel	25·0	67·0	30·8	2·2
Thomas process ingot iron without added FeMn	20·0	64·5	35·4	0·0
Thomas process ingot iron with added FeMn and FeSi . . .	22·0	86·4	12·7	0·4
Thomas process ingot iron with added FeSi	6·0	54·7	45·3	0·0

Boudouard ("Stahl und Eisen," 1907, p. 451) found that turnings at high temperature under exhaustion can contain much greater amounts of gas, and actually up to ten times the volume of the metal, and ascertained the composition of this gas to be

H 50·4 per cent., CO 34·2 per cent., CO_2 9·9 per cent.,
N 4·1 per cent.

One sees that in the gases which escape during casting, carbon monoxide forms the chief constituent, whilst the gases which are retained by the solidified metal consist principally of hydrogen, and contain only very little carbon monoxide.

It appears now not inopportune to differentiate between the gases which are dissolved in the metal and such as are only mechanically retained. In respect of the former, it is probable that no means are at disposal to essentially influence their amount, whilst metal manufactured wholly in the converter, or in the open-hearth furnace, will be simply saturated with gases taking part in the process.

For the gases retained mechanically, on the contrary, the relations are different. The chief constituent of the same is, as Ruhfuss' table shows, carbon monoxide gas, and this gas originates in the interior of the metal itself under conditions which do not permit of its instantaneous exit from the metal. The very minute gas bubblets formed must first unite themselves into large bubbles before they can escape. In order that this can happen, time must be allowed, and during the same the metal must be maintained liquid by means of high temperature.

Thus the conditions for the production of a metal with low gas content become obviously the most favourable if the termination of the gas formation be awaited in the furnace itself, *i.e.*, if it be not tapped out until the state of equilibrium between the slag and metal has made its appearance. Reaction becomes slower and slower with approach to a state of equilibrium, and therefore if one wishes to end the "heat" under such conditions, one must sacrifice a certain time. But then, and indeed only then, it becomes possible to produce a metal which exhibits a minimum of the mechanically retained gases, and which, on this account, up to setting in the test mould, also behaves quietly throughout. Metal with high carbon content also then solidifies quietly, whilst it appears like an effervescent liquid supersaturated with gases under a strongly oxidising slag.

(*d*) DEOXIDATION.

In spite of the most painstaking observation of all precautionary measures, which are adapted to prevent an excess of oxygen in the slag, the entry of oxygen into the metal is not avoided, and almost always the amount of the same is so large that at least a portion thereof must be removed. This is done by means of deoxidation, reducing agents being added again to the bath.

Manganese has already been pointed out to be the agent which reacts in the most favourable manner under the conditions ruling, and hence manganese is generally used as a deoxidising agent. It possesses greater affinity for oxygen and also for sulphur than iron does, and it eliminates the two harmful substances named, or paralyses their action. It possesses, however, in addition the desirable property of increasing to a certain degree the tenacity of the metal and of giving it the capability at high temperature to preserve cohesion; and also, if it is strongly exposed to strains which are not to be avoided in mechanical working.

On these grounds, a manganese addition, which takes up the excess of oxygen, is made at the end of the "heat." The reaction occurs without evolution of gas, and the resultant manganese protoxide does not markedly impair the quality of the metal if it should not be allowed time to separate, and it therefore remains suspended in the metal.

But the action of manganese also is not complete. An excess must, therefore, be employed, and this excess increases the manganese content of the metal. Therefore, the degree of the completeness of the deoxidation depends on the manganese addition, and as to this, H. H. Campbell, speaking of the acid open-hearth furnace process, says (p. 188):

" . . . If 1·00 per cent. of Mn be added, there will be ·60 per cent. in the metal, being a loss of 40 per cent., while if ·50 per cent. be added, the steel will have ·40 per cent., being a loss of only 20 per cent. It seems as if with the lower manganese the action was not perfect, and that with each successive increment of ferro an additional atom of oxygen is removed. This fact holds good whether the recarburiser is added in the furnace or the ladle."

The same is valid for the basic open-hearth furnace.

Manganese is always employed in the form of an alloy with iron, and indeed mostly as highest possible percentage ferromanganese, which always contains carbon. This, however, likewise takes place in the reaction, whilst carbon-monoxide is formed anew, and therefore deoxidation by means of ferromanganese gives rise to a renewal of gas formation, which is the greater the more oxygen has been taken up by the metal, and under some circumstances allows it to assume a quite considerable extent.

If one taps out a highly oxygenated metal immediately after ferro-manganese addition without allowing the bath time for reaction throughout, or for degasification, it can happen that the reaction still continues its course in the ladle; but the powerful disturbance which the metal in the ladle undergoes in consequence of the infalling stream itself exercises at least an increased elimination of the mechanically mixed gases, and then the metal in the ladle can froth up, and this suddenly appear too small to contain the amount. The same action can occur once again on running into the moulds, the smaller section of which, and the simultaneously appearing influence of greater chilling, can then become the cause that the gas makes the metal in a moment to froth up to the brim of the mould, whereon it immediately sinks back again deeply. Such phenomena have been formerly very frequently observed, and they admit of being avoided in open-hearth steel if care is taken by means of a correct composition of the slag that the metal does not obtain an opportunity of taking up large amounts of oxygen, and if deoxidation takes place in the furnace itself and the metal is allowed time before tapping to throw off amounts of gas evolved by any possibility.

Manganese is without influence on the gases already present in the metal.

Other reducing agents to bring about deoxidation have been experimented with, but their use has been discontinued.

Silicon has proved itself unsuitable on many grounds. Its action on the oxygen is at once much feebler than that of manganese, and therefore for attainment of an equal action a much greater excess must be employed. The product of oxidation, silica, is, according to Ledebur ("Eisenhuttenkunde," Vol. III., p. 11), retained by the metal in the state of fine division, and therefore prejudices the forgeability. The excess of Si which remains in the metal in addition reduces the forgeability.

Aluminium acts on the oxygen in iron more energetically than manganese, but it cannot replace the good properties of the latter for the further working. In addition, its employment has disadvantages as a consequence; it makes the iron viscous, even with small additions, and increases the contraction so that the disposition to formation of cavities on solidification is greater.

Both aluminium and silicon possess a property which manganese does not, and which is very much valued for a certain purpose, *i.e.*, they hold gases dissolved in the metal in solution, so that these are retained on solidification. Aluminium was formerly frequently brought into use in large amounts in the manufacture of soft steel; on this ground during casting, small pieces thereof were thrown into the moulds, and as a consequence made metal rich in gas quieter. This dodge, nevertheless, does not require to be employed for the open-hearth process, since one is in the position, by means of correct slag composition and deoxidation by manganese alone, to produce metal poor in gas, so that one needs to employ costly aluminium only for special objects, and then only in small amounts.

(*e*) RECARBURISATION.

The deoxidised metal must finally be given the desired properties, of which the most important is the right degree of hardness. The hardness of the metal is in the main specified by the carbon content, which, therefore, must each time be introduced proportionately to the desired quality. As stated frequently already, all the remaining reducing agents can be eliminated in the open-hearth furnace before the carbon, so that it appears possible to break off the process at the desired carbon content, and thereby make recarburisation generally capable of being dispensed with. It is unfortunately not always possible to regulate the composition of the slag so exactly that it is exhausted of oxygen precisely at the moment desired, and one more often permits the metal to become lower in carbon, and therefore recarburisation must be resorted to. The same is usually only needed to a small extent, and admits of being accomplished by means of small quantities of spiegeleisen, or low phosphorous pig iron, and one is able to produce steels of the hardest kinds by these means without being obliged to carbonise by means of large quantities of spiegeleisen, or nearly pure carbon (Derby process).

Often other substances must be added to the metal for special purposes, *e.g.*, silicon, aluminium, nickel, chromium, etc., and it is desirable as much as possible only to make these additions after deoxidation, in so far as their physical properties do not forbid, and (as with aluminium or high percentage ferro-silicon) make the addition only during running out into the ladle.

(*f*) Phenomena in Casting and Solidification.

Steel has, in common with most substances, the property of occupying more space in the molten state than in the solid state. It, therefore, contracts on setting.

In the production of ingots, steel is cast into thick walled cast iron moulds, which rapidly absorb heat from the molten metal, and bring it to setting point at its exterior more rapidly than in the interior. The set portions shrink further on cooling, but to less extent than the molten interior on setting, and therefore cavities or faulty places must originate in the ingots.

Most fusible materials exhibit these properties, and H. M. Howe and Bradley Stoughton have established the same phenomena, which appear in steel ingots, in test ingots, of stearic acid (*vide* reference in "Stahl und Eisen," 1908, p. 118), and enabled them to render clear the cause of the same experimentally. The most essential conditions which determine size, state, and position of the cavities are the following : The absolute size of the cavities is dependent on the degree of the superheating with which the molten material reaches the mould, and increases with the superheating.

If the cooling down in the mould is at an equal rate throughout and progressing in the direction from outside to inside, the material sets in layers parallel to the walls of the mould, and originates a cavity which lies in the axis of the ingot and comes to an end at a certain length, somewhat as shown in Fig. 17.

But if chilling takes place unequally, so that only the bottom and side layers solidify whilst the upper portion remains liquid, this fluid material will sink down and hinder the formation of cavities and the entire defect of the material must manifest itself as a funnel-shaped cavity in the top of the ingot, of which the base is the larger, and the height the lesser, the slower the setting of the upper portion takes place. Inversely, in proportion as the upper portion sets more rapidly, the base of the funnel will be smaller and its height greater (*vide* Fig. 18.)

Finally, if chilling takes place in an unequal manner, so that one side of the ingot remains warmer and therefore remains fluid longer than the other side, the cavity will shift to this side, as shown in Fig. 19.

Generally, combinations of the three conditions obtain and correspondingly alter the shape and locality of the cavities in the ingot.

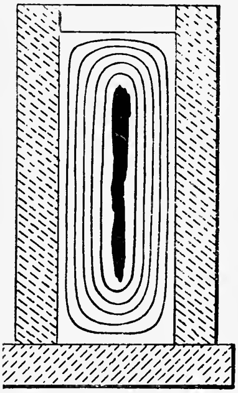


FIG. 17.

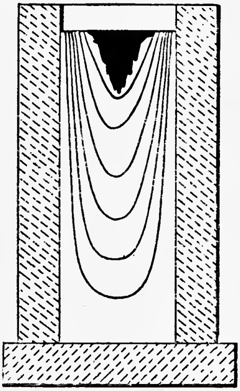


FIG. 18.

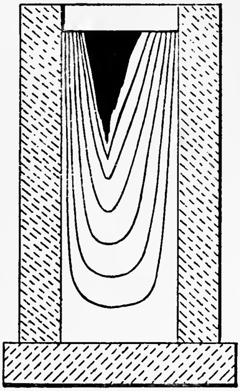


FIG. 19.

The magnitude of the cavities depends on the degree of superheating and admits of being influenced by the mode of casting. If one casts slowly, or permits (as for example happens in ascensional casting) the steel to rise slowly in the moulds, whereby much heat is able to be lost by radiation, the amount of the cavities or " pipe " is decreased. But it can never in this wise come below a specified minimum, and the absolute magnitude of the same must become greater the larger the ingots.

The explanation of the pipe formation indicates the means of reducing the harm thereof to a minimum. By prolonging the time in which the upper portion of the ingot solidifies, the piping is located at the top of the ingot and can be removed therewith. In order to achieve this in large ingots (over five tons) the upper portion of the mould is lined with a refractory material, which is preheated before casting, and thus absorbs much less heat from the molten metal than the walls of the chill mould beneath this. Further, the head of the ingot is maintained molten as long as possible by means of a gas flame or by so-called "pipe thermit," and feeding by means of hot molten steel as the molten metal sinks by contraction on solidification of the body of the ingot. Further detail as to this matter is to be found in Ledebur's "Eisenhuttenkunde," Vol. III., p. 237, *re* Riemer's Process; also "Stahl und Eisen," 1907, pp. 1119 *et seq.* A. Obholzer, "Prevention of pipe formation by employment of 'Pipe Thermit,'" and Ledebur, p. 245, "Hermet process," in which steel ingots are rendered, by means of presses, sound and of reduced dimensions.

No process which ensures practical results has yet been found for prevention of formation of pipe, in small ingots, and one must, therefore, be confined to employment of the proper casting temperature and thereby hindering the piping from attaining too great dimensions.

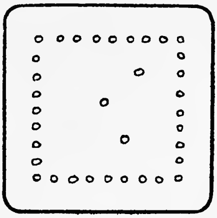
The phenomenon of segregation takes place parallel with the piping, that is to say, the separation of material which differs in its composition from the average composition of the material employed, and actually contains the impurities of the iron in much larger amounts. Segregation makes itself the more perceptible the greater the dimensions of the masses of steel, and it makes its appearance exactly like the pipe formation in the places which last remain liquid. It is hence possible in the main to limit them to that portion of the ingot which is later removed; that is to say, to the so-called "head." Moreover, one can thus make them less sensible, so that only the purest possible steel is produced.

The peculiarities of piping and segregation mentioned only make their appearance as described if the metal solidifies without evolution of gas. They may be partly or wholly covered up in other cases. Formation of gas on solidification of the ingot will in general be regarded as harmful, and often on this ground it is sought to hinder this in brands of hard steel by means of additions of aluminium or silicon.

In a special case, however, viz., in the production of soft ingot iron, which forms the main product of many open-hearth furnace works, this (evolution of gas on solidification) is able to be of considerable use, provided it does not exceed a certain limit. Soft metal properly manufactured, which has been deoxidised by means of manganese only, allows a portion of the gases to escape on solidification in a very regular manner, which, as always is the case, begins on the walls of the moulds, and proceeds in layers parallel to these.

The remainder of the metal remains so liquid that it admits of the passage of gases evolved, so that the solidified layers of metal retain no gas, and become quite sound. Only on the sound layer attaining a thickness of about 20 to 50 millimetres the metal in the interior of the ingot becomes viscous, thus causing some gas bubbles to be unable to escape through it to the atmosphere, and thus being retained in the metal. These group themselves quite regularly and form bubble zones parallel to the walls of the mould. The interior of the ingot, again, becomes quite sound and exhibits only odd irregularly-situated small blowholes. The fracture of such an ingot shows the class of appearance indicated in Fig. 20 herewith.

Fig. 20.



The total volume of blowholes require about the space which otherwise would have been taken up by the pipe; whilst still the latter may appear to some extent in small detachments in the ingot in the neighbourhood of its axis over a large portion of its length, but at best causes the head of the ingot to be quite unusable, whilst these portions are sound. The faulty places are divided over the entire ingot, in the form of small blowholes, which are filled with pure hydrogen and possess metallic surfaces. Therefore, the walls of the blowholes weld on being forced into contact by rolling or forging, or are actually made imperceptible. Thanks, therefore, to this peculiarity of the evolution of gas during solidification, it is possible to produce ingots of ingot-iron which show equal behaviour on rolling from top to bottom, and yield so little scrap that one might imagine they were pre-rolled blooms. Of course, this can only be attained if the deoxidation by manganese is practically complete, and casting takes place at a proper temperature. If the metal be cast at a too low temperature, it is able to give rise to blowholes situated too near the surface, forming so-called "brim holes."

With such bubbles, the thin outer surface of the metal often is burnt through in the re-heating furnace, and the fire gases reach their interiors and oxidise their surfaces. Such metal on rolling acquires scrafs and slag holes involving its rejection.

Soft ingot iron, manufactured in the open-hearth furnace from a manganiferous charge free from red shortness and tapped out without manganese additions, casts like a metal to which silicon or aluminium has been added.

It flows quietly like oil, and shows neither during casting nor setting the play of escaping gases, which detach particles of metal from the upper surface of the ingot, and allow them to burn with lively scintillations.

The ingots also become sound, but are deeply piped, or have bad heads.

Therefore, one willingly adds manganese to such metal, and always perceives from its action that the metal contains oxygen, and to such large amount that the carbon of the manganese is attacked by it. Then again on casting, the play in the mould takes place and renders manifest the formation of CO. One again obtains faultless ingots with good interiors and heads, with the characteristic arrangement of unharmful small blowholes.

CHAPTER XXII

THE PRINCIPAL METHODS OF WORKING THE BASIC OPEN-HEARTH PROCESS

(a) *The Pig and Scrap Process.*

The oldest and most widely distributed mode of open-hearth steel-melting is the pig and scrap process. This allows of working with a high per cent. charge of old iron (called scrap), and furnishes thus the means of regenerating huge amounts of iron which are daily withdrawn in all orders of human activity as having become unusable. Nevertheless, one cannot exclusively employ wrought iron or steel scrap, since the amount of reducing agents contained therein do not suffice to take up the oxidising action of the gases of the flame. It soon became apparent that pig iron was the most suitable material through which reducing agents lacking in the scrap could be added. Pig iron is a concentrated solution of several reducing agents in iron, and various advantages arise due to this. Firstly, pig iron melts much more easily than scrap. Therefore, it forms itself soon into a pool of molten metal in the furnace in which the remainder of the charge dips, whereby this also more rapidly attains fusion. The reducing agents already in the dissolved state in the pig iron thereby distribute themselves over the whole mass of metal when it becomes fused, and this thus obtains an equalised and desirable composition for the process. The value of the individual reducing agents for open-hearth furnace working is different; therefore the course of the same depends to some extent on the selection of the reducing agents, and consequently the quality of pig iron to be employed.

Silicon causes an increased heat demand, and therefore appears undesirable. On the other hand, silicon is easily oxidised, and facilitates considerably the formation of slag, since the resultant silica is capable of dissolving much scale. Since, however, additional silica generally comes into the furnace in not inconsiderable quantities as an impurity of the metallic charge, and the additions in the furnace, and since this substance is the cause of the formation of large quantities of slag, a high silicon is not willingly employed ; it is frequently fixed at not more than 1 per cent. in the conditions attached to deliveries. In localities where scrap is considerably cheaper than pig iron, and where it is, therefore, most advantageous to work with the least possible pig iron, one may dispense with this restriction. Therefore, the risk is taken of having as much reducing agents as possible in the pig iron, as in the foregoing case ; or also, if an after-addition of reducing agent is required for a too soft charge, one may employ highly siliceous brands of pig iron without reason to fear outstandings. It then involves, of course, taking quite special care in regard to the purity of the remaining materials in respect of high silica impurities.

In the open-hearth process, carbon plays the weightiest rôle of all the reducing agents. Its combustion diminishes a little the heat required, but its main action rests on the property of liberating a gaseous product of oxidation, which originates in the interior of the metal itself, and thereby brings the bath into motion, thus favouring exchange of heat between the flame and bath, also good reaction throughout the latter is rendered possible ; and through this alone the open-hearth process is capable of being carried out. The most favourable course is directly produced by the carbon content of the bath being correctly adjusted.

Now, the conditions under which pig iron is produced in the blast furnace admit of regulation of the carbon content only to a limited extent, because at the temperature employed a metal saturated with carbon always results. Therefore, prescriptions cannot well be made for the carbon content of the pig iron, and it remains the task of the open-hearth furnace manager to correctly adjust the percentage of pig iron to scrap to suit the carbon content of the mixture.

In the open-hearth furnace, phosphorus likewise gives rise to a slight gain of heat, but nevertheless it is also an undesirable addition in the pig and scrap process, in the basic open-hearth furnace.

In most cases, a phosphorus content up to about 0·5 per cent. is actually self-acting, and therefore removed without trouble, but larger amounts of phosphorus make themselves disagreeably sensible, as is clearly apparent from Harbord's trials at Bilston, quoted on pp. 173 and 192.

This is due to the circumstance that dephosphorisation is only achieved in the basic open-hearth furnace if after its removal from the iron the phosphorus is able to go over undestroyed into the stable form of calcium phosphate. Such large amounts of iron peroxide are requisite for dephosphorisation that not only dephosphorisation as iron phosphate may occur, but that adequate iron peroxide remains over, to be engaged on the carbon so long and to hold it from the iron phosphate until in time its decomposition is completed.

In the pig and scrap process, such like amounts of iron oxide are not, however, at disposal, and therefore any iron phosphate by chance formed must be again at least partially decomposed by carbon, and thus a corresponding amount of phosphorus returned to the iron.

Hence, purification of the bath takes place only slowly, and a final product must be produced, which has taken up large quantities of oxygen and is therefore superoxidised.

Nevertheless, working with highly phosphoric pig iron is possible in the open-hearth furnace, but only by employment of an artifice. The bath must then be charged with an excess of carbon, and a large amount of ore must be added immediately after melting down. The removal of phosphorus takes place immediately, and also the change into lime phosphate can be accomplished without difficulty. The high carbon content hereafter consumes the oxygen of the ore added. The reduction of the ore necessitates, however, a higher heat demand, and thereby causes a protraction of the process.

The employment of highly phosphoric pig iron consequently involves a deviation from the pure pig and scrap process, and the method approximates to that of the pig and ore processes, to be described later.

In the real purely pig and scrap process it is sought so to regulate the quantity of the reducing agents which are added to the charge in the form of pig iron, that they contain exactly the balance for the oxidising action of the flame, and the employment of large amounts of ore is not requisite. If this has been well adjusted, the conditions for the best working results have been created.

This may, however, be equally well achieved when employing the most varied kinds of pig iron, highly phosphoric excepted, and owing to this, the open-hearth process possesses a great advantage over the pneumatic refining methods, which are only able to be conducted with pig irons of quite definite composition, with the result of variations being permissible only within quite narrow limits.

Also, the chemical composition of the scrap for the basic open-hearth process is quite immaterial ; but the external condition of the same has a certain importance. Neither too large nor too small pieces are most convenient for manual working. Rusty charges come into consideration in so far as owing to them an increase in percentage of reducing agents, and thus of pig iron, is required, and that involves in the case of the production of a first-class quality an increase in the manganese content of the mixture.

Furnaces were charged by hand until recently, and then good scrap meant an economy of time in charging, but by employing charging machines, this condition, of course, vanishes. Nevertheless, in this case also, medium-sized scrap possesses an advantage, since melting down takes place more rapidly than if very large or very small pieces are employed.

A good charge, of full weight, melts in three to four hours; soon thereafter the boil begins, which, if the pig iron percentage has been correctly adjusted, reaches its highest point after about half-an-hour, and thereafter diminishes again. In about a further half-hour the boil becomes quite faint; the bath has reacted throughout, and has thereby come up to the necessary temperature for casting ; and the slag is exhausted of oxides. In former times no attention was paid to the latter condition. A harmful influence on the metal was always attributed to the slag, and therefore it was sought to remove it as much as possible from the furnace before proceeding with improvement of the metal, *i.e.*, deoxidation. But the removal of the slag, especially with fixed open-hearth furnaces, cost much trouble and, above all, time. Latterly, it has been recognised that a slag low in oxides is unharmful. Therefore, such are now aimed at and are left in the furnace until the end of the process. In this case deoxidation can be accomplished in a few minutes by means of an addition of about 0·75 per cent. of 80 per cent. ferro-manganese, after which the charge is ready for tapping. All reactions proceed practically spontaneously, also the regulation of the heat, and the entire process requires only little superintendence and aid. This method of steel-melting is, therefore, very easy to carry out, and is in all respects convenient.

It has been already mentioned on pp. 188—191 that in most furnaces, in the pig and scrap process, approximately 2·5 to 3 per cent. of oxygen (taken on the weight of the metal) is taken up by the bath owing to furnace action, whereby about 1·2 per cent. C, 0·3 per cent. Si, 0·6 per cent. Mn, and 0·2 per cent. P are removed from the charge, and, in addition, about 1 per cent. iron is burnt. The oxidation of all these substances influences the quantity of heat to be delivered by the furnace, in such wise that heat gains per kilogramme steel are given rise to as follows:—

From formula (62) 1·2 per cent. C × 14 = 16·8 calories.
,, ,, (61) 0·6 ,, Mn × 17 = 10·2 ,,
,, ,, (60) 0·2 ,, P × 11 = 2·2 ,,
Total heat gains 29·2 calories less loss as under;
from formula (58) 0·3 per cent. Si × 15 = 4·5 ,,
Or net heat gain 24·7 calories per kg. steel.

That is to say, the furnace work is diminished by the above amount, whereby the heat requirement for the production of 1 kilogramme steel is placed at about 325 calories. This heat gain is, however, counteracted if the charge is admixed with 0·5 per cent. SiO_2, since 1 per cent. SiO_2, according to formula (59), involves a heat absorption of 43 calories.

The elimination of the reducing agents gives rise to a loss of weight or loss of charge of 1·2 per cent. C, 0·3 per cent. Si, 0·2 per cent. P, 0·6 per cent. Mn, 1·00 per cent. Fe, or a total of 3·3 per cent., so that an output of 96·7 per cent. must result. Of this, however, some metal is always scattered in casting, and goes for practical purposes irretrievably into loss, so that one can only reckon on about 95 per cent. output with an ideal pig and scrap process.

Although it very frequently happens that one can adjust the pig addition so exactly that the process can be carried out to the end in the manner described, without aid, still it is not always possible. If it should be somewhat too small, the bath cannot rightly attain the "boil," and spiegeleisen or pig iron must be further added according to the stillness of the bath. But this always indicates a not inconsiderable lengthening out of the process, and therefore it is sought throughout to avoid a too small pig iron charge, which works too "soft," or has as a result a "set" charge. Somewhat too much pig iron rather than too little is most preferably provided. In order to obtain evidence as to the composition of the metal at the proper time, tests are taken from the bath during the "boil," which are investigated as to their degree of hardness by the mechanical test methods. If thereby it is perceived that the carbon content of the bath is higher than necessary, then the process is accelerated by means of some shovelfuls of ore, which, added to a hot bath, cause a more violent boil, and an increased elimination of carbon. In this manner, a small excess of reducing agents is rendered unharmful, without perceptible expenditure of time.

The process is rendered more difficult if the scrap does not consist of pieces of desirable sizes. Very large, massive pieces melt with difficulty, and crops off ingots of large section lie longer in the remaining molten metal before they completely melt down. Small-sized scrap admits of being worked with still more difficulty, and turnings especially set up easily important conditions. If one introduces such-like material in large quantities into the furnace, the upper layer fuses rapidly, but the fused portion sets again by sinking in the pile, and thereby the under-portion of the charge becomes a compact mass, which contains a whole quantity of occluded air, which, as a bad conductor of heat, renders the entrance of heat more difficult, and considerably delays the melting down. Between whiles the carbon content of the already melted materials is slowly used up, and the bath can then in general not again reach a "boil." Therefore, scrap requires higher percentage of pig iron in the charge the smaller its pieces.

Silica, which reaches the furnace as an impurity, exercises a further unfavourable influence. Owing to being the cause of a considerable increase in the quantity of slag, the furnace must liberate much more heat in the production of a specified quantity of steel. Silica adheres to pig iron usually in larger amounts than one believes, and especially if the pig iron is cast in sand; a sand covering of 2 or more per cent. is not rare, but also the scrap brings sand into the furnace, and generally the more, the smaller sized the scrap. Shearings, punchings, turnings, and the like admit generally only of being taken up from the flooring by the shovel, and thereby it is unavoidable that certain amounts of sand and earth are picked up, and then also get into the furnace. Silica, in the form of remnants of refractory materials, often adheres to the scrap produced in steel works, and is frequently charged with it into the furnace because, very wrongly, the cost involved in the removal of the same is shunned.

The diminution of output, which is occasioned through employment of unclean material, makes itself more felt than the increase of heat demand mentioned. There are, for the greatest part, sand on the one hand, and, on the other hand, rust on the scrap, paint on old roofing sheets, and tin and solder on tin sheet scrap, completely weighed in with the iron, and as such placed in the reckoning, and in this manner a considerable loss of charge is given rise to. As to this, for each 1 per cent. of SiO_2, 0·5 per cent. iron must go into the slag (according to formula 45), and if this amount also is not very considerable, it is, nevertheless, so large that it cannot be overlooked.

If, for example, the ideal charge before-considered, which yielded 3·3 per cent. charge loss, be taken as being impurified by 4 per cent. SiO_2 and 1 per cent. of other impurities, it will fix the charge loss at $3{\cdot}3+4+4\times0{\cdot}5+1=10{\cdot}3$ per cent., and since on casting about 1 to 2 per cent. can be lost, at a total of 12 per cent., so that the output would amount to only

88 per cent. But that is a result which occurs likewise in the Bessemer process, or is even more unfavourable than in this. It can, nevertheless, be still worse if the process is terminated without complete utilisation of the iron content of the slag. Such-like methods of working are at the present still practised in many places, whereof the best evidence is given by the slag analyses, which are set out on p. 175, in which up to above 18 per cent. Fe may be found.

Owing to a high iron content in the final slag, a considerably higher requirement of ferro-manganese, and therewith an increase in the manufacturing costs, is caused in addition. In illustration of these disadvantages, let some data be furnished which issue from some works which were compelled to work exclusively with bad scrap, and of that much tin sheet scrap, and as little as possible pig-iron, which contained very little manganese. The normal duration of the "heat" was seven to eight hours with 12 to 13-ton charges; the loss of charge amounted to 10 to 12 per cent, the metal was strongly oxygenated, and required 1·2 per cent. ferro-manganese for deoxidation. The normal final slag had (after resultant manganese addition) the following composition:—

27 per cent. SiO_2, 9 per cent. FeO, 5 per cent. Mn,
47 per cent. CaO, 8 per cent. MgO, 3 per cent. P_2O_5.

A "heat" from a like charge, but which had melted down too soft, necessitated several additions of spiegel and pig iron; since, however, these had evidently not been correctly adjusted, the heat remained fourteen hours in the furnace and required 3·25 per cent. ferro-manganese for deoxidation. The material, in spite of this, was of very inferior quality. The composition of the final slag, with

16·17 per cent. SiO_2, 19·32 per cent. FeO, 6·18 per cent.
Mn, 36·4 per cent. CaO, 16·14 per cent. MgO, and
2·5 per cent. P_2O_5

shows clearly the cause of the failure; a deficiency of reducing agents ruled, and thereby the oxidising action of the furnace could not be sufficiently taken up.

The great difference in price between individual pig irons and kinds of scrap makes it in many localities impossible to admit of providing the furnaces only with good charging materials, and one must often work with much inferior material, if not even exclusively such. Therefore, naturally, disadvantages in buying obtain. Such market conditions are the cause that, by degrees, the sub-methods of steel melting described below have been built up. Their result under the unfavourable conditions is also an evidence of the adaptability and the elasticity, and thus also of the perfection of the Basic open-hearth process.

(b) *The Scrap-Carbon Process.*

There are localities where scrap is a drug on the market and is to be had at low prices, whilst pig iron is only able to be procured at high prices. Under such conditions good service can be rendered by a process for which Leopold Pszczolka, of Graz, took out a patent in the year 1890. According to this process, the deficit of reducing agents in the charge was aided by additions of the most active of all, namely, of carbon, in the forms given below, in that for each 1 per cent. deficient carbon, 1 to 1·5 per cent. graphite, anthracite, or coke; of 2 per cent. coal, 2·5 to 3 per cent. brown coal, or 5 per cent. dried wood was added.

According to Schmidthammer (Stahl und Eisen, 1906, p. 1248), for each unit of carbon to be added, 1·5 to 2 units of coke is added, which is ground up, in order that it be able to be taken up more rapidly. In order to protect it as much as possible from burning, it should be mixed with about five times the amount of turnings. The rich carbon material so obtained is appropriately placed bottom-most in the furnace and covered with the remainder of the charge. In this manner working 100 per cent. scrap is achieved, *i.e.*, entirely without pig iron.

This carbon can, however, only be taken up by the metal, when the same is melted down or, at least, has reached the pasty condition. Since, with scrap, very high temperature is necessary for this, it is clear that melting down is much more prolonged than when pig iron is used, and, further, the formation of larger amounts of scale is caused. Thus again, more carbon must be brought into the bath than is necessary with the pig and scrap process, the after-removal of which prolongs the process, and thus working without pig involves still further expenditure of fuel.

Further, there is a deficit of silicon from pig iron, on which ground care should be taken that the necessary amount of SiO_2 for slag formation is at the disposal of the bath. A deficiency is not to be feared with bad scrap, but with good scrap it may well take place, and then an addition of good final slag from a previous charge is to be recommended.

In charges consisting solely of scrap the manganese is low under all circumstances, which must have, as a consequence, metal containing oxygen, which again requires increased additions of ferro-manganese for deoxidation. This defect can sometimes be redressed by means of additions of manganese ores.

The remainder of the course of the scrap-carbon process, which is seldom carried out, is the same as the pig-iron-scrap process. Dr. Ing. Th. Naske gives in "Stahl und Eisen," 1907, p. 191, an example of a charge of the sort. Sixteen thousand kilogrammes soft steel-scrap were charged together with briquettes which consisted of 320 kilogrammes small coke, 160 kilogrammes tar, and 420 kilogrammes Caucasian manganese ore containing 50 per cent. Mn, and 320 kilogrammes limestone and 10 kilogrammes river sand served as further additions. After melting down, the metal was soft, contained 0·66 per cent. Mn, and was free from red shortness. The "finished" test showed 0·45 per cent. Mn and 0·07 per cent. C, and the "heat" took 315 minutes, reckoned from the beginning of charging to tapping. The same furnace produces 20,000 kilogrammes steel in 280 minutes by the pig and scrap process.

(c) *The Pig and Ore Process with Solid Charges.*

The development of the open-hearth process admitted of the stocks of scrap present in the great centres of the iron industry being rapidly depleted, so that there soon began to be a deficiency of the usual good charging materials. In order to be able to carry it on further, one was compelled to resort to working with scrap of inferior value, and, as this material became dearer owing to the costs of carriage from further removed localities, finally to deal with an increase in the pig iron percentage in the charges. The excess of reducing agents which was thereby brought into the charges could, rationally, only be removed by means of corresponding additions of iron oxides, and one soon arrived at bringing this iron oxide into the furnace simultaneously with the metal, so that it became active during the melting down. By means of such artifice, one, of course, put out of reach observation of the details of the action, but one was enabled to obtain metal after melting down exhibiting the same composition as a pig and scrap charge at the same stage of the process. Only thereby much larger quantities of slag were given rise to than in the pig and scrap process. One attributed a harmful influence to this and, therefore, sought to remove the slag as much as possible as soon as it showed above the molten charge. One thereby also arrived at diminishing the amount of slag which remained in the furnace so far that the finishing of the charge was able to take place under somewhat like conditions to those usual in the pig and scrap process. Through such-like modes of working the demonstration was brought about in many localities that the convertion into steel of charges with larger percentages of pig iron, even of pig iron alone, is possible if oxygen in ore is used as an aid in adequate amounts. Nevertheless, the following difficulties were given rise to thereby:—

1. It much damaged the basic structure, since holes frequently formed in the bottom, there always took place a very great cutting away of the banks, so that the hearth repairs required considerably more time and material.

2. Large quantities of ore were required, and likewise the amount of limestone required increased, whereby the costs of the charge were raised.

3. The melting-down period lasts much longer with the increase of pig iron and ore additions, and therewith total duration of the "heat" as well as the coal consumption and the wearing away of the acid structure of the furnace.

Owing to all these circumstances, the production of the plant went down very much, whilst the manufacturing costs were increased in a manner that absolutely brought the pneumatic refining processes into competition.

The cause of all these defects admits of being well explained in the following manner: The easily fusible pig iron trickles down after melting and comes in contact with the ore, whereby the characteristic changes result, *i.e.* iron silicate and phosphate are first formed which dissolve iron oxide and now reach the bottom of the furnace on which they must exercise their action. Only when the quantities of molten metal become larger are the iron-rich slags forced away from the bottom and compelled to react on a larger scale on the limestone charged with it. It cannot at the outset, however, do this, since the ferruginous slag acts on all the reducing agents in the molten iron, thus also on the carbon, which gives with it, as is known, strongly endothermic reactions. The quantities of heat which reach the reaction zone with the melted iron are here consumed until the limit of the action of carbon on ore is arrived at. It is, therefore, impossible to permit of the origination of a hot bath of metal of uniform composition; most usually the under portion of the charge forms itself into a paste, which consists of ferruginous slag and particles of metallic iron, which in different places are unequally strongly pre-refined. This mass conducts heat somewhat equally as badly as bad small-sized scrap. The iron peroxide of the iron ore is thereby for the most part only reduced to iron protoxide, and the occurrences permit of being expressed by the formulæ:

$$\mathrm{Si+Fe_2O_3=SiO_3Fe+Fe.}$$
$$\mathrm{C+Fe_2O_3=2FeO+CO.}$$

One also sees clearly during the melting down that carbon monoxide issues by fits and starts through isolated canals which reach from the interior to the upper surface of the mass, which belch out small amounts of slag forming small craters round the outlet places, thus giving evidence of the work of the reactions taking place in the interior. Only after further time making the upper surface so hot is achieved that it forms itself into a proper bath of iron, which then afterwards liquefies the under layers. Only then has the temperature become high enough in order to set up the essential reactions typical of the basic open-hearth process, namely the transference of large quantities of iron silicates and phosphates into the corresponding limesalts and the reduction of iron protoxide set free to metallic iron. If the slag was allowed to run out of the furnace before the ending of the last-named reactions, the reducing agents were removed out of the iron, but their products of elimination were removed in a form which did not permit of the using up of the iron content of the ore. One had almost completely allowed this iron content to go to loss, and on the other hand attained a loss of charge which is approximately equal to the sum of all reducing agents in the pig iron.

But if the ore addition has not been exactly adjusted, some further defects manifest themselves. If it be too small, the metal after melting down contains more carbon than usual in the pig and scrap process, and under the influence of iron ore additions it effervesces; it forms considerable new quantities of slag, and the finishing of the "heat" is much prolonged.

If *per contra* the ore addition be too large, the metal becomes so soft that it admits of being melted with difficulty, and then much pig iron must be added afterwards, often causing trouble enough even to bring the charge out of the furnace.

To achieve the avoidance of the evils on melting down and to produce in addition favourable utilisation of the ore additions, even in that case it gives rise to larger absolute heat requirement than is necessary for the pig and scrap process. This surplus requirement admits of being estimated for each given charge, from the figures previously ascertained. For example, were a pig iron employed with 1 per cent. Si, 0·5 per cent. P, 2 per cent. Mn, and 4 per cent. C, of which during melting down there would be eliminated by the oxidising action of the furnace, say 0·3 per cent. Si, 0·2 per cent. P, 0·6 per cent. Mn and 1·2 per cent. C, there would remain for removal by means of the oxidising action of the furnace and ore, up to finishing, 0·7 per cent. Si, 0·3 per cent. P, 1·4 per cent. Mn, and 2·8 per cent. C.

During melting down, the heat required would be diminished by the oxidising action of the furnace as follows:—

0·2 per cent.	P ×11=	2·2 calories	(from 60)
0·6 ,,	Mn×17=	10·2 ,,	(from 61)
1·2 ,,	C ×14=	16·8 ,,	
	Total	29·2 calories	
Less 0·3 ,,	Si×15=	4·5 ,,	(from 58)
	Net	24·7 calories	

The heat required up to finishing would be increased by the action of the ore to the extent of:

0·7 per cent.	Si×65=	45 calories
0·3 ,,	P ×40=	12 ,,
2·8 ,,	C ×25=	70 ,,
		127 calories
Less 1·4 per cent.	Mn×7=	10 ,,
	Net	117 calories.

The surplus heat which would have to be provided per kilogramme steel would amount to 117 — 24 = 93 calories, or about 27 per cent., and would be still further considerably increased if the ore employed contained silica.

In conjunction with this, instead of a charge shrinkage of (1 per cent. Si + 1 per cent. Fe) + 0·5 per cent. P + 2 per cent. Mn + (4 per cent. C + 0·2 per cent. Fe) = 8·7 per cent., there must be produced a charge growth of

0·7 Si×1·00=	0·7 per cent.	*vide* (69)
0·3 P×2·00=	0·6 ,,	,, (71)
2·80C×1·47=	4·1 ,,	,, (75)
	5·4 per cent.	
Less 1·4 per cent. Mn×0·32 +above 2·3[1] =	2·75 ,,	,, (74) and foregoing.
Net	2·65 per cent.	

This provides some compensation for the great heat demand and for the higher cost of charge, which is to be attributed to the ore requirement.

It is not difficult to ensure this latter advantage if one adopts the mode of working which is given in the description of the pig-iron process with molten charges.

The figures ascertained for the increase of the heat required

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[1] Oxidising action during melting down.

show immediately that a considerable facilitation of the furnace working must result if the pig iron is introduced into the furnace in an already molten instead of the solid state. This appears adoptable without anything further in works which have their own blast furnaces. It will warrant to these works the further advantage that the blast furnaces are spared the costs of casting the pig iron into pigs, and breaking and carriage of the same. Of course, the oxidising action of the furnace during melting down will be lacking, whence the ore addition must undergo a further increase.

For pig iron of the previously assumed composition, *i.e.*, 1 per cent. Si, 2 per cent. Mn, 0·5 per cent. P, and 4 per cent. C, one would proceed thus. Such a metal must give rise to a charge growth of

1 per cent. Si × 1·00 = 1·00 per cent.
0·5 ,, P × 2 = 1·00 ,,
4 ,, C × 1·47 = 5·88 ,,
7·88 ,,
Less 2 per cent. Mn × 0·32 = 0·64 ,,
Net 7·24 per cent.

This is thus 4·59 per cent. more than yielded by the preceding, whilst the increased heat required per kilogramme steel must be as follows:—

1 per cent. Si × 65 = 65
0·5 ,, P × 40 = 20
4 ,, C × 25 = 100
185
Less 2 ,, Mn × 7 = 14
Net 171 calories.

If the pig iron be introduced into the furnace with an available heat of 250 calories, there would be received from the pig iron $\frac{250}{107\cdot24}=233$ calories per kilogramme steel. Thus the pig-iron process with molten charges, with respect to the amount of heat required from the furnace, appears at the least not less advantageous than the pig and scrap process.

(d) *The Pig-iron Process with Molten Charges.*

The pig process with molten charges has been sought in many quarters, though it has generally yielded few favourable results. H. H. Campbell sees the main difficulties in this process in the powerful effervescence of the bath during the first period of decarburisation, owing to which working is very inconvenient in ordinary fixed open-hearth furnaces. The bath rises, and slag, indeed also metal, reach the acid portions of the furnace structure, at times even flowing into the regenerator chambers, thus soon bringing the furnace to an early stoppage, if one does not elect to permit slag to run over the door sills on to the working platform, whereby again approach to the furnace is rendered difficult, or made quite impossible. Campbell overcame these difficulties by means of employing a tilting furnace of his own design, which differed from the Wellmann construction, in that the gas and air ports, and therewith the heating action, did not require to be broken off when the furnace was tipped. Molten pig iron was introduced into this furnace direct from the blast furnace on to properly prepared quantities of ore and limestone. Campbell describes the course of this process as follows (p. 211):—

"During the combustion of silicon, no violent reaction occurs, but immediately afterward a general movement takes place, whereupon the furnace is tipped over until the metal is thrown away from the doors and up on the back side. In this way, the capacity of the furnace is practically doubled, while the flame enters and goes out as usual. The furnace is kept in this position for two or three hours, until the bath has quieted down. Meanwhile, the slag is trying to froth out of the ends of the furnace and down the ports, but to do so it must flow over the open joint between the ports and the furnace. This joint is not wide, but special provision is made to allow the slag to run out through a small hole and fall down beneath the end of the furnace in a slag pit. In this way, a considerable quantity is removed, and the time of the operation lessened."

Further, he says:—"This practice of using direct metal has been in more or less continuous use for several years on furnaces of fifty tons capacity. Working in this way, the iron of the ore is reduced in such quantity that the product of steel, counting both ingots and scrap, exceeds the weight of pig iron charged by from 4 to 6 per cent. when the charge is entirely pig iron."

Campbell thus obtained very good results, but he found apparently no very great advantage in the same, since he asserted that he had also obtained nearly equally good results with pig iron charged cold. A fifty-ton furnace, which was charged with cold charges prepared from 97·5 per cent. pig iron produced, in the year 1896, 437 tons of steel in a week, which is equal to a month's production of 1,894 tons. Campbell states further that working with direct metal, contrary to pointing to a revolution in the steel industry, involves disadvantages up to a certain extent, and did not save as much time as one would have expected. Experiments in many other localities yielded, so far as known to the author, much less favourable results. Talbot was the first who guaranteed to obtain higher production by working with molten pig iron, than by the employment of solid charges. This depends principally on the higher output and the advantages which are attained by his method.

(1.) The Talbot Process.

Talbot proceeded on the general assumption that decarburisation proceeds with the greatest intensity if the carbon content of the metal amounts to under 1·5 per cent. In order to bring the high carbon content of the pig iron down to this amount, he adopted the artifice of diluting the pig iron by means of a larger amount of molten steel. As an apparatus, he selected a large tilting furnace, originally of 75 tons capacity, in which at first about 40 tons of steel were produced in the usual way. After complete decarburisation, iron oxide in the form of ore or roll scale was added and heated up, whereon then about 10 tons of molten pig iron were added. A very lively reaction ensued, by which Si, Mn and P were completely eliminated, and carbon partially so, to an extent which corresponded to the quantity of heat stored up. During pouring in the pig iron the action was always so powerful that gas and air must be shut off, and in spite of that a flame given rise to by the CO formed blew out of the furnace doors. The metal was thereafter exposed to furnace action, and completely decarburised in a short time. When the furnace was filled up in this manner he began to cast therefrom in regular periods, whilst corresponding quantities of ore and pig iron were thereafter charged. The process became a continuous one in the manner described. But only decarburised metal is obtained in the furnace, and recarburisation in the ladle must be adopted, since otherwise the ferromanganese required would be inordinately increased.

At the commencement, it was feared that much destruction must be caused by damage to the bottom. It has, however, proved that these fears were groundless, inasmuch as the reactions take place in the upper portion of the bath, and the actual bottom does not become injured. On the contrary, the banks are attacked at the slag line and must be repaired after each charge, which, however, is able to be done without difficulty.

Since melting down is saved by such a method of working, and the treatment of metal is set up when it is of similar composition throughout, to a pig and scrap charge, on completion of melting down, and since this admits of finishing in a short time, one ascribed to the Talbot process the capacity of achieving very large production. One overlooked that carbon elimination by means of ore gave rise to a large heat requirement, which Campbell had pointed out as a result. In addition, also, the pig iron must be heated up from the temperature of molten pig iron to the higher temperature of castable steel, and the furnace must furnish the entire demands of heat likewise. But this requires time. On this ground, the expectations as to the productive capacity of the Talbot process were not quite fulfilled, and it was sought to enforce the object in view by increasing the capacity of the furnaces.

K. Poech describes in "Stahl und Eisen," 1906, p. 1301 *et seq.*, the newest Talbot plants of the Cargo Fleet Works in Middlesbrough, and the Jones & Laughlin Steel Company in Pittsburgh.

The former comprises three tipping furnaces of 175 tons capacity each; the latter has furnaces with a capacity of about 200 tons. The method of working is essentially the same for both plants. After pouring off 50 tons of steel, the additions of ore and lime are next charged and heated up, and whilst they melt, the necessary repairs at the slag line, which should be much less than with fixed furnaces, are taken in hand. As soon as the additions are melted down, the first ladleful of pig iron is run in. Hereon again additions are charged, and on these is poured the second ladleful, which always exercises a much smaller reaction. Special value is laid on obtaining as complete reaction as possible, after teeming in the pig iron. After this, the bath contains only about 0·3 per cent. C. The larger the amount of pig iron poured in at a time, and the higher the silicon content of the same, the livelier reaction takes place. If the bath has quietened down to some extent, after the second addition of pig iron, a portion of the slag is removed, since too thick a slag covering hinders the finishing. The ferro-manganese is added in the casting ladle. In spite of decarburisation appearing from the description to take place so rapidly, a charge of 50 tons is only tapped off every six hours, which is thus equal to a production of 200 tons per diem. The first furnace produced in the first twelve working weeks somewhat less, namely a round 1,000 tons per week, or 120 kilogrammes steel per minute. The coal consumption amounted to approximately 25 per cent., the output (taken on the weight of the metal charged) to 105·7 per cent.

The condition that tilting furnaces are required, the building of which is very costly, is mainly the cause of the process having found relatively small adoption. A. Surzycki sought to make it adaptable to fixed furnaces, by means of providing several tap-holes at different heights.

(2.) THE COMBINED PROCESSES.

Two other processes, which enable the open-hearth furnace to work pig iron without scrap, are the combined processes, namely the Witkowitz duplex process and the process of Pszczolka-Daelen. Both are based on the idea of removing the greatest portion of the reducing agents from the pig iron before it is introduced into the open-hearth furnace. As a suitable pig iron for this process, Witkowitz employs one which contains enough silicon in order to admit of being decarburised in an acid-lined Bessemer converter, not to become too cold thereby, whilst on the other hand, the phosphorus content is so high that treatment in a basic hearth must follow and is nevertheless too low in order to permit of treatment in a basic Bessemer converter. Metal taken from the blast furnace is desiliconised and decarburised down to about ·1 per cent. in the acid converter, whereon it is transferred to the open-hearth furnace and there dephosphorised by means of ore additions, and simultaneously decarburisation proceeds to finality. The demands on the open-hearth furnace are considerably reduced thereby, the time of treatment is short, and the furnaces attain quite double the production which they could turn out by the ordinary pig and scrap process with cold charges. The process requires, however, a complete Bessemer plant, which is costly to build and work, on which ground it has found few imitators.

L. Pszczolka sought to remedy these defects by means of employing the transport ladle (which conveyed the molten pig iron from the blast furnace to the open-hearth furnace) for the pre-blowing. He saved the requisite blowing engines by means of taking the blast from the blast conduits of the blast furnaces. In order to be able to utilise this blast for pre-blowing in spite of the low pressure, he did not admit it, as occurs in the Bessemer converter, by passing it upwards through the iron, but it acted on the upper surface of the same. Since, moreover, the manufacturing costs in the open-hearth furnace are smaller if the silicon content of the pig iron is low, but one cannot well employ cold blast with a pig iron with less than 1 per cent. Si, so Pszczolka-Daelen employed the blast from the hot blast conduits by means of the available heat of which, as well as the heat developed from the combustion of the CO developed in the iron, the deficiency of silicon in the iron would be compensated for. The process is nevertheless fettered apparently by many difficulties; at all events it has not been capable of adoption. It shares equally with the Witkowitz process the disadvantage that the reducing agents in the iron are completely lost, and that a not inconsiderable loss of metallic iron takes place in addition.

(3.) THE BERTRAND-THIEL PROCESS.

This process, the first patent for which was taken out in the year 1894, was first carried out with solid charges, as also Monell's process described hereafter. Great results were, however, only achieved after resorting to molten charges.

It was originated on the assumption that the large quantities of slag proceeding from the elimination of the reducing agents must unfavourably influence the process if the "heat" were burdened with them to the end, and this assumption made it appear advantageous to divide the process into two operations, rendering possible the removal of the slag which occurred in the first operation. It proved that in the main Si, Mn and P were removed in the first operation, whilst the carbon content was only reduced about one-third.

This first portion of the process is, therefore, uncommonly like the Krupp process, but since it is conducted in a basic open-hearth furnace, which permits the attainment of higher temperatures, it achieved the immediate decomposition of the iron silicates and phosphates almost completely into the limesalts, and reduction to a minimum of the iron content of the resulting slag. Owing to this, the possibility increased of better utilisation of the materials charged, and simultaneously of yield of metal.

As shown by the statements on p. 183, in the case of only partial decarburisation, one can diminish the quantity of slag due to 1 unit SiO_2 to 2·9 units, whilst in the case of complete decarburisation this rises to 4·78 units. Therefore, an interruption of the process at a lesser decarburisation involves the products of elimination of silicon, manganese and phosphorus going over into a more concentrated form than is otherwise possible, thereby giving rise to a diminution in the quantity of slag, and as a consequence also of total heat required.

The first advantage, namely, greater concentration of SiO_2, and P_2O_5 in the slag is fully attained actually. The second, however, the diminution of the total amount of slag and its influence on the total heat requirement is, owing to another condition, made illusory. After ending the first operation the bath is tapped out, and thereby the metal is freed from the slag in the most rational way; and it arrives free from slag in the second furnace. Here it should be freed from the remainder of the carbon content, but for this a specified amount of slag is necessary, in order that sufficient amounts of dissolved iron oxides should be at the disposal of the carbon. This quantity of slag must be thus created afresh. Since silicon, which alone admits of spontaneously producing molten iron silicate, is now no longer present in the metal, this must first be formed in the furnace from iron oxide and silica, and for this a larger supply of heat is required. In addition, with employment of very pure ore, it may occur that too little silica is present and new additions of silica be required.

The process, for which originally two furnaces were employed (of which the one was placed higher and tapped directly into the lower), was later modified, so that the furnaces lay alongside each other; the charge from the first furnace was tapped into a ladle and this then lifted up and its contents transferred to the second furnace. Nowadays the process is carried on according to Hösch's patent in a single furnace, from which the metal is tapped after the first operation, and immediately after the removal of the slag put back again into the same furnace.

As to the working results which have been obtained by the process in modern times, H. Darby and G. Haddon communicated to the Iron and Steel Institute (Vol. I., p. 122, 1905) that the production of a group of two furnaces, of which the first contained 15 tons and the finishing furnace 20 tons, amounted in five days to 908,435 kilogrammes steel, which per furnace and day amounts to 91 tons, in connection with which were required: 26·7 per cent. coal for the producers, 5·1 per cent. basic material, 8·3 per cent. lime, and 6·3 per cent. limestone, 22·3 per cent. Swedish ore, and 3·4 per cent. roll scale, against which a yield was attained of 104·02 per cent., and in another experimental series 104·5 per cent.

The slag of the first furnace when employing highly phosphoric pig irons is very rich in phosphoric acid, and is therefore equally valuable if not still more valuable than basic Bessemer slag. This will be discussed later.

(4.) The Monell Process.

In the year 1900 Ambrose Monell, of Pittsburg, took out a patent for a process to render possible the employment of pig iron in ordinary fixed open-hearth steel furnaces. It is characterised throughout by dephosphorisation of pig iron taking place before removal of large quantities of carbon, if ore in sufficiently large amounts is brought into action.

In carrying out the process, first a portion of the charge is charged cold into the furnace; then the usual lime addition together with ore equal to 20 per cent. on the weight of the iron. Afterwards the entire preparation is heated up to a red heat, and the remainder of the pig added thereon in the molten form. A lively formation of basic slag takes place with rapid oxidisation of the phosphorus, silicon and manganese, and a portion of the carbon.

Obviously here also the remaining in the furnace of the slag obtained was regarded as harmful, since it was specified that of this slag up to 80 per cent. should be drawn off after about an hour, and the metal should remain nearly uncovered. It was then decarburised in about five hours by means of further additions of ore. The process shows a gain in time over the usual, for in 40-ton furnaces it admitted of making 18 instead of 11 charges per week.

In the year 1902 Monell and Rees-James improved the process by employing the entire amount of pig iron in the molten state, and only charging it after the additions (25 per cent. sinter and 6 to 7 per cent. lime, on weight of pig iron) were already heated to a white heat. Then, after a short time, 80 per cent. of the slag was removed and with rise of temperature and further additions of sinter it was decarburised in four hours or more.

(5.) Pig and Ore Process with Molten Iron in Ordinary Fixed Open-Hearth Furnaces.

Shortage of scrap was also the cause of the general adoption of the pig and ore process in the South Russian works of the Donetz-Jurjewka Company.

This stimulated the desire by study of the theoretical heat problem to render useful the large quantity of heat stored in the molten pig iron from the blast furnace, and which is lost in ordinary methods of working.

The first result was knowledge of the differences in energy change, which took place by the reactions between iron ore and the reducing agents in molten pig iron, and it was concluded therefrom that the elimination of substances, the reactions of which were exothermic, might in no wise lay claims on the heat liberation of the furnace, that the heat thereby set free must be previously usable by contributing to assistance of the endothermic carbon reaction.

Further, since generally two substances react with greater intensity the more concentrated their solutions, it was to be expected that with the object of successful elimination of the carbon it was not necessary to dilute the carbon content of the metal down to approximately 1 per cent. as Talbot did, whose process was at that time known.

The correctness of the above conjectures was confirmed in the main by experiments, in which first solid pig iron without scrap and without other additions were melted down in the open-hearth furnace itself, and thereafter refined by means of additions of ore, and then there were also made charges of molten pig iron direct from the blast furnace, and thereby the heat saved employed in melting down solid pig iron. Immediately from the beginning the process yielded favourable results.

In its further development, stress was placed on utilising as much as possible all materials used for the charge, and thus economising with the utmost care the iron content of the ore requisite. It proved that it was by no means necessary to remove the highly ferruginous slags originated at the commencement of the process. On the contrary, the knowledge was more and more established that the slag is nothing more than the solvent for the requisite chemically combined oxygen, and that a large quantity of slag by no means exercises the harmful action which was manifestly almost always attributed to it. An ample quantity of slag proved itself rather useful, if it were not quite inordinately large.

One further perceived that the removal of highly ferruginous slags from the furnace involved not only the corresponding loss of iron from the ore, but a diminution of the growth of the charge which the reducing agents were capable of producing. Slag drawn off contains iron principally in the form of the protoxide, which is formed from the iron peroxide added, as a corresponding portion of the reducing agents of the metal are oxidised, which naturally readily are lost; that is to say, a charge shrinkage must result. Charge growth can only result if the protoxide is reduced to metal. Therefore, iron protoxide only is the truly valuable oxidising agent for the open-hearth process, which, after it is once produced at a sacrifice in the furnaces, should now be also completely utilised. On this ground then (in opposition to the remaining known processes) measures should be found which are capable of preventing a loss of such ferruginous slags.

The process was generally carried out by employing 20 tons of molten charges in furnaces built for 25 tons for the pig and scrap process. In the result, increasing the depth of the bath by raising the ports and door openings was resorted to, and thereby brought the capacity of the furnaces to 30 tons of molten pig iron without alteration of the dimensions of the regenerator chambers.

At the beginning of the process the requisite additions of limestone and ore were first brought into the furnace, and the door sills heaped up so high with coarsely-ground limestone, that the frothing over of the bath by lively reactions was not to be feared. With as little loss of time as possible then, molten pig iron was poured into the furnace, thereby avoiding a more intense preheating of the ore. Forthwith, on contact of the molten pig iron, the exothermic reactions ensued, and indeed so quietly that production of the flame was not checked. After a short time, the carbon elimination set in, ultimately growing up to full intensity. The slag rose up and became frothy, and from its upper surface carbon-monoxide gas issued on a large scale. One could thereby very well observe the influences which on the one hand from the formation of carbon-monoxide from the bath, on the other hand from the pressure of the flame gases in the combustion chamber of the furnace exercised on the extent of the foaming up of the slag. Between both factors a state of equilibrium established itself, which expressed itself in a specified height of the slag layer. If one reduced the pressure of the gases in the combustion chamber, so this height rose, and at times it occurred on reversal when the gas and air were cut off, and the chimney draught itself produced a suction for a moment that the slag frothed over the door sills, until on the re-entrance of the flame, and therewith the former pressure conditions, it sunk down again to the former level. The small quantities of slag lost in this manner were returned again to the furnace. The carbon elimination required several hours by such-like working methods, and its relative extent depended on the amount of heat supplied. The ore added was gradually dissolved by the slag, so that this constituted for a length of time a solution of protoxide of iron of high concentration, from which iron was freely reduced and was taken up by the bath of metal. After the entire ore is dissolved, the iron content of the slag soon sinks, and the "heat" can be finished under conditions which are throughout analagous to those at the conclusion of pig and scrap charges, only the quantity of slag is larger.

An excess of ore causes the same disadvantage as in the pig and ore process with solid charges, or as a deficit of reducing agents in the pig and scrap process, and must be, therefore, carefully avoided. This is most simply done by means of selecting the ore addition initially somewhat too small and then adding it according to requirement. By correctly hitting upon ore additions, the growth of charge attains the value which was hereinbefore ascertained, and the slag becomes so low in oxides at the finish that not more ferro-manganese is requisite for deoxidation than in charges which are produced by the pig and scrap process employing the best charge materials. The watching of the process is likewise simple, only tests must be frequently taken and investigated for their hardness, in which connection care is to be taken that the boil always proceeds with an intensity corresponding to the carbon content of the metal; a too previous diminution of this is to be aided by means of ore additions. If this proviso is correctly observed, the regulation of the temperature becomes a very simple matter, since it takes place almost spontaneously. One can give the furnace the maximum of gas and air (naturally in the correct ratios to one another) which the furnace is capable of holding, without being compelled to fear overheating of the same, since the great heat demand of the endothermic carbon reaction does not admit of an excess of heat taking place. The temperature fixes itself in conformity with the carbon content of the bath for the time being, and merely the carbon elimination takes place the more rapidly the more heat is supplied to the bath. Danger to the furnace can only make its appearance if the carbon in

TABLE V.—CHARGE 8,996.

No. of Test.	Time test taken.	Minutes from the start.	Metal.				Slag.						Remarks.
			C	Si	P	Mn	Fe	Mn	SiO_2	CaO	MgO	P	
			Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	
1	9·25 9·40	— 15	4·26	1·03	0·16	1·92	—	—	—	—	—	—	Pig iron from both ladles.
2	10·0	35	4·04	0·19	0·06	0·50	34·25	14·80	20·68	11·32	1·22	0·62	
3	10·15	50	3·84	0·04	0·02	0·28	31·60	14·87	20·42	13·32	2·23	0·77	
4	10·45	80	2·78	0·04	0·01	0·30	33·41	13·12	18·30	14·71	1·73	0·82	
5	11·15	110	2·38	trace	0·01	0·26	31·35	12·76	18·54	18·07	3·53	0·77	
6	11·45	140	1·77	,,	0·01	0·28	27·96	11·91	18·06	21·49	4·61	0·77	
7	12·15	170	1·50	,,	0·02	0·26	26·75	11·30	17·40	25·30	3·89	0·76	At 12·0. 230 kilogrammes ore added.
8	12·45	200	0·70	,,	0·02	0·36	14·76	12·19	21·58	34·26	4·75	0·79	180 kilogrammes ore added.
9	1·15	230	0·12	,,	0·02	0·46	11·50	11·62	21·10	37·57	5·83	0·77	20 kilogrammes sand added.
10	1·45	260	0·09	,,	0·02	0·71	9·93	12·12	20·92	39·54	6·41	0·68	200 kilogrammes ferro-manganese added Tapped about 1·55.

the metal or the iron protoxide in the slag begins to be deficient.

CHARGE No. 8,996.

Molten pig iron	26,200	kilogrammes	
Limestone	2,330	,,	= 8·5 per cent.
Ore	5,720	,,	=21·8 ,,
,,	330	,,	= 1·26 ,,
,,	180	,,	= 0·69 ,,
Ferro-manganese	200	,,	= 0·76 ,,

FIG. 21.

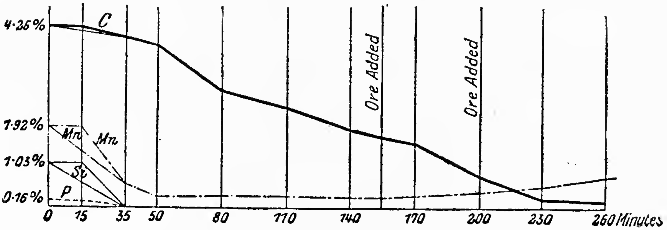

DIAGRAM I.—Removal of Reducing Agents.

FIG. 22.

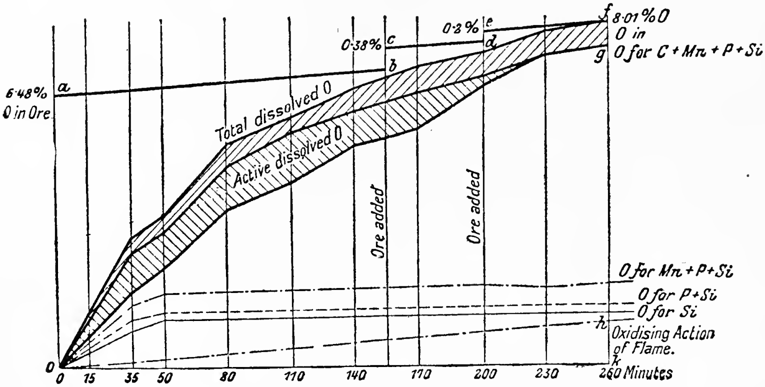

DIAGRAM II.—Action of Oxygen.

The author regards as a good example of a charge of such a kind in the usual course, that which is given in "Stahl und

Eisen," 1905, p. 1434, Charge 8,996 of 16th September, 1904, which is, therefore, quoted here also (for analysis see p. 171). 26,200 kilogrammes molten pig iron was used, which was poured on to 2,300 kilogrammes, or 8·5 per cent., of limestone, and 5,720, or 21·8 per cent., of ore 99 per cent. Fe_2O_3. Afterwards 330 kilogrammes and 180 kilogrammes ore were added, *i.e.*, 1·94 per cent. ore. For deoxidation, 200 kilogrammes = 0·76 per cent. of 80 per cent. ferro-manganese was used.

In order to make the course of the process more perceptible the numerous figures of the analyses made are set out in Figs. 21 and 22, of which the first illustrates the elimination of the reducing agents in the manner usually customary, whilst the second renders apparent the work of the oxygen. The figurative values for the latter have been calculated in the manner previously given. The total oxygen consumption of this heat is again estimated on the variation of the composition of the metal, and of the oxygen combined with iron. The quantity of the final slag was ascertained on the basis of of the amount of silica which had been active. For the foregoing example, it had been found that 1·2 kilogramme SiO_2 per minute was added to the bath from the furnace structure, thus in 260 minutes $260 \times 1{\cdot}2 = 312$ kilogrammes $= \frac{31,200}{26,200}$ $= 1{\cdot}19$ per cent. on the weight of the metal charged.

In the first slag there was therefore:—

1.	Originating from the furnace structure . .	1·19 per cent.
2.	From 1·03 per cent. Si × 2·14, producing . .	2·20 ,,
3.	,, 8·5 ,, limestone, at 1·65 per cent.	0·14 ,,
4.	,, 23·8 ,, ore, at 1 per cent. . .	0·24 ,,
5.	,, 20 kilogrammes sand	0·08 ,,
	Total . . .	3·85 per cent. SiO_2

From this as well, the content of SiO_2 in the final slag amounting to 20·92, one ascertains the weight of the latter as $\frac{385}{20{\cdot}92} = 18{\cdot}40$ per cent. The slag contained 9·93 per cent. Fe, and 0·29 O is combined with 1 per cent. Fe, thus the content of oxygen in combination with iron in the final slag is $18{\cdot}40 \times 0{\cdot}0993 \times 0{\cdot}29 = 0{\cdot}53$ per cent.

The amount of oxygen employed in changing the composition of the metal would be (having regard to the additions of ferro-manganese and spiegel) as under :—

4·21 per cent. C ×1·33=5·600 per cent. O
1·03 ,, Si ×1·14=1·17 ,, O
0·14 ,, P ×1·29=0·18 ,, O
1·82 ,, Mn×0·29=0·53 ,, O
Total . . 7·48 per cent. O

The total oxygen consumption therefore is 7·48+0·53 = 8·01 per cent.

All the amounts of oxygen just now found out are set out on the line *k.f.* of the second diagram, Fig. 22, and in similar manner the quantities of oxygen have been ascertained for the intermediate periods.

In order to establish the oxidising action of the furnace gases, there is to be deducted from the total oxygen utilised of 8·01 per cent, the oxygen content of the ore, *i.e.* 7·06 per cent. Thus the furnace action supplied 0·95 per cent O.

This amount is set out in the portion *k.h.* on the ordinate (*k.f.*) whereof the point (*h*) is connected in a straight line with (*a*). On the assumption that the oxidising action of the furnace during the entire course of the "heat" is constant, the height of the points of intersection of the line (*o.h.*) with the various ordinates, from the abscissæ represents the furnace action.

Further, the amounts of oxygen charged into the furnace in the form of ore are set out upon the ordinates, which correspond to the times the additions were made, and that of the intersection points of these ordinates with the line (*o.h.*) of the furnace action, and from the thus obtained points, *a*, *c* and *e* are set out parallel to the line of the furnace action. In this way, the lines *ab*, *cd*, *ef*, show how much total oxygen has been at disposal of the bath at each moment, and from the individual ordinates how much was utilised and for what purpose it was consumed.

The surface bounded by the line *o*, *b*, *f.g.o.*, which for its identification is simply hatched, limits the portions of ordinates, which furnish the amounts of oxygen contained in the slag in the form of iron protoxide. Since, however, this oxygen becomes inactive as soon as the iron content of the slag has gone down below 10 per cent., so also these amounts of oxygen were ascertained which are combined with the amounts of iron which exceeded 10 per cent. on the weight of the slag, and in this way were found the division lines of the two differently shaded surfaces. Now, the portions of ordinates within the lower shaded surface show the content of active oxygen in the slag. One sees that the oxygen requirement of the substances Si, P and Mn has been completely satisfied in the first 50 minutes, and that the changes taking place later are so small that they are in the main so minute as to be no longer perceptible on the small scale chosen for the diagram. Only the manganese reduction is at the finish of the "heat" a little perceptible. On the contrary, the carbon at the commencement used up a relatively small amount of oxygen and soon afterwards became the sole and thereby large consumer of the same.

In criticism of the result of this charge, let there be further derived from the data

There was introduced into the furnace with the ore . .	23·74×0·99×0·7	=16·47 per cent. Fe
Contained in the final slag . .	18·4 ×0·0993	= 1·83 ,, ,,
Thus, since nothing went to loss from the slag, iron reduced .		14·64 per cent. Fe
There were eliminated 4·21 per cent. C+1·03 per cent. Si+0·14 per cent. P+1·82 per cent. Mn		= 7·20 per cent.
Thus the net charge growth		7·44 per cent.

The charge growth should have amounted, according to the previously ascertained values, as under:

4·21 per cent.	C×1·47	(from formula 74)	=6·18
1·03 ,,	Si×1·00	(,, ,, 68)	=1·03
0·14 ,,	P×2·00	(,, ,, 70)	=0·28
			7·49
Less 1·82 per cent.	Mn×0·32	(,, ,, 72)	=0·58
		Net total	6·91 per cent.

It has thus actually been about 0·5 per cent. higher than was to be expected from the formulæ. This has been attained owing to that instead of the ore addition being as under:

$$\begin{array}{llr}
4{\cdot}21\ \mathrm{C}\times3{\cdot}60 & (\text{from formula } 73)= & 15{\cdot}49\\
1{\cdot}03\ \mathrm{Si}\times4{\cdot}32 & (\quad\text{,,}\qquad\quad\text{,,}\qquad 67)= & 4{\cdot}45\\
0{\cdot}14\ \mathrm{P}\times4{\cdot}30 & (\quad\text{,,}\qquad\quad\text{,,}\qquad 69)= & 0{\cdot}60\\
1{\cdot}82\ \mathrm{Mn}\times0{\cdot}97 & (\quad\text{,,}\qquad\quad\text{,,}\qquad 71)= & \underline{1{\cdot}76}\\
 & & \underline{\underline{22{\cdot}30}}\ \text{per cent. } \mathrm{Fe_2O_3}
\end{array}$$

or=22·5 per cent. ore containing 99 per cent. Fe_2O_3 which was theoretically required, it had in reality amounted to 23·77 per cent., and this would indicate under the check of the condition that final slag with not over 10 per cent. Fe only was possible by this means, that always sufficient oxygen from ore was at the disposal of the charge; the refinement could, therefore, proceed with full energy, whereby it permitted the oxidising action of the furnace gases to be lowered further than was assumed in the previous calculation. For comparison with the later examples, let two more data be ascertained, namely the quantities of oxygen rendered useful per minute, and the quantum of steel produced in the same time. There has been rendered useful in the combustion of the reducing agents 7·48 per cent. of oxygen (on the charge weight), or 26,200×0·0748=1,959 kilogrammes in 260 minutes, or $\frac{1,959}{260}=$ about 7·8 kilogrammes O per minute.

From the 26,200 kilogrammes pig iron, 26,200×1·0744=28,149 kilogrammes steel was produced in 260 minutes, which is equivalent to $\frac{28,149}{260}=$about 108 kilogrammes steel per minute.

Dr. Ing. Th. Naske gives in "Stahl und Eisen," 1907, from the great abundance of material which he has accumulated with untiring industry, further very interesting examples of which some are set out below. In these the different conditions were purposely varied in order to be able to establish the influence of the individual factors on the course of the process.

The first example ("Stahl und Eisen," 1907, p. 231, Table 6) indicates similar conditions to Charge No. 8996, previously

Table W.—From "Stahl und Eisen," 1907, p. 231 (Table 6), Dr. Naske.

Test No.	Time Test Taken.	Minutes from Start.	Metal.					Slag.						Remarks.
			C	Si	Mn	P	S	Fe	FeO	Fe_2O_3	Mn	P_2O_5	SiO_2	
			Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	
1	2·40	—	4·61	0·84	2·20	0·15	0·02	—	—	—	—	—	—	Composition of pig iron.
2	3·0	20	4·56	0·19	0·45	0·05	0·01	41·51	47·88	6·10	15·22	2·36	17·68	
3	3·20	40	3·82	0·09	0·45	0·03	0·02	31·67	36·29	4·91	15·71	2·93	19·05	
4	5·00	140	2·04	0·06	0·45	0·02	0·01	14·71	16·67	2·71	13·96	2·44	21·66	
5	5·15	155	1·56	0·05	0·52	0·03	0·04	10·79	12·04	2·03	13·51	2·50	23·05	
6	5·40	180	1·47	0·05	0·63	0·03	0·02	10·32	10·36	3·23	12·67	2·35	23·00	820 kilogrammes ore added.
7	6·15	215	0·42	0·05	0·49	0·03	0·05	10·56	11·44	2·37	12·04	2·03	22·90	81 " " "
8	7·10	270	0·08	0·05	0·86	0·03	0·05	9·25	9·76	2·87	11·80	2·03	23·60	After addition of 100 kg. spiegel.
9	7·30	290	0·07	0·02	0·91	0·03	0·03	7·35	7·47	2·20	14·49	1·72	22·25	Finish test 245 kg. Ferro-Mn.

considered. A large addition of ore was charged into the furnace and molten iron poured over it before the ore had time to be strongly preheated. The ore charged, however, amounted to only 16·1 per cent., against 21·8 per cent. in the foregoing example. The amount of pig iron employed amounted to 20 tons, which is also smaller than in Charge No. 8,996. On this ground, one cannot directly compare the figures for the average production per minute, as well as the amounts of oxygen made useful on the average in the unit of time, since large charges exhibit better results in this respect. In opposition to this, the duration of the "heat" with smaller charges must be shorter than with large ones, even if the saving of time be not in direct ratio to the diminution of the weight of charge. 20,303 kilogrammes molten pig iron, and 4,181 kilogrammes ore containing 98 per cent. Fe_2O_3 were consumed. The chemical course is illustrated by Table W.

One sees at once from the analysis that the metal was only for a short time exposed to strongly ferruginous slag, and that in the period from 140 minutes from the beginning up to the end must be satisfied by a low ferruginous slag, in spite of ore being afterwards added.

The yield from this charge admits of being ascertained as follows:—

Iron from the ore charged 20·54 per cent. × 0·98 × 0·7	14·09 per cent.
Contained in the final slag (weight of same is derivable as being 17·5 per cent.) 17·50 per cent. × 0·073 .	1·28 ,,
Net iron reduced from the ore	12·81 per cent.
Reducing agents eliminated,[1] *i.e.*, 4·54 per cent. C + 0·82 per cent. Si + 2·30 per cent. Mn + 0·12 per cent. P.	7·78 ,,
Net result. Charge growth	5·03 per cent.

The growth should have been as follows:—

$$4{\cdot}54\ C \times 1{\cdot}47 + 0{\cdot}82\ Si \times 1{\cdot}0 + 0{\cdot}12\ P \times 2{\cdot}0 - 2{\cdot}30\ Mn \times 0{\cdot}32 = 7{\cdot}00 \text{ per cent.}$$

It is thus about 2 per cent. under that theoretically remaining. Wherein lies the cause?

The ore consumption should have been as follows:—

$$4{\cdot}54\ C \times 3{\cdot}60 + 0{\cdot}82\ Si \times 4{\cdot}32 + 0{\cdot}12\ P \times 4{\cdot}30 + 2{\cdot}30\ Mn \times 0{\cdot}97 = \frac{22{\cdot}68}{0{\cdot}98} = 23{\cdot}1 \text{ per cent.}$$

---

[1] The growth of charge due to additions does not admit of exact figures, but error too small to affect result on which argument is based. Both C and Mn added in Spiegeleisen and ferro-manganese are taken into account in arriving at these figures.—[Translator].

Charge 20,303 kilogrammes molten pig iron.
984 ,, limestone = 4·84 per cent.

	3,280 kilogrammes ore	= 16·1 per cent.	= 4·75 per cent. O
at 180 m.	820 ,, ,,	= 4·04 ,, ,,	= 1·18 ,, ,, O
at 215 m.	81 ,, ,,	= 0·40 ,, ,,	= 0·12 ,, ,, O
	4,181 kilogrammes ore	= 20·54 per cent.	= 6·05 per cent. O

FIG. 23.

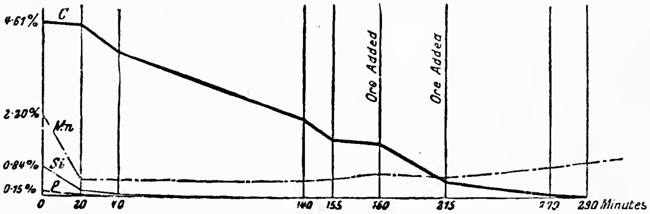

DIAGRAM I.—Removal of Reducing Agents.

FIG. 24.

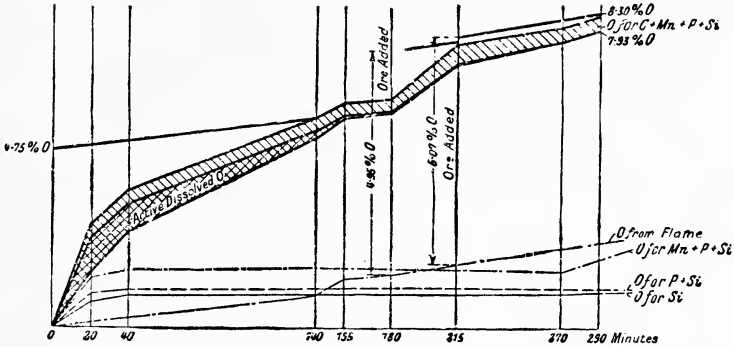

DIAGRAM II.—Action of Oxygen.

But it has only been 20·54 per cent. Thus the quantity of ore employed was too small, and there were greater demands placed on the oxidising action of the flame, whereby at the same time also a lengthening of the duration of the "heat" would be enforced.

From the diagram of the work of the oxygen (Fig. 24) one perceives that the metal was refined solely by the oxidising action of the flame in the period from 155 to 180 minutes and from about 225 to 290 minutes, which naturally must have caused longer course of the "heat" and shrinkage of charge. One further sees that the initial temperatures were low, in that quite as in example 8996 the carbon in the first 20 minutes (corresponding to 35) only consumed very little oxygen and left over the lion's share to the remaining reducing agents.

In this "heat" there were rendered available

$$\frac{0\cdot0793\times20{,}303}{290}=5\cdot5 \text{ kilogrammes O per minute,}$$

and the steel produced $=\frac{20{,}303\times1\cdot0487}{290}=73$ kilogrammes per minute, thus so much less compared with the previous example that the smaller charge weight alone is not sufficient explanation of the difference.

The following example (Table X) shows the course of a charge in which one sought to make the ore additions in small amounts corresponding to the requirements of the intervals of time. The chemical course is given in the table.

Here the slag during the entire course of the process is quite low in iron, excepting perhaps the periods from the beginning up to 40 minutes and between 105 and 175 minutes.

	Per cent.
With the ore (23·9 per cent.) there was introduced into the furnace Fe 23·9×0·98×0·7 . . . . . =	16·39
Fe contained in final slag 18·3×0·1067 . . . . =	1·95
Thus iron reduced . . . . =	14·44
There were removed reducing agents:— 3·55 per cent. C+1·24 per cent. Si+2·41 per cent. Mn+0·13 per cent. P . . . . =	7·33
Thus giving rise to a charge growth of	7·11

The ore charge of 23·9 per cent. for the period of time of 220 minutes, again analogously to the first example, Charge 8,996, had been greater than the theoretical amount which would have been only 21·4 per cent. On this ground the charge growth of 7·11 per cent. is greater than that calculated theoretically on the assumed formulæ, which only amounts to 6 per cent. Unfortunately, the composition of the final

TABLE X.—FROM "STAHL UND EISEN," 1907, P. 231 (TABLE 7).

Charge 2,460 kilogrammes ore, 820 kilogrammes limestone, on to which charged 20,580 kilogrammes pig iron.

No. of Test.	Time Test Taken.	Minutes from Start.	Metal.					Slag.						Remarks.
			C	Si	Mn	P	S	Fe	FeO	Fe_2O	Mn	P_2O_5	SiO_2	
			Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	
1	4·0	—	4·26	1·26	2·83	0·18	0·02	—	—	—	—	—	—	Composition of pig iron.
2	4·15	15	3·87	0·14	0·56	0·07	0·02	18·62	22·41	1·70	18·43	2·05	25·20	
3	4·40	40	3·74	0·07	0·35	0·02	0·02	14·59	16·47	2·54	17·80	2·35	24·70	820 kilogrammes ore added.
4	5·45	105	3·14	0·05	0·35	0·01	0·02	22·06	25·00	3·73	14·59	2·13	21·65	820 ,, ,, ,,
5	6·55	175	1·91	0·05	0·35	0·01	0·04	13·64	16·00	1·70	13·06	1·73	22·20	410 ,, ,, ,,
6	7·20	200	1·25	0·04	0·42	0·03	0·04	12·10	14·02	1·70	12·74	1·67	23·75	410 ,, ,, ,,
7	7·40	220	0·71	0·02	0·42	0·05	0·08	10·67	12·51	1·34	12·43	1·53	24·30	
8	9·0	300	0·05	0·01	0·56	0·05	0·06	—	—	—	—	—	—	Test before casting,

REFINING WITH REPEATED ORE ADDITIONS.

EXAMPLE X.

Molten pig iron . . .	20,580 kilogrammes			
Limestone . . .	820 ,,	=4	per cent.	
Ore with 2 per cent. SiO_2, 98 per cent. Fe_2O_3				
Initial charge . .	2,460 kilogrammes	=3·5	,,	O
Added at 40 minutes .	820 ,,	=1·17	,,	O
,, 105 ,, .	820 ,,	=1·17	,,	O
,, 175 ,, .	410 ,,	=0·58	,,	O
,, 200 ,, .	410 ,,	=0·58	,,	O

FIG. 25.

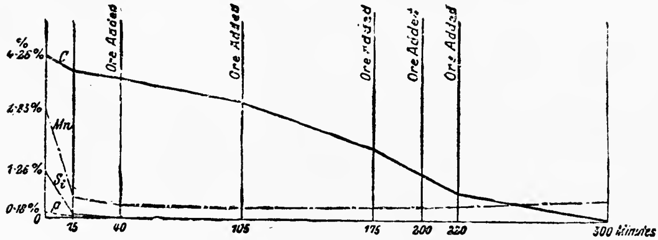

DIAGRAM I.—Removal of Reducing Agents.

FIG. 26.

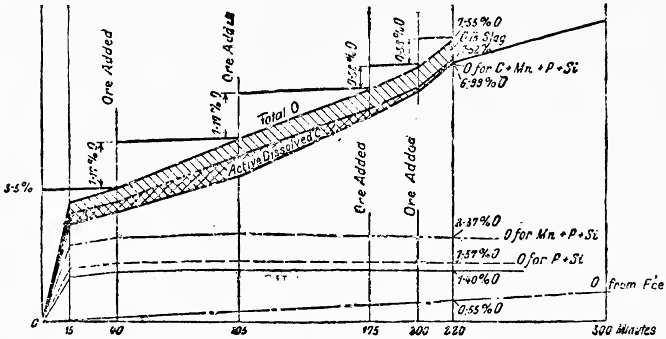

DIAGRAM II.—Action of Oxygen.

slag is not given, therefore it is not possible to follow up the occurrences during the time interval from 220 to 300 minutes, that is to say the decarburisation from 0·71 per cent. to 0·05 per cent. The rise in the manganese content of the metal in this period and the long duration of the same, admits of the conjecture that no more ore was added, and the action took

Example Y.

Charge: 20,018 kilogrammes molten pig iron heated for 90 minutes without addition.

Ore added, at	90 mins.	820 kg.=	4·1 per cent. ore	=1·205 per cent. O
,, ,,	115 ,,	1,640 ,, =	8·2 ,,	,, =2·41 ,, O
,, ,,	140 ,,	820 ,, =	4·1 ,,	,, =1·205 ,, O
,, ,,	195 ,,	820 ,, =	4·1 ,,	,, =1·205 ,, O
	Total	4,100 kg.=	20·5 per cent. ore	=6·025 per cent. O

Fig. 27.

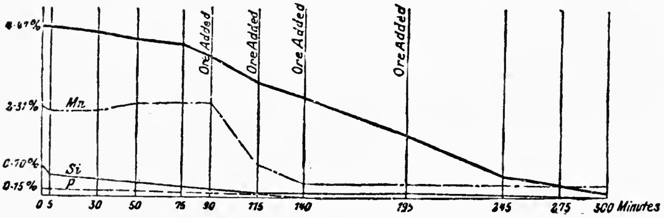

Diagram I.—Removal of Reducing Agents.

Fig. 28.

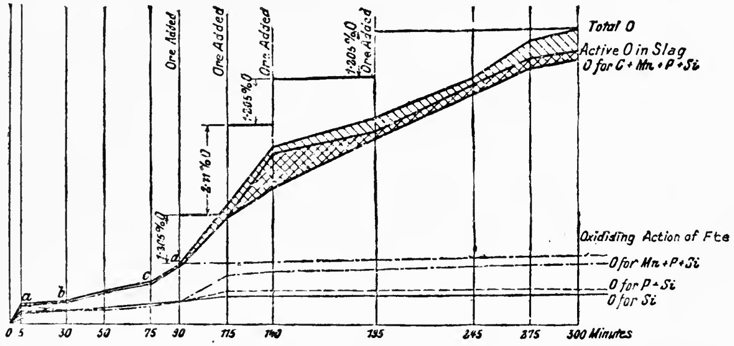

Diagram II.—Action of Oxygen.

place only by means of oxidising action of the flame under low oxygenous slag. Thereby the yield at the end of the "heat" would then have been lowered.

The oxygen rendered available up to the end of 220 minutes

TABLE Y.—DR. NASKE, "STAHL UND EISEN," 1907, PP. 230 AND 233 (TABLES 5 AND 10).

20,018 kilogrammes molten pig iron charged, heated 90 minutes, after which ore additions made and metal worked up into ingot-iron.

No. of Test.	Time Test. Taken.	Minutes from Start.	Metal.					Slag.						Remarks.
			C	Si	Mn	P	S	Fe	FeO	Fe_2O_3	Mn	P_2O_5	SiO_2	
			Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	
1	10·0	—	4·47	0·70	2·31	0·15	0·04	—	—	—	—	—	—	Test of "teeming" into furnace.
2	10·5	5	4·45	0·44	2·17	0·12	0·03	4·86	N.O.	N.O.	16·96	1·65	27·70	Test from OH furnace.
3	10·30	30	4·31	0·40	2·27	0·15	0·03	3·14	,,	,,	7·42	0·21	34·60	
4	10·50	50	4·14	0·33	2·41	0·15	0·02	1·07	,,	,,	3·71	0·05	41·30	
5	11·15	75	4·04	0·23	2·48	0·14	0·02	0·95	,,	,,	2·94	0·02	39·80	
6	11·30	90	3·76	0·18	2·48	0·14	0·02	1·72	,,	,,	2·94	0·05	35·80	Charge very hot; 820 kg. ore.
7	11·55	115	2·98	0·05	0·87	0·06	—	10·85	12·05	2·11	18·97	2·29	22·90	After test, 1,640 kg. ore.
8	12·20	140	2·56	0·05	0·35	0·02	—	26·03	29·43	4·48	16·24	2·00	18·50	,, ,, 820 ,,
9	1·15	195	1·60	0·05	0·31	0·04	—	14·88	17·55	1·77	14·42	1·74	22·80	,, ,, 820 ,,
10	2·5	245	0·46	0·02	0·28	0·01	—	—	—	—	—	—	—	Charge overted.
11	2·35	275	0·22	0·02	0·28	0·01	—	14·88	17·83	1·44	11·76	1·85	20·70	Bath cold.
12	3·0	300	0·05	0·01	—	0·01	—	13·52	14·82	2·87	10·85	1·58	18·70	Pretest red short.

was 6·6 kilogrammes per minute, whilst the steel production taken on the entire run of the charge must have been 73 kilogrammes per minute. Had a further small ore addition been made, the end of the "heat" would have been reached easily about 20 minutes earlier, and the production brought up to 80 kilogrammes per minute, and thus have been able to be increased 10 per cent.

Another very interesting example, in which the pig iron was first heated during 90 minutes in order to bring it up to a high temperature and to be able to observe the influence of the latter on the behaviour of the charge, is shown in Table Y.

From the oxygen diagram (Fig. 28) one sees at once that in the period of heating the pig iron without additions, a small sudden removal of reducing agents took place immediately on the introduction of the pig iron into the furnace, which can only be traced to some slag having been present from the previous charge, the oxide of which caused these changes. The greatest portion of the amount of oxygen which is given by the line *o.a.b.* must be allocated to this slag, by means of which Si, P and Mn were mainly attacked. After 30 minutes, however, the carbon began to reduce the manganese protoxide formed, thanks to the low-oxygen slag, whilst it could not get hold of the products of elimination of the silicon. The somewhat powerful oxidising action of the flame in the preheating period is set out by means of the line *o.b.c.d.*, the assumed points of which were estimated by the known method. After being heated for 90 minutes, the bath received the first—of course too small—addition of ore, to which then, but at proper intervals, generous additions followed, through which greed of oxygen of the charge was more than covered. One sees, therefore, also that the oxidising action of the flame in the interval between 90 and 300 minutes only exhibited the still very small amount of 0·3 per cent. so that the line which illustrates this runs almost parallel with the abscissa.

The first ore addition completely removed the silicon and phosphorus from this very hot bath indeed, in the interval between 90 and 115 minutes, whilst of the manganese, small amounts took a still further 15 minutes. Afterwards, the ore (possibly in consequence of the high temperature of the metal, and good transference of heat) was reduced by the carbon as rapidly as it could be dissolved by the slag, so that the iron content of the latter did not rise.

If one considers this charge from the moment of the first ore addition, *i.e.*, from 90 minutes, up to the end of the same, one finds

Iron contained in 20·5 per cent. Ore $=20{\cdot}5\times0{\cdot}98\times0{\cdot}7$	$=14{\cdot}0$ per cent.
Remaining in 20 per cent. final slag $=20\times0{\cdot}1352$	$=2{\cdot}7$,,
Iron reduced . .	$=11{\cdot}3$ per cent.
Reducing agents removed 3·71 per cent. C+2·20 per cent. Mn+0·17 per cent. Si+0·13 per cent. P	$=6{\cdot}31$,,
Charge growth hence	$=4{\cdot}99$ per cent.
	say 5·0 per cent.

It should have been

$$3{\cdot}71\mathrm{C}\times1{\cdot}47+0{\cdot}17\mathrm{Si}\times1+0{\cdot}13\mathrm{P}\times2-2{\cdot}20\mathrm{Mn}\times0{\cdot}97=5{\cdot}18 \text{ per cent.}$$

It has thus fallen somewhat too low, and actually due to that instead of the requisite addition of 17·7 per cent., this time 20·5 per cent. was employed. The too large ore addition has thus only a little damaged the yield, but the ore had been badly utilised, and in addition the previously quoted evils of strongly chilled and over-oxidised metal had made their appearance, as is to be perceived from the remarks accompanying the results of analysis.

The steel produced per minute was $\frac{20{,}018\times1{\cdot}05}{210}=100$ kilogrammes, and this high figure clearly shows the effect which the preheating exercised in acceleration of the endothermic carbon reaction. One perceives from the diagram a difference from the earlier ones, since now the carbon already within the first 15 minutes laid claim to more than half the oxygen used up, whilst it was satisfied in the previously considered examples with less than one-third.

The quantity of oxygen rendered active per minute amounts in the present case, however, to only $\frac{20{,}018\times(0{\cdot}0704-0{\cdot}0452)}{210}$ = about 5·2 kilogrammes, and is thus smaller than in all previously considered examples. The ground for this remarkable result appearing is simple: the metal contained at the

TABLE Z.—DR. NASKE. "STAHL UND EISEN," 1907, P. 232, TABLE 9.

3,280 kilogrammes ore melted down (18·5 per cent.), on which 17,843 kilogrammes molten pig iron was charged, and re-acted therewith.

No. of Test.	Time Test Taken.	Mins. from Start.	Metal.				Remarks.
			C	Si	Mn	P	
			Per cent.	Per cent.	Per cent.	Per cent.	
1	1·20	—	3·90	1·03	1·56	0·14	Analysis of pig iron.
2	1·35	15	3·35	0·05	0·28	0·01	
3	2·15	55	2·51	0·05	0·24	0·01	After test, 820 kilogrammes ore.
4	2·40	80	1·69	0·05	0·24	0·01	
5	3·20	120	0·66	0·05	0·31	0·01	After test, 820 kilogrammes ore.
6	3·50	150	0·29	0·05	0·35	0·01	
7	4·10	170	0·07	0·02	0·39	0·02	Pretest red short; 50 kilogrammes Spiegel.
8	4·20	190	0·07	0·02	0·39	0·02	Final test.

time of the first ore addition, contained carbon almost solely of the reducing agents, whilst the remaining oxygen consumers already were eliminated. Such a metal, therefore, demanded less oxygen. But this circumstance shows that the characteristic chosen by Dr. Naske, of oxygen consumed in the removal of reducing agents, cannot well be employed for a general comparative value of the performance of the furnace.

Similar results (*i.e.*, acceleration of the carbon elimination) are shown also by the next example (Table Z), in which the ore had been subjected to the highest attainable temperatures in the open-hearth furnace, namely, was molten before the introduction of the pig iron.

Unfortunately, the slag analyses were not given, thus one cannot completely investigate the example.

One sees from the following diagrams (Figs. 29 and 30) that here also the carbon removal took up a large portion of the oxygen, although the remaining reducing agents for all that were removed immediately. The action of the molten ore

EXAMPLE Z.

"STAHL UND EISEN," 1907, P. 232 (TABLE 9).

Charge 1st	Limestone	820 kilogrammes	Melted down
	Ore	3,280 ,,	
2nd	Molten pig iron	17,843 ,,	

Ore, etc., used.

Original charge.	Limestone	820 kg.=	4·6 per cent.	
	Ore	3,280 kg.=	18·5 per cent.	Ore=5·44 per cent. O
At 55 minutes.	Ore	830 ,, =	4·6 ,,	,, =1·25 ,, O
At 120 ,,	,,	81 ,, =	0·45 ,,	,, =0·13 ,, O
Totals	Ore	4,181 kg.=	23·55 per cent.	Ore=6·82 per cent. O

FIG. 29.

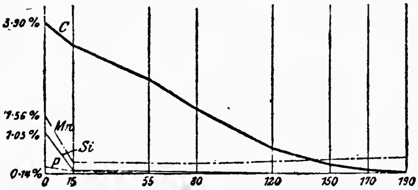

DIAGRAM. I.—Removal of Reducing Agents.

FIG. 30.

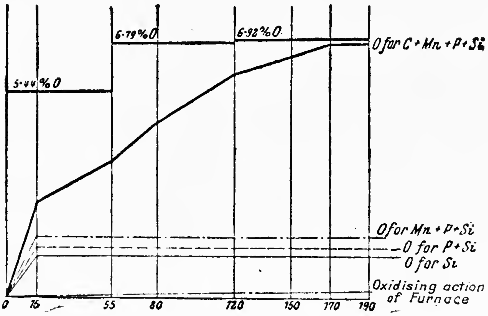

DIAGRAM II.—Action of Oxygen.

manifested itself in the large production of 99 kilogrammes per minute, in spite of the charge amounting to only 17,800 kilogrammes, in connection with which 6·4 kilogrammes oxygen was rendered useful on the immediately preceding composition of the pig iron.

The examples given should suffice in order to characterise the process and conditions by which the best results should be obtained. One sees that the correct adjustment of the ore addition yields the highest output and shortest time per "heat," in connection with which it is practically indifferent whether one adds all the ore immediately at the start or if one adds it in successive small doses. The former is, however, more to be recommended, since one can more easily avoid periods with ore deficit. The presence of sufficient quantities of ore strongly diminishes the furnace action; indeed it disposes of it almost completely, whilst ore deficiency forthwith permits it to make its appearance. Through the oxidising action of the furnace, the yield is at the same time diminished, and the duration of the "heat" longer drawn out.

The disadvantages of too large ore additions have been cited already several times.

The rapidity of the course of the process depends directly on the greater or less quantities of heat which are at disposal. Hot pig iron and preheated ore permit the carbon elimination to begin and proceed with correspondingly more powerful intensity. Therefore, it is advantageous for the process to retain as much as possible in the pig iron from the blast furnaces its available heat, previous to charging it in the open-hearth furnaces. One should adopt measures to ensure this, the more especially as a high degree of heat in the pig iron causes no kind of disadvantage. At least in more than five years' practice of this method the eventuality has not arisen in a single instance.

Preheating of the ore can scarcely come in question since the utilisation of the heating action of the furnace might be considerably less favourable in melting down ore than during the refining of the metal with oxygen from ore. If, however, not sufficient pig iron is present, and the open-hearth furnace must await the same, the consideration of preheating the ore has much attractiveness. One would then have no longer pauses in working, since in such, one could exercise the furnace action on the ore, and store up in it the respective quantities of heat, in order to be afterwards in the position to correspondingly more quickly finish the "heats." Such a method of working does not appear impossible; it is actually adopted in the Talbot process. But it has its great disadvantage since if the molten pig iron comes into contact with highly heated ore, immediately the action of the carbon on the same takes place in so violent a manner that the furnace is no longer capable of overcoming the gases developed. One must shut off the gas and air and pour the pig iron in very slowly. In spite of this, the gases blow out of the furnace doors, and they issue with such violence from the bath that shreds of viscous slag are flung upon the roof and port blocks, the duration of life of which must be much injured by such direct treatment with basic materials. It even happens that portions of the furnace contents are actually thrown out. Furnaces which are frequently exposed to such conditions must quickly be brought to a stoppage. Dr. Naske, indeed, mentions in his essay that "by means of corresponding construction of the hearth, but still more by means of suitable work with the preheated materials, this objection is to be met, and injuries to the furnace can be completely obviated"; but it might not be easy to produce proof of the correctness of the above assertion.

The employment of large charges is very favourable to obtaining large production, as shown by the first example given, *i.e.*, Charge 8,996. The furnaces of the South Russian works quoted, which were capable in the best instances of producing 17 to 18 tons of steel in 4 hours by the pig and scrap process, are now running charges of 30 tons of molten pig iron and converting them into steel in the same time. This large production does not result at all at the expense of good quality, but a metal is thereby obtained which on the ground of the mechanical tests as well as behaviour under further working, and not last, the judgment of the consumers is faultless, and even appears superior to that formerly made by the pig and scrap process. The ground thereof is obviously the low content of oxygen, and the latter is possible by the means that with all properly conducted "heats," at the finish manganese is reduced from the slag into the metal, so that for deoxidation, in spite of the large quantity of slag, not more manganese is devoted than in charges which are made by any other process from the best materials. That the charge growth actually attains the amounts previously ascertained by methods of calculation has been also established by weighing, in which connection one must always take into account the small losses, due to portions of metal remaining in the slag as well as the particles lost by splashes during casting.

In regard to the quality of the pig iron to be employed, it was at first believed that the smallest possible content of reducing agents in the same must give the best results. This view has proved erroneous, inasmuch as charges of white iron exhibit a very "dull" course, will not boil long, and therefore require ample time in the furnace. Possibly, low silicon content of white iron is the cause, since it is conceivable that such an iron admits of the production of too small a quantity of slag, or an undesirable composition of the same in the earlier stages of the process, and is the cause hindering a rapid course of the "heat." A pig iron with 1 per cent. to 1·5 per cent. Si works best. Higher amounts thereof are undesirable owing to the large quantities of slag resulting; nevertheless they give rise to no special difficulties if they are only employed for a time, and if one adds to them correspondingly more ore and lime. Wear and tear of the basic bottom does not in general take place exactly as in the Talbot process, but the slag zone is here also subjected to wear and tear, which is the greater the more Si in the charge and the more SiO_2 present in the additions. In order to determine the difficulties which were able to occur in working highly siliceous iron, in the year 1903, the following charge was worked, the tapping weight of which was chosen lower than usual:—

(See Table AA. and Figs. 31 and 32.)

One sees that the furnace was also in the position to work this quite extraordinarily unfavourable charge, and, indeed, in spite of the defects which were created thereby. Since first lime had been deficient, which one sees throughout, for the slag showed a much too high silica content. It was obliged, therefore, to very strongly attack the furnace banks, at times its amount was abnormally large, which one can derive from the figures under the heading "Amount of slag" in the table below, which were ascertained in the known way.

TABLE AA.—CHARGE 1,093 OF FEB. 1ST, 1903.

Charged 16,213 kg. molten pig iron (3·78 per cent. Si).
5,000 ,, ore (about 95 per cent. Fe_2O_3 and 5 per cent. SiO_2).
1,500 ,, limestone.
80 ,, ore . . . . . at 221 minutes from start.

Time.	Minutes from start.	Metal.				Slag.						Calculated weight of slag per cent. in charge.	Remarks.
		O	Si	P	Mn	Fe	FeO	Fe_2O_3	Mn	P_2O_5	SiO_2		
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	
11.27 11.45	—	3·32	3·78	0·05	1·34	—	—	—	—	—	—	—	Pig iron from both ladles.
11.58	31	2·98	0·75	0·01	0·45	28·81	30·85	6·87	3·96	0·38	34·00	24·6	Bath hot; reaction violent; slag thick.
12.15	48	2·88	0·19	0·01	0·28	26·04	30·24	3·60	4·17	0·52	29·15	33·3	Reaction equally violent; 12.25 slag rose.
12.30	63	2·67	0·05	0·01	0·17	23·52	27·62	2·91	4·24	0·64	28·60	35·3	Reaction very violent; 12.40 bath sunk down, reaction feebler.
12.45	78	2·50	0·05	0·01	0·10	22·80	26·54	3·08	4·27	0·63	28·20	36·1	Reaction subsided.
1.15	108	1·50	0·02	0·01	0·21	16·32	18·82	2·40	4·66	0·66	30·00	34·9	Charge cool, 600 kg. limestone added.
1.45	138	0·85	0·02	0·01	0·17	10·20	12·03	1·20	4·87	0·64	32·00	33·5	400 kg. limestone added; 2.10, charge cool, reaction present; 2.20, bath warmer; 2.25, 110 kg. limestone; slag thin, further 100 kg. limestone added; 2.40, 80 kg. ore and 150 kg. limestone added.
3.8	221	0·08	0·02	0·01	0·28	6·24	6·48	1·71	4·42	0·59	31·40	36·4	Charge hot, 100 kg. limestone; test not forgeable, 50 kg. ferro-manganese added; 3.40, test forgeable, free from red shortness; 3.45, 160 kg. ferro-manganese added.
4.0	273	0·09	0·02	0·01	1·02	4·80	4·94	1·37	6·25	0·47	30·40	38·9	Tapped.

PIG IRON WITH 3·78 PER CENT. SI.

		Per cent.	Per cent.	Per cent.
Charge . .	16,213 kg. molten pig iron			
	1,500 ,, Limestone (9·3 per cent.)			
At 193 mins.	5,000 kg. Ore (	95 Fe_2O_3	=30·3 Ore	=8·630
	80 ,, ,,	,, ,,	= 0·5 ,,	=0·140
	5,080 kg. Ore		=30·8 Ore	=8 770

FIG. 31.

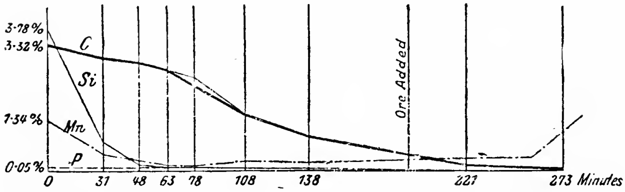

DIAGRAM I.—Removal of Reducing Agents.

FIG. 32.

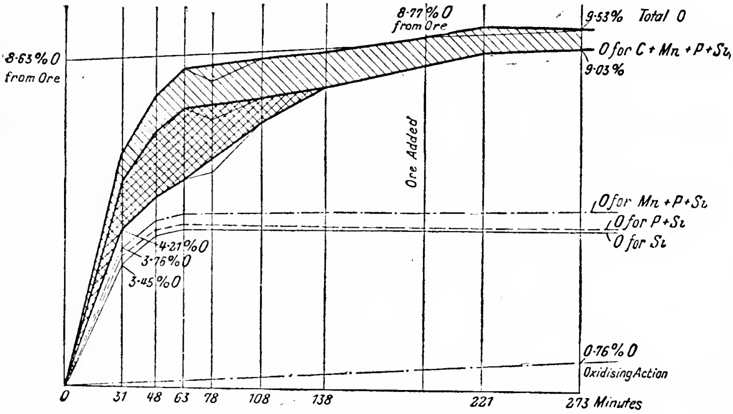

DIAGRAM II.—Action of Oxygen.

The second fault consisted in that the charge nearly half the time (viz., from 138 minutes to the end) was permitted to suffer deficiency of oxygen, which had as a result that the iron content of the slag was lowered down to 4·8 per cent., which naturally could only occur under expenditure of a great quantity of time. By means of small ore additions during the period given, one would have been able to considerably reduce the duration of the " heat."

The example shows once more that the amount of oxygen which was used up per unit of time in oxidation of all reducing agents cannot be regarded as a scale for the furnace performance. This quantity of oxygen attained, viz., in the foregoing example, in the first 31 minutes the colossal height of $\frac{16{,}213\times 0{\cdot}421}{31}=22$ kilogrammes per minute, of which only 2·3 kilogrammes pertain to the carbon, 1·7 kilogrammes to the manganese, and quite 18 kilogrammes alone to the silicon, whilst the quantity of oxygen made useful for the entire charge was only 5·36 kilogrammes per minute.

It has actually resulted that deviation in the composition of the pig iron which at times is unavoidable in the blast furnace, need only have a small influence on the production of the open-hearth furnaces. One obtains reckoning from tapping to tapping, thus including repairs to hearths:

	Per cent.				Per hour.
From pig iron with	0·6 Si	average of	8	charges,	4,440 kg.
,, ,, ,, ,,	1·0 ,,	,,	15	,,	4,820 ,,
,, ,, ,, ,,	1·5 ,,	,,	14	,,	4,590 ,,
,, ,, ,, ,,	2·0 ,,	,,	4	,,	4,540 ,,
,, ,, ,, ,,	2·5 to 2·8 Si	,,	7	,,	4,490 ,,

This is, therefore, evidence that the open-hearth furnace is not only a very forbearing, but also a very complete apparatus; it is capable of working, with only small additional efforts, materials of the most varied composition, and is in this respect far superior to the acid or basic Bessemer converter.

CHAPTER XXIII

VALUATION OF THE PHOSPHORUS CONTENT OF THE PIG IRON

The desire to utilise the raw material in the most complete manner directed attention to the phosphorus content in the pig iron, which in the Thomas-Gilchrist process yields a good saleable by-product, the value of which not inconsiderably lowers the manufacturing cost of the steel. In the basic open-hearth furnace, the removal of the phosphorus takes place under similar conditions to those in the basic Bessemer converter; therefore it appears possible to win it in a useful form. The following remarks should render clear the composition pig iron must possess in order to render possible the production of a marketable phosphate slag.

The market requires a product with the highest possible phosphoric-acid content, which may in no case amount to under 14 per cent. of P_2O_5. If one fixes 17 per cent. P_2O_5 as the lowest limit, this demands that the slag must contain

$$17 \times \frac{P_2O_9Ca_4}{P_2O_5} = 17 \times \frac{366}{142} = 45 \text{ per cent. } P_2Ca_4O_9.$$

The remainder, *i.e.*, 55 per cent., of the slag would consist of the hypothetical silicate slag. The latter must now by ordinary methods of working in the open-hearth furnace contain about 21 per cent. SiO_2, and thus the silica content of the entire slag amount to $55 \times 0{\cdot}21 =$ about 11 per cent. There would thus be per 11 per cent. SiO_2, 17 per cent. P_2O_5, or per 1 per cent. SiO_2 there would be 1·56 per cent. P_2O_5.

Now since the phosphoric acid usually originates only from the phosphorus content of the pig iron, thus for each unit of weight of SiO_2 which reaches the slag there must be $\frac{1{\cdot}56}{2{\cdot}29} = 0{\cdot}68$ units of weight of phosphorus present in the pig iron.

Taking into account the individual amounts of silica which flow into the bath from the different sources, and calculating the quantities of phosphorus belonging to each, which the charge must exhibit in order to give the slag the desired content of phosphoric acid, one obtains the following:—

(*a*) By ordinary working methods 0·45 per cent. SiO_2 reaches the bath from the furnace structure, and consequently the pig iron must contain in relation to this amount of silica	0·45 × 0·68 = 0·30 per cent. P
(*b*) Further, the pig iron may not contain less than 0·6 per cent. Si if one wishes not to place the furnace working under too unfavourable conditions; this, however, yields 0·6 × 2·14 = 1·3 per cent. of SiO_2, which again demands 1·3 × 0·68	= 0·90 per cent. P
a total of . . .	1·20 per cent. P

A pig iron with 0·6 per cent. Si must, therefore, possess at the least a phosphorus content of 1·20 per cent. Now since, however, for the refinement of the same, frequently up to 30 per cent. of ore is necessary, and since one may well admit up to 5 per cent. SiO_2 in the ore, so will still 0·05×30= 1·5 per cent. on the weight of the pig iron reach the bath, and, therefore, the phosphorus content of the pig iron be increased by 1·5×0·68=about 1 per cent. and amount to at least 2·2 per cent.

It is the merit of the Bertrand-Thiel process to have first practically shown that the production of a phosphoric open-hearth furnace slag of equal value to that of the Thomas process is possible with charges with an average of 1·5 to 2·7 per cent. P. The experience gained thereby permitted also the perception of the conditions which admit the best utilisation of the phosphorus content of the pig iron.

One knows that the phosphorus can be removed before the carbon, and further that the slag which takes up the resultant phosphoric acid increases in its amount with progressive decarburisation. Therefore, the phosphoric acid will be present in the highest concentration in the slag, if the decarburisation during the winning of the phosphoric acid remains reduced to the smallest possible extent, and in this case one is able to win a slag with the same content of phosphoric acid from a material with low phosphorus content, as would be possible by complete decarburisation of the metal.

By lesser decarburisation, the hypothetical silicate slag (*vide* 40A) contains 34 to 35 per cent. SiO_2. Now, then, if again the slag must have 17 per cent. P_2O_5, which corresponds to 45 per cent. $Ca_4P_2O_9$, the slag will contain 45 per cent. $Ca_4P_2O_9$, and 55 per cent. hypothetical silicate slag with the above 34 per cent. SiO_2; the entire slag will thus contain 55 per cent. $\times 0{\cdot}34 = 18{\cdot}7$ per cent. SiO_2 against 17 per cent. P_2O_5, and per unit SiO_2 there will be $\frac{17}{18{\cdot}7} = 0{\cdot}91$ unit P_2O_5, for the production of which $\frac{0{\cdot}91}{2{\cdot}29} =$ only 0·4 unit P will be needed to be present in the charge.

A further advantage of such mode of dephosphorisation is caused owing to then a less quantity of silica taking part in the proceedings. Firstly, the furnace structure is less attacked, since the action requires less time, nevertheless let no account be taken of this condition, and the silica supply, for safety's sake, be taken at the full amount previously reckoned. One then obtains :

	SiO_2 entering into reaction.	P in charge requisite in consequence.
From furnace structure	0·45 per cent.	$0{\cdot}45 \times 0{\cdot}4 = 0{\cdot}18$ per cent. P
From 0·6 per cent. Si .	1·30 ,,	$1{\cdot}30 \times 0{\cdot}4 = 0{\cdot}52$,, P
	Minimum total . . .	0·70 per cent. P

The ore addition might now only correspond to the quantity of reducing agents which must be eliminated at the same time as the phosphorus. For a pig iron with 0·6 per cent. Si, 2 per cent. Mn, and about 1 per cent. P, there is necessary for

0·6 Si (*vide* 63) $0{\cdot}6 \times 7{\cdot}62 = 4{\cdot}6$ per cent. Fe_2O_3
2·0 Mn (,, 65) $2{\cdot}0 \times 0{\cdot}97 = 1{\cdot}9$,, ,,
1·0 P (,, 64) $1{\cdot}0 \times 7{\cdot}80 = 7{\cdot}8$,, ,,
Or a total of . . 14·3 per cent. Fe_2O_3

And if again 5 per cent. SiO_2 in the ore is admitted, the ore requirement is $\frac{14{\cdot}3}{0{\cdot}95} = 15{\cdot}0$ per cent. which brings into the slag 15×0·05=0·75 per cent. SiO_2, and therefore requires 0·75×0·4=0·3 per cent. P in the charge.

One could thus produce slag with 17 per cent. phosphoric acid if the iron contained not less than 0·7+0·3, or round about 1 per cent., phosphorus, to a silicon content of a maximum of 0·6 per cent., and actually if it were possible to employ an ore which itself were free from phosphorus.

Were so much ore added in the open-hearth furnace to such a pig iron as needed for the removal of the substances Si, Mn and P, according to the formulæ 63 to 65, and so much lime that the oxidation products of the phosphorus and silicon from the compounds originally produced with iron protoxide were able to go over into the lime salts whereby the iron content of the slag might go down to the minimum, the utilisation of the ore would reach the maximum.

On the appearance of a state of equilibrium between metal and slag, the quantity of slag would be the smallest, and the concentration of the phosphoric acid, therefore, the greatest, which in the main is attainable.

For a pig iron of the foregoing composition, the quantity of the slag admits of calculation in the following manner :—

1 per cent. P yields 5·9 per cent. calcium phosphate (*i.e.*, P × 5·9).
0·45 per cent. SiO_2 from the furnace structure
1·30 ,, ,, ,, ,, Si in iron
0·75 ,, ,, ,, ,, ore

Total 2·50 per cent. SiO_2, which × 2·9 = 7·25 per cent. hypothetical silicate slag (from formula 40) ; one thus obtains a total of 5·9 + 7·25 = 13·15 per cent. total slag on the weight of the metallic charge employed.

The composition of this slag would be approximately

(*a*) Calcium phosphate = 45 per cent. of the total amount, or 17 per cent., P_2O_5+28 per cent. CaO.

(*b*) The hypothetical silicate slag = 55 per cent. of the total, containing

55 × 0·34 = 11·7 per cent. SiO_2
55 × 0·13 = 7·1 ,, ,, FeO
55 × 0·13 = 7·1 ,, ,, MnO
55 × 0·49 = 27·0 ,, ,, CaO+MgO
55 × 0·04 = 2·1 ,, ,, Al_2O_3, etc.

The complete analysis of the slag would thus be approximately 17 per cent. P_2O_5, 11·7 per cent. SiO_2, 7·1 per cent. Fe

7·1 per cent. MnO, 55 per cent. (CaO and MgO) and 2·3 per cent. Al_2O_3, etc.

This slag must now be removed from the metal. This admits of being most simply performed if one taps out the whole bath, whereby then the slag is won, whilst the metal must be further decarburised and therefore must be returned again into the open-hearth furnace.

The extent of the decarburisation which the metal should have underdone during the winning of the phosphoric slag depends upon the composition of the pig iron employed, and admits of being easily calculated as follows:—For example, if the pig iron contained as above 0·64 per cent. Si, 1 per cent. P, 2 per cent. Mn and 4 per cent. C, the elimination of the substances Si, Mn and P would need 14·3 per cent. Fe_2O_3 according to the preceding, whilst these substances for their elimination on complete decarburisation there would only be required $0{\cdot}64\text{Si}\times4{\cdot}32+1\text{P}\times4{\cdot}3+2\text{Mn}\times0{\cdot}97=8{\cdot}84$ per cent. Fe_2O_3; there would thus have been an excess of $14{\cdot}30-8{\cdot}84=5{\cdot}46$ per cent. Fe_2O_3 employed which was capable of removing, according to formula 73, $\frac{5{\cdot}46}{3{\cdot}60}=1{\cdot}52$ C. The carbon content of the metal must then on the first tapping amount to $4{\cdot}0-1{\cdot}52=$ about 2·5 per cent.

For each 1 per cent. more phosphorus in the charge, the surplus of iron peroxide in winning phosphoric acid increases to the extent of 7·8 (*vide* 64)—4·3 (*vide* 69)=3·5 per cent., and owing to this the carbon content in the dephosphorised metal be further lowered to the extent of $\frac{3{\cdot}5}{3{\cdot}6}=$ about 1 per cent. C.

One sees that the Bertrand-Thiel process actually fulfils all the conditions which render possible the complete utilisation of the phosphorus, and further perceives that it possesses a superiority over the Thomas-Gilchrist process, in that losses of phosphorus through volatilisation are completely prevented. In spite of the process having now been so many years in use, brands of pig iron with low phosphorus content (1 per cent.) have not been brought into use in large quantities for winning saleable phosphate slags.

In many works, the circumstances are such that pig iron can be most cheaply produced with a phosphorus content of approximately 1 per cent.

Such brands of pig iron involved until recently such difficulties in working that it was generally regarded as imperative to alter the phosphorus content often at considerable cost. It was frequently increased so far that the pig iron became usable for the Thomas-Gilchrist (basic Bessemer) process.

Where this increase was omitted, since phosphorus is regarded as an unmitigated evil, one was glad to have found in the puddling furnace and basic open-hearth furnace, apparatuses which admitted of its being rendered harmless, even if it be itself completely lost, and its removal caused considerable expense into the bargain.

The basic furnace creates herein a change of conditions; it permits the phosphorus to be changed into a valuable product without loss of material, and thereby opens up new sources of revenue to works of the class quoted.

The high carbon metal which is obtained in the winning of the phosphatic slag must, after returning to the furnace, receive additions of iron peroxide for the removal of the carbon. This iron peroxide must be dissolved, and for this silica is requisite, which now no longer can be produced from the metal because the silicon already has been removed by the first operation. The decarburisation can further only take an intense course if sufficient quantities of dissolved iron peroxide are at disposal, and on this ground an addition of silica is necessary. One could well now employ ores with a higher silica content than was permissible for the dephosphorisation. Nevertheless, another circumstance tells on the other hand—namely, there now is a deficit also of the manganese of the pig iron which likewise was removed in the first furnace. One must, therefore, have a care for a manganese content in the slag, in order to hinder red shortness making its appearance. One could thus derive silica as well as a large portion of the necessary manganese from final slags, which originate from former "heats" of completely decarburised metal, which O. Goldstein ("Stahl und Eisen," 1905, p. 1,230) and others have adopted in similar instances. Such slags offer the advantage which silica presents in the already combined state. This slag then needs, besides the requisite iron ore, only a little lime and the addition of only so much manganese compounds as corresponds to the manganese reduction which will occur during the decarburisation.

Tapping of the metal at the end of the first operation and returning the same into the furnace involves heat losses which must be replaced. Further, the heat for the production of the second slag is needed, and this total surplus amount of heat as well as the loss of time, which is caused by all the operations mentioned, involves, as opposed to the usual method of the open-hearth process, surplus costs, but which are very amply made up for by the revenue from the phosphatic slag by-product.

It will occur at times that the blast furnaces are not in the position to maintain the requisitely low silicon content of the pig iron. One does not want in this case to waive the advantage of useful open-hearth furnace slag, but one may remove the excess of silicon in the transport ladle by means of corresponding amounts of ore during the tapping from the blast furnace, and rectify the composition of the same without difficulty. The resultant ladle slag, however, one might render useful for the complete decarburisation in the second operation in the open-hearth furnace, since this slag contains, in addition to silica and iron protoxide, usually ample manganese, which was eliminated from the pig iron. The cost of such an operation need be debited neither to the blast furnace nor the open-hearth furnace, provided the same is not demanded to too great extent, and not too frequently.

CHAPTER XXIV

THE OPEN-HEARTH PROCESS AND THE PNEUMATIC REFINING PROCESS

WITH practical demonstration of the practicability of producing ingot iron and steel from pig iron without scrap additions, the monopoly previously exercised by the pneumatic process in the production of steel from pig iron was taken away. This fact had, however, up to the present little practical importance, since the pneumatic refining process has, thanks to support on all sides and to quite a special extent owing to the gross capital fallen to its share, experienced an unthought-of development, which has attained expression in almost fabulous increase of its productive capacity, and again has resulted in extraordinary cheapening of the costs of production. The process has thereby achieved results which many regard as being simply beyond rivalry.

Meanwhile, the open-hearth refining process has made progress also, and there are already those who forcibly proclaim that open-hearth furnace refinement is not only capable of successful competition with pneumatic refinement, but to quite outstrip the same.

The economical result of a process is settled by the manufacturing costs of its products. A comparison of the manufacturing costs must, therefore, at once yield full explanation as to which process preference is due in regard to economy. Unfortunately, however, it is not easy even only for a special case to draw up free from objection the manufacturing costs for the different processes, and quite impossible to obtain generally valid estimates in this way. Since the manufacturing costs are compounded from a great mass of items, the amount of which is dependent on the local conditions, and varies up and down with prices of materials and workmen's wages, and is in addition very much dependent on the completeness of the mechanical auxiliaries which are at disposal for the work. It therefore appears to be more correct for clearing up the question to only partially ascertain the manufacturing costs, and, indeed, in such wise that one leaves open a portion x thereof, which is to be made up of all those items which possess the same value in all the processes taken for comparison, or can be brought to the same value.

To this quantity x undoubtedly belong the entire costs of casting the finished steel, since it is absolutely indifferent for this operation by what method the metal has been won if it is supplied in like intervals of time and in equal quantities, and if it is cast into the same products.

One can further allocate the cost of deoxidation to the item x since it is possible in all processes, to so conduct the process, that the object is attained with the same ferro-manganese.

Further, one can with some qualification also allocate to this item the costs of the weighing of all materials within the works, since with suitable disposition of, and the excellent mechanical plants which are nowadays installed in modern works, these costs take up in general no great amount; in addition, the quantities of materials in the pneumatic and open-hearth processes to be compared, are not very different, as will be made apparent later.

Finally, one can likewise take the general charges, inclusive of amortisation, as about equal, and to be reckoned with the foregoing.

In respect of workmen's wages, the pneumatic plants appear at first sight to be at an advantage, since one sees only very few people in their manufacturing departments, whilst in the open-hearth furnaces, quite a numerous personnel shows up. But the pneumatic refining plants possess a quite extensive apparatus, and the people who must serve this, work, so to say, behind the scenes. If one takes this into account, as indeed must be done, the difference appears no longer so great. O. Thiel has even claimed (" St. und E.," 1901, p. 1306) that the basic open-hearth furnace requires fewer people and, therefore, is able to cost less in wages than the Thomas-Gilchrist process. Now the total wages per ton of steel amount to only about 3 Marks per ton, and therefore one will make no great error if one also includes wages under the item x for both processes.

The lining of the apparatuses is much used up in both processes, and the costs for their maintenance are different in all processes. But one can here also well allocate a portion of the costs to the heading x without disturbing the results, if one assumes that the costs for the renewal of the converter linings are approximately equal to the costs for dolomite and other refractory material, which are needed for the running upkeep of the open-hearth furnaces during working; so that to the open-hearth working only the entire costs of the large furnace repairs at end of each furnace run must be written to debit, whilst for the pneumatic refining process, these expenditures are contained in the item x.

The fuel consumption in both processes is not inconsiderable. The converters require coke for preheating, which must take place quite frequently, and for the production of the high pressure blast, machine power is requisite. Now, it is able to occur that the necessary fuel for the purpose is supplied gratis in the form of blast-furnace gases. Such an assumption is not really justified, since this fuel could otherwise obtain productive employment, if the steel works did not admit of it. In order, however, not to make the comparison too favourable for the open-hearth process, let it be assumed that the fuel for the pneumatic process actually costs nothing.

Against this the open-hearth furnace requires gas which must be produced from the special materials suitable therefor. By experiments which have already been made with several furnaces, it has been demonstrated that one is able, in working with molten pig iron, now to work with 20 per cent. of gas coal. That makes, with coal at a price of 12 Marks per ton, 2·4 Marks per ton of steel, which must be placed in the account wholly to the debit of the open-hearth furnace.

Suitable melting materials exhibit different values for each process in the manufacturing costs, in spite of the same price per unit of weight, since from the pig-iron different amounts of finished products result, and also different additions must be employed. The acid Bessemer process does not require them at all; the basic Bessemer process requires lime, and the basic open-hearth process, besides this material which it is itself capable of producing from limestone, also considerable quantities of iron ore.

As to which process the first place with regard to economy is to be assigned, admits of being easily ascertained on this class of basis, aided by the values previously obtained in special cases.

In order to obtain a better lucidity of view as to the results of the following calculations, let it be assumed that for all cases the same amount of pig iron, say, 1,000 tons, shall be worked in 24 hours.

Had one now a pig iron of the composition:

1 per cent. Si, 0·5 per cent. Mn, 0·08 per cent. P, and 4 per cent. C, the following would be necessary for the working of the same in the open-hearth furnace:

1st.—Ore.

1·00 per cent.	Si × 4·32 (*vide* 67) =	4·32 per cent. Fe_2O_3
0·50 ,,	Mn × 0·97 (,, 71) =	0·49 ,, ,,
0·08 ,,	P × 4·30 (,, 69) =	0·34 ,, ,,
4·00 ,,	P × 3·60 (,, 73) =	14·40 ,, ,,
	Total . .	19·55 per cent. Fe_2O_3

With ore containing 95 per cent. Fe_2O_3 and 5 per cent. SiO_2 there must, therefore, be employed about 20 per cent. of ore.

(NOTE.—Here, as also later, the small amounts of reducing agents which the metal still contains on complete refinement are disregarded. The ore requirement is, therefore, simply estimated on the total quantity of reducing agents.)

2nd. Limestone.

There is necessary for fixing the phosphoric acid, from formula (38):

0·08 × 3·61	= 0·30 per cent. CaO
For fixing the silica:	
2·14 per cent. SiO_2 from Si in pig iron	
1·00 ,, ,, ,, the ore	
0·45 ,, ,, ,, the furnace structure	
Thus 3·59 per cent. SiO_2 × 2·33 (*vide* 41) . .	= 8·40 ,, ,,
or a total of . .	8·70 per cent. CaO
of which there would come from the furnace hearth (*vide* formula 31A)	4·50 ,, ,,
Thus required to be added . . .	4·20 per cent. CaO

This corresponds to 4·2 × 2 = 8·4 per cent. limestone.

3rd. From the removal of the reducing agents there is a growth of bath of iron to the following extent:—

	4·00 per cent.	C × 1·47 (*vide* 74)	= 5·88 per cent.
	1·00 ,,	Si × 1·00 (,, 68)	= 1·00 ,,
	0·08 ,,	P × 2·00 (,, 70)	= 0·16 ,,
		Total . .	7·04 per cent.
Less	0·50 ,,	Mn × 0·32 (*vide* 72)	= 0·16 ,,
		Net growth .	6·88 per cent.

The foregoing pig iron is suitable for the acid Bessemer process; its composition is, according to Campbell and Ledeber, actually that which yields the best of all results with this process, namely the highest production and a shrinkage of only 8 per cent.

Assuming the following prices, viz.:

Pig iron . . .	75 Marks per ton
Limestone . .	5 ,, ,,
Ore . . .	25 ,, ,,

one obtains the following comparison:—

Charge.	Acid Bessemer Process.	Basic Open-Hearth Furnace.
	Tons.	Tons.
(*a*) Pig Iron . .	1,000 at 75M. = 75,000M.	1,000 at 75M. = 75,000M.
(*b*) Additions—		
Limestone .	—	84 ,, 5M. = 420M.
Ore . . .	—	200 ,, 25M. = 5,000M.
(*c*) Contingent Materials—		
Furnace repairs .	—	1,070 ,, 2M. = 2,140M.
Fuel . . .	—	214 ,, 12M. = 2,570M.
Value of Materials	75,000M.	85,130M.
Steel produced .	920	1,068
Cost of Material per ton of steel produced . .	$\frac{75,000}{920} = 81·50$M.	$\frac{85,130}{1,068} = 79·71$M.

This yields the certainly unexpected result that under the circumstances the basic open-hearth furnace can work cheaper than the acid Bessemer process itself. Naturally in such investigations, the exact prices of pig iron and ore must be taken into account.

The foregoing investigation furnishes also explanation as to the quantities of materials to be handled in each process This amounts per ton of steel

In the acid Bessemer process to $\frac{1,000}{920}=1{\cdot}09$ tons.

In the basic open-hearth ,, ,, $\frac{1,284}{1,068}=1{\cdot}21$ tons.

If, on the other hand, the pig iron at disposal consists of the following composition, 1·8 per cent. P, 0·5 per cent. Si, 2 per cent. Mn, and 4 per cent. C, according to which it is suitable for the basic Bessemer process, so there would be necessary for the working of the same in the open-hearth furnace in conjunction with the winning of the phosphoric acid in the most concentrated form:

1. Iron ore for dephosphorisation :

For 0·5 per cent.	Si (*vide* 63)	×7·62=	3·81 per cent. Fe_2O_3
,, 1·8 ,,	P (,, 64)	×7·80=	14·04 ,, ,,
,, 2·0 ,,	Mn (,, 65)	×0·97=	1·94 ,, ,,
	Total . . .		19·79 per cent. Fe_2O_3

For the elimination of the same reducing agents with complete decarburisation, there would, however, only be needed :

For 0·5 per cent.	Si (*vide* 67)	×4·32=	2·16 per cent. Fe_2O_3
,, 1·8 ,,	P (,, 69)	×4·30=	7·74 ,, ,,
,, 2·0 ,,	Mn (,, 71)	×0·97=	1·94 ,, ,,
	Total . . .		11·84 per cent. Fe_2O_3

Thus there remains from the first considered iron peroxide requirement, an excess of 19·79−11·84 or 7·95 per cent. Fe_2O_3, which could serve for the removal of a portion of the carbon content. The 4 per cent. carbon present requires inclusively, 4×3·60=14·4 per cent. Fe_2O_3 (*vide* 73), so that for the decarburisation in the second stage of the process still 14·40−7·95=6·45 per cent. Fe_2O_3 would be added. The total requirement of iron peroxide amounts, therefore, to 19·79+6·45 =26·24 per cent. Fe_2O_3, and the ore requirement, employing ore containing 95 per cent. Fe_2O_3, would equal $\frac{26{\cdot}24}{0{\cdot}95}=$ about 28 per cent.

For the second operation, there would in addition be about 1 per cent. manganese ore.

2. The lime required is :

For the phosphorus 1·8 P × 3·61 (*vide* 68)=6·50 per cent. CaO.
For the silica, viz. :—
0·45 SiO_2 from furnace structure
1·07 ,, *i.e.*, Si in pig iron × 2·14
1·00 ,, from the ore
Total . 2·52 per cent. SiO_2 × 2·33 (*vide* 41) =5·87 ,, ,,
Total . . 12·37 per cent. CaO.
Of which there will be derived from hearth 4·45 ,, CaO+MgO
Thus there must be added 7·92 per cent. CaO.
Or, say, 16 per cent. limestone.

3. The amount and composition of the phosphoric slag can now be ascertained from the foregoing figures.

One obtains from the first operation :

From 2·52 per cent. SiO_2 × 2·9 (*vide* 40A)= 7·31 hypothetical silicate slag.
,, 1·80 ,, P × 5·9 (,, 38)=10·62 calcium phosphate.
Or a total of . . 17·93 per cent. slag.

It may be assumed that of this slag, ·93 per cent. is scattered about and lost, so that only about 17 per cent. is won.

Reckoned in percentages, one finds the same to be composed of 59·2 per cent. Calcium phosphate, *i.e.*, 23 per cent. P_2O_5, and 36 per cent. CaO, and 40·8 per cent. silicate slag, containing the following :

40·8 × 0·34=13·8 per cent. SiO_2 (*vide* 40a).
40·8 × 0·13= 5·3 ,, FeO (,, 37).
40·8 × 0·13= 5·3 ,, MnO(,, 37).
40·8 × 0·04= 1·7 ,, Al_2O_3, etc. } *vide* p. 183.
40·8 × 0·36=14·7 ,, (CaO+MgO) }

The complete composition thus would be approximately :
23 per cent. P_2O_5, 14 per cent. SiO_2, 5 per cent FeO, 5 per cent. MnO, 51 per cent. (CaO+MgO)+2 per cent. Al_2O_3, etc.

The growth of bath would be as follows :—

0·5 per cent. Si × 1·00 (*vide* 68)=0·50 per cent.
1·8 ,, P × 2·00 (,, 70)=3·60 ,,
4·0 ,, C × 1·47 (,, 74)=5·88 ,,
Total . . . 9·98 per cent.
Less shrinkage due to 2 per cent. Mn × 0·32 (*vide* 72)=0·64 ,,
Yielding net . . . 9·34 per cent.

If one assumes the same prices for materials as before and for the charge shrinkage in the Thomas process only 12 per cent., the following comparison is yielded:—

Charge.	Thomas Process.	Basic Open-Hearth Process.
	Tons.	Tons.
(*a*) Pig iron . .	100 at 75 M. = 75,000 M.	1,000 at 75 M. = 75,000 M.
(*b*) Additions:		
Lime . .	125 at 12 M. = 1,500 M.	
Limestone. .	. . . . . .	160 at 5 M. = 800 M.
Ore . . .	. . . . . .	280 at 25 M. = 7,000 M.
Manganese ore .	. . . . . .	10 at 60 M. = 600 M.
	1,125 76,500 M.	1,450 83,400 M.
Other items:		
Furnace repairs.	*Nil* *Nil*	1,093 at 2 M.=say 2,200 M.
Producer coal .	*Nil* *Nil*	220 at 12 M. = 2,640 M.
Total . .	76,500 M.	88,240 M.
Less value of by-products:		
Slag containing .	18 per cent. P_2O_5 170 tons at 20 M.= 3,400 M.	23 per cent. P_2O_5 170 tons at 20 M.= 3,400 M.
Net cost . . .	73,100 M.	84,840 M.
Steel produced .	830 tons at 83·00 M.	1,093 tons at 77·60 M.

On the prices assumed, a difference is yielded in favour of the open-hearth furnace of more than 5 Marks per ton of steel. With pig iron 60 Marks per ton and other prices as before, this difference is reduced to 1·20 Marks per ton in favour of the open-hearth furnace.

The materials to be weighed up per ton of steel amount to:

$$\text{Thomas process } \frac{1{,}125}{880} = \text{about } 1{\cdot}30 \text{ ton.}$$

$$\text{Open-hearth process } \frac{1{,}450}{1{,}093} = \text{about } 1{\cdot}33 \text{ ton.}$$

These results, which have been founded on the basis of assumptions which certainly have not been made specially favourable to the open-hearth process, show that the latter may well only have to be avoided in competition with the basic Bessemer process in exceptional cases. It obtains a still greater importance if one takes into regard the advantage which arises to the blast furnaces from working in conjunction with the open-hearth furnace. H. H. Campbell writes that in works which further work pig iron direct from the blast furnace, the converting apparatus only performs one-half of the work, whilst the other half is performed by the blast furnace. With such modes of working both apparatuses essentially thus actually form an organic whole, and each lightening of the task which one can achieve in the one portion comes as profit to the whole. The utilisation of the open-hearth furnace for the conversion grants the following facilities:

1. The phosphorus content of the pig iron can be higher or lower than the Thomas process admits of, and, therefore, often the manufacturing costs of the pig iron figure lower, without thereby actually being obliged to sacrifice the advantage which the winning of a marketable phosphatic slag carries with it.

2. One can without difficulty manufacture all classes of steel on the market.

3. One can with ease lower the production of the plant in times of bad trade, without specially unfavourably influencing manufacturing costs. One requires only to put out of employment the corresponding number of furnaces; thereby of course the general charges grow, but since the remaining furnaces may be driven at full capacity, their purely working costs need not go up. On the contrary, a basic Bessemer works can only produce good results if the working can be forced, and each shrinkage of the same at once permits the manufacturing costs to rapidly go up in a grievous manner.

4. But the greatest advantage which the blast-furnace-open-hearth furnace combination affords consists in the greater productive capacity of the entire plant, which, as is apparent from the examples cited, is due to the increased output of finished steel from the same amount of pig iron worked. This larger output amounts, as against the basic Bessemer converter, to 1,093—800=213 tons of steel per 1,000 tons pig iron produced, and to attain such an increase of output would in the most favourable circumstances involve in a basic Bessemer works the installation of at least one new blast furnace.

All these advantages have for eight to ten years been emphasised by O. Thiel. They have, however, up to the present only little smoothed the way of the open-hearth process. The ground thereof will be sought partly in that one overrated the difficulties which the production of such large quantities of steel in the open-hearth plants involved. Of course, if nowadays an open-hearth furnace were not able to produce more than 50 to 60 tons of steel per diem, as was formerly the case, so one could attribute a certain justification to a hesitancy against working up very large quantities of pig iron in open-hearth furnaces, but the conditions have also nowadays become different, as O. Thiel has likewise pointed out. To-day data are at hand, according to which outputs of 130 to 150 tons of ingots per 24 hours are produced in ordinary fixed 30-ton open-hearth furnaces, and therefrom it is clear that a plant for working up 1,000 tons of pig iron per diem would not be extraordinarily large, and thereby its superintendence interfered with, ten open-hearth furnaces, of which eight working and two in reserve, sufficing for this quantity of pig iron. The plant for all these ten furnaces could scarcely be more costly than the plant of a new blast furnace.

A further condition which unfavourably influenced the mind as to the open-hearth process, lies in the general broad view that the iron content of the very dear (because pure) ore employed in the open-hearth furnace is only very incompletely utilised. In order to test this view as to its justification, let the last example working with basic Bessemer pig in the open-hearth furnace be still further gone into.

In the slag of the dephosphorising process in the open-hearth furnace, of a weight of about 18 per cent. of the metal charged there is contained about 0·7 per cent. Fe (taken on the weight of the charge). In the second operation, the quantity of slag amounts to about 10 to 15 per cent. on the weight of the iron, and this contains 10 per cent. Fe. Thus herewith there is lost about 1 to 1·5 per cent. Fe (taken on the weight of the charge). Thus the total loss amounts to $0{\cdot}7+1$ to $1{\cdot}5=1{\cdot}7$ per cent. to 2·2 per cent. Fe.

Now since 26·24 per cent. Fe_2O_3, corresponding to $26{\cdot}24\times 0{\cdot}7=18{\cdot}37$ per cent. Fe in the form of pure ore, must be added to pig iron, thus only 12 to 10 per cent. of this iron remains in the slag, and 88 per cent. to 90 per cent. on the other hand are rendered useful.

One will now certainly object that this result is not brilliant, that the blast furnace could have utilised it much better, in that nothing or as good as nothing would have been lost. For testing this contention, one again does best to regard the blast furnace and converting apparatus as a whole, and establish a balance as to the amounts of iron which take part in the entire process (*i.e.* from winning the pig iron up to the completion of its conversion). Assuming that absolutely nothing goes to loss in the blast furnace, so the whole of the iron present in the ore reaches the conversion apparatus.

In the example of the basic Bessemer process under consideration, the pig iron employed contained 1·8 per cent. P, 0·5 per cent. Si, 2 per cent. Mn, and 4 per cent. C, and (by difference) 91·7 per cent. Fe. Thus one brought into employment per metric ton 917 kilogrammes Fe, and obtained therefrom 880 kilogrammes steel, having thus lost 37 kilogrammes Fe., or suffered a loss of iron of $\frac{3,700}{917}=4$ per cent. of the total handled.

In the open-hearth furnace, however, one employed per metric ton of pig iron 917 kilogrammes Fe, one introduced in 262·4 kilogrammes iron peroxide, 183·7 kilogrammes Fe, thus having handled 1,110·7 kilogrammes Fe, and produced 1,093·4 kilogrammes steel. The loss thus amounts to 7·3 kilogrammes Fe, or, say, 0·7 per cent. of the total quantity of iron employed in working.

By working up Bessemer pig iron, the metallic iron loss fixes itself at 2·6 per cent. for the converter, and only 1·1 per cent. for the basic open-hearth furnace.

It is, therefore, beyond doubt that utilisation of the identical materials is the more complete in the open-hearth furnace.

These excellent results, permit it to appear justified to call attention anew to the advantages of the basic open-hearth process. In order to be able to utilise them to the full, of course, the theoretical side of the process must be duly valued.

APPENDIX

TABLES AND FORMULÆ

1. Heats of Combustion (Th. Beckert).

Combustible.		Product of Combustion.	Amount Burnt.	
			1 kg. yields Calories.	1 cbm. yields Calories.
Carbon	C_2	2 CO	2,387	—
,,	C_2	2 CO_2	8,080	—
Carbon monoxide	CO	CO_2	2,440	3,063
Hydrogen	H_2	H_2O water at 0°	34,600	3,110
,,	H_2	H_2O steam at 0°	29,140	2,620
Methane	CH_4	mH_2O (vapour) + nCO_2	11,980	8,600
Ethelene	C_2H_4	(gas) at 0° and 760 mm.	11,295	14,185
Aluminium	Al_2	Al_2O_3	7,090	—
Iron	Fe_2	2 FeO	1,353	—
,,	Fe_2	Fe_3O_4	1,644	—
,,	Fe_2	Fe_2O_3	1,796	—
Manganese	Mn_2	2 MnO	1,724	—
,,	Mn_2	2 MnO_2	2,115	—
Phosphorus	P_2	P_2O_5	5,965	—
Silicon	Si_2	2 SiO_2	7,830	—
Sulphur	S_2	2 SO_2	2,221	—

2. Relation between Volume and Weight of Certain Gases at 0° and 760 Millimetres Pressure.

Volume of 1 kilogramme in cubic metres.

Air.	O.	N.	H.	CH_4.	C_2H_4.	CO.	CO_2.	SO_2.	H_2O.
0·7729	0·6991	0·7958	11·1236	1·3931	0·7998	0·7965	0·5055	0·3482	1·2421

Weight of 1 cubic metre in kilogrammes.

Air.	O.	N.	H.	CH_4.	C_2H_4.	CO.	CO_2.	SO_2.	H_2O.
1·2937	1·4304	1·2567	0·0899	0·7178	1·2503	1·2555	1·9781	2·8723	0·8051

Mean Specific Heats C_0^t per Kilogramme and Cubic Metre Gas respectively from 0° to 2,000° C (Th. Beckert).

Temperature.	1 Kilogramme.										1 Cubic Metre.					
	Air.	O.	N.	H.	CO.	CH$_4$.	Vapour H$_2$O.	CO$_2$.	SO$_2$.	C$_2$H$_4$.	Air O N.H.CO.	CH$_4$.	Vapour. H$_2$O.	CO$_2$.	S$_2$O.	C$_2$H$_4$.
0°	0·2375	0·2175	0·2438	3·4090	0·2425	0·5930	0·4415	0·1952	0·1450	0·3710	0·3073	0·4256	0·3555	0·3861	0·4164	0·2967
100°	·2405	·2202	·2468	3·4516	·2455	·6004	·4702	·2079	·1544	·3951	·3111	·4309	·3786	·4112	·4435	·3160
200°	·2434	·2229	·2499	3·4942	·2486	·6078	·4989	·2206	·1638	·4192	·3150	·4362	·4017	·4363	·4705	·3353
300°	·2464	·2257	·2529	3·5369	·2516	·6152	·5276	·2333	·1733	·4434	·3188	·4416	·4248	·4614	·4976	·3546
400°	·2494	·2284	·2560	3·5795	·2546	·6226	·5563	·2460	·1827	·4675	·3227	·4469	·4479	·4865	·5247	·3739
500°	·2523	·2311	·2590	3·6221	·2576	·6300	·5850	·2586	·1921	·4916	·3265	·4522	·4710	·5116	·5517	·3931
600°	·2553	·2338	·2621	3·6647	·2607	·6375	·6137	·2713	·2015	·5157	·3303	·4575	·4942	·5367	·5788	·4124
700°	·2583	·2365	·2651	3·7073	·2637	·6449	·6424	·2840	·2109	·5398	·3342	·4628	·5173	·5618	·6059	·4317
800°	·2612	·2393	·2682	3·7500	·2667	·6523	·6711	·2967	·2204	·5640	·3380	·4682	·5404	·5869	·6330	·4510
900°	·2642	·2420	·2712	3·7926	·2698	·6597	·6998	·3094	·2298	·5881	·3419	·4735	·5635	·6120	·6600	·4703
1000°	0·2672	0·2447	0·2743	3·8352	0·2728	0·6671	0·7285	0·3221	0·2392	0·6122	0·3457	0·4788	0·5866	0·6371	0·6871	0·4896
1100°	·2702	·2474	·2773	3·8778	·2758	·6745	·7572	·3348	·2486	·6363	·3495	·4841	·6097	·6622	·7142	·5089
1200°	·2731	·2501	·2804	3·9204	·2789	·6819	·7859	·3475	·2580	·6604	·3534	·4894	·6328	·6873	·7412	·5282
1300°	·2761	·2528	·2834	3·9631	·2819	·6893	·8146	·3602	·2675	·6846	·3572	·4948	·6559	·7124	·7683	·5475
1400°	·2791	·2556	·2865	4·0057	·2849	·6967	·8433	·3729	·2769	·7087	·3611	·5001	·6790	·7375	·7954	·5668
1500°	·2820	·2583	·2895	4·0483	·2879	·7041	·8720	·3855	·2863	·7328	·3649	·5054	·7021	·7626	·8224	·5860
1600°	·2850	·2610	·2926	4·0909	·2910	·7116	·9007	·3982	·2957	·7569	·3687	·5107	·7253	·7877	·8495	·6053
1700°	·2880	·2637	·2956	4·1335	·2940	·7190	·9294	·4109	·3051	·7810	·3726	·5160	·7484	·8128	·8766	·6246
1800°	·2909	·2665	·2987	4·1762	·2970	·7264	·9581	·4236	·3146	·8052	·3764	·5214	·7715	·8379	·9037	·6439
1900°	·2939	·2692	·3017	4·2188	·3001	·7338	·9868	·4363	·3240	·8293	·3803	·5267	·7946	·8630	·9307	·6632
2000°	0·2969	0·2719	0·3048	4·2614	0·3031	0·7412	1·0155	0·4490	0·3334	0·8534	0·3841	0·5320	0·8177	0·8881	0·9578	0·6825
D=	0·00297	0·00272	0.00305	0·04262	0·00303	0·00741	0·02870	0·01269	0·00942	0·02412	0·00384	0·00532	0·02311	0·02510	0·02707	0·01929

SPECIFIC HEATS TAKEN ON EQUAL WEIGHT OF WATER.

Charcoal 0·1653. Graphite 0·3555. Coal 0·201. Coke 0·203. Ash 0·215. According to Violle, the mean specific heat of C below 1,000° increases in direct ratio to the temperature, thus:—

$$C_o^t = 0{\cdot}355 + 0{\cdot}00006\,t.$$

No.	FORMULÆ FROM TEXT.	PAGE
1	Ratio of N to O in air (volumes) $N = 3{\cdot}762\ O$	23
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3	$N = 3{\cdot}762\ CO_2$	26
4	1 kg. C yields 1·86 cbm. CO_2 at 0° and 760 mm.	27
5	1 kg. C yields with air 1·86 cbm. CO_2 + 7·00 cbm. N = 8·86 cbm. gas (0° and 760 mm.)	27
6	$C + \boxed{\begin{matrix}1\text{ cbm.}\\ O\end{matrix}} = \boxed{\begin{matrix}2\text{ cbm.}\\ CO\end{matrix}}$	27
7	Air-gas by volume 34·7 per cent. CO + 65·3 per cent. N	27
8	$N = 3{\cdot}762\ \frac{CO}{2}$	27
9	1 kg. C yields 1·86 cbm. CO (0° and 760 mm.)	28
10	1 kg. C yields air-gas (0° and 760 mm.) in cbm. 1·86 CO + 3·50N = 5·36 gas	28
11	Under simultaneous formation of CO_2 and CO from C and air $N = 3{\cdot}762\left(\frac{CO}{2} + CO_2\right)$	28
12	Formation of water-vapour $\boxed{\begin{matrix}1\text{ cbm.}\\ O\end{matrix}} + \boxed{\begin{matrix}2\text{ cbm.}\\ H\end{matrix}} = \boxed{\begin{matrix}2\text{ cbm.}\\ H_2O\end{matrix}}$	29
13	Relation between volumes of O and H from steam $O = \frac{H}{2}$	29
14	Characteristic for water gas (I) (formation of pure CO) $H = CO$	30
15	Characteristic for water gas (II) (formation of pure CO_2) $CO_2 = \frac{H}{2}$	30
16	Characteristic for steam-air-gas from pure C, $N = 3{\cdot}762\left(CO_2 + \frac{CO}{2} - \frac{H}{2}\right)$	31
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CO 34·8 ,,
H 4·6 ,,
N 59·8 ,,
100 per cent.</td><td>CO_2 0·04 cbm. } 1·86 cbm.
CO 1·82 ,, } C gases.
H 0·24 ,,
N 3·13 ,,
5·23 cbm. steam-air-gas.</td><td></td></tr>
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<tr><td></td><td>Composition—
C_mH_n 3·1, CH_4 23·7, H 56·0, CO 8·8, CO_2 3·0,
or O 7·4 cubic metres, N nil, H 109·6 cubic metre
Per cubic metre H_d
Combustible value, 3,850 cals.</td><td>Composition—
C_mH 4·5, CH_4 34·0, H 47·6, CO 8·3, CO_2 1·8, O 0·2, and N 3·5 per cent.,
or O 6·15 cubic metres, N 3·5 cubic metres, H 124·6 cubic metres.</td><td></td></tr>
</table>

No.	Formulæ from Text.	Page.
	Distillation Gas—*continued.*	

C-poorest Gas.	C-richest Gas.
	Per cubic metre H_d
	Combustible value, 4,060 cals.
C = 0·20 kilogramme	C = 0·23 kilogramme
CH_4 = 0·27 cubic metre	CH_4 = 0·35 cubic metre.
O = 0·07 ,, ,,	O = 0·05 ,, ,,
N = 0·03 ,, ,,	N = 0·03 ,, ,,
CO_2 = 0·03 ,, ,,	CO_2 = 0·015 ,, ,,
CO = 0·07 ,, ,,	CO = 0·07 ,, ,,

Correction for H_d by combustion method

Amount to be added, 15·6 %.	Amount to be added 9·10 %.

27 Combustion of C_2H_4 and CH_4 :— 75

$$\boxed{\begin{matrix}1\text{ cbm.}\\ C_2H_4\end{matrix}} + \boxed{\begin{matrix}3\text{ cbm.}\\ O\end{matrix}} = \boxed{\begin{matrix}2\text{ cbm.}\\ CO_2\end{matrix}} + \boxed{\begin{matrix}2\text{ cbm.}\\ H_2O\text{ vapour}\end{matrix}}$$

$$\boxed{\begin{matrix}1\text{ cbm.}\\ CH_4\end{matrix}} + \boxed{\begin{matrix}2\text{ cbm.}\\ O\end{matrix}} = \boxed{\begin{matrix}1\text{ cbm.}\\ CO_2\end{matrix}} + \boxed{\begin{matrix}2\text{ cbm.}\\ H_2O\text{ vapour}\end{matrix}}$$

28 Fe_2SiO_4 contains 29·4 per cent. SiO_2 and 70·6 per cent. FeO, or 2·4 units FeO per unit SiO_2 (by weight) 148

29 $FeSiO_3$ contains 45·5 per cent. SiO_2 and 54·5 per cent. FeO, or 1·2 units FeO per unit SiO_2 (by weight) 148

30 **Slag-forming Substances.**

(*a*) Silica : from impurities on charge, to be estimated in each case 152

(*b*) 1 per cent. Si in metal gives rise to 2·14 per cent. SiO_2 . 152

(*c*) (Assumed) about 0·15 per cent. SiO_2 acid-structure of furnace reaches slag 153

(*d*) (Assumed) about 0·30 per cent. SiO_2 from basic hearth, etc., reaches slag 153

(*e*) (Assumed) total SiO_2 from furnace structure reaching slag = about 0·45 per cent. 153

31 (*a*) (Assumed) total of earthy bases derived by slag from furnace structure = 4·45 per cent. 154

(*b*) Limestone required = about double lime required . . 154

No.	Formulæ from Text.	Page.
	OXYGEN REQUIRED TO OXIDISE REDUCING AGENTS.	
32	1 per cent. Si requires 1·14 per cent. O, yielding 2·14 per cent. SiO_2	156
33	1 ,, P ,, 1·29 ,, O ,, 2·29 ,, P_2O_5	158
34	1 ,, Mn ,, 0·29 ,, O ,, 1·29 ,, MnO	161
35	1 ,, C ,, 1·33 ,, O ,, 2·33 ,, CO	164
36	1 ,, Fe ,, 0·29 ,, O ,, 1·29 ,, FeO	171
37	State of approximate equilibrium between metal and slag is attained when slag contains about 10 per cent. Fe, *i.e.*, 13 per cent. FeO, and 10 per cent. Mn, *i.e.*, 13 per cent. MnO	176
	RELATIVE RATIOS OF INDIVIDUAL SUBSTANCES IN THE SLAG.	
38	1 per cent. P requires 3·61 per cent. CaO and yields 5·9 per cent. $P_2Ca_4O_9$	177
39	For each 1 per cent. P there must be present 0·3 per cent. SiO_2 for slag formation	183
40	Per 1 per cent. Si on complete decarburisation there must be 4·78 per cent. silicate slag, containing 20·92 per cent. SiO_2	183
	(*a*) per 1 per cent. Si on partial decarburisation there must be 2·9 per cent. silicate slag containing 34·35 per cent. SiO_2	183
41	1 per cent. SiO_2 corresponds on complete decarburisation to 2·33 per cent. CaO and MgO	184
	(*a*) 1 per cent. SiO_2 corresponds on partial decarburisation to 1·06 per cent. CaO and MgO	184
	AMOUNT OF SLAG.	
42	1 per cent. Si yields 10·23 per cent. final slag	185
	(1 per cent. P yields 5·9 per cent. final slag)	185
43	C content of bath (assumed) yields 2·15 per cent. slag (taken on charge)	185
	(*a*) Each 1 per cent. SiO_2 on surface of charge produces 4·78 per cent. final slag	186
	CHARGE SHRINKAGE.	
44	C contained in bath produces loss of C+0·2 per cent. Fe=1·2 per cent.	186
45	1 per cent. Si contained in bath produces loss of Si+1 per cent. Fe=2 per cent.	186
45A	1 per cent. SiO_2 contained in bath produces loss of 0·5 per cent. Fe	
	P and Mn contained in bath produce loss of their own amounts	187
	HEAT CONTENTS.	
46	1 kg. pig iron—melted but not overheated 250 cals.	199
47	1 ,, slag from cupola 375 ,,	199
48	1 ,, steel, casting heat 350 ,,	199
49	1 ,, slag, belonging to above 525 ,,	199
50	Heat absorbed liberating CO_2 from 1 kg. limestone 180 ,,	200
51	,, ,, ,, CO ,, 1 ,, C 800 ,,	200
52	,, ,, decomposing 1 kg. limestone 425 ,,	201

No.	Formulæ from Text.	Page.
	Heats of Combustion and Combination.	
53	1 kg. Si yields on combustion to SiO_2[+7,830 cals.] 1 ,, P ,, ,, ,, ,, P_2O_5[+5,965 ,,] 1 ,, Mn ,, ,, ,, ,, MnO[+1,784 ,,] 1 ,, C ,, ,, ,, ,, CO[+2387 ,,] 1 ,, Fe ,, ,, ,, ,, FeO[+1,350 ,,] . . .	201
54	1 ,, SiO_2 ,, ,, combination with CaO forming $SiCaO_3$ [+254 cals.]	202
55	1 ,, SiO_2 ,, ,, ,, ,, MnO ,, $(SiO_2)_2(MnO)_3$ [+134 cals.]	202
56	1 ,, SiO_2 ,, ,, ,, ,, CaO ,, $SiCa_2O_4$ [+384 cals.]	202
57	1 ,, P_2O_5 ,, ,, ,, ,, CaO ,, $P_2Ca_4O_9$ [+1,131 cals.]	202
	Change of Heat Requirement Due to the Reducing Agents. Per Kilogramme Steel Produced.	
58	1 per cent. Si increases heat demand by + 15 cals. . .	203
59	1 ,, ,, SiO_2 ,, ,, ,, ,, + 43 ,, . .	203
60	1 ,, ,, P diminishes ,, ,, ,, − 11 ,, . .	204
61	1 ,, ,, Mn ,, ,, ,, ,, − 17 ,, . .	204
62	1 ,, ,, C ,, ,, ,, ,, − 14 ,, . .	206
	Fe_2O_3 Required to Remove Reducing Agents from Iron.	
63	1 per cent. Si requires for its elimination in the form of $SiFe_2O_4$ . . . . 7·62 per cent. Fe_2O_3 . . .	211
64	1 per cent. P requires for its elimination in the form of $P_2Fe_4O_9$ . . . . 7·80 per cent. Fe_2O_3 . . .	212
65	1 per cent. Mn requires for its elimination in the form of MnO . . . . 0·97 per cent. Fe_2O_3 . . .	212
66	1 per cent. C requires for its elimination in the form of CO . . . . 4·44 per cent. Fe_2O_3 . . .	212

No.	Agent.	Fe_2O_3.	Effect on Charge Growth + Charge −	Page.
67	1 per cent. Si	4·32 per cent.		224
68	1 ,, ,, Si		+1 per cent.	225
69	1 ,, ,, P	4·30 ,, ,,		225
70	1 ,, ,, P		+2 ,, ,,	225
71	1 ,, ,, Mn	0·97 ,, ,,		225
72	1 ,, ,, Mn		−0·32 ,, ,,	225
73	1 ,, ,, C	3·60 ,, ,,		228
74	1 ,, ,, C		+1·47 ,, ,,	228

TABLE FOR DETERMINING THE RELATIVE VALUES OF O AND N IN AIR.

Ratio of O to N in Air.

O.	N.	Air.	O.	N.	Air.	O.	N.	Air.	O	N.	Air.
1	3·76	4·76	46	173·05	219·05	91	342·34	433·34	136	511·5	647·5
2	7·52	9·52	47	176·81	223·81	92	346·10	438·10	137	515·3	652·3
3	11·28	14·28	48	180·57	228·57	93	349·87	442·87	138	519·1	657·1
4	15·05	19·05	49	184·34	233·34	94	353·63	447·63	139	522·8	661·8
5	18·81	23·81	50	188·10	238·10	95	357·39	452·39	140	526·7	666·7
6	22·57	28·57	51	191·86	242·86	96	361·15	457·15	141	530·4	671·4
7	26·33	33·33	52	195·62	247·62	97	364·92	461·92	142	534·2	676·2
8	30·10	38·10	53	199·39	252·39	98	368·68	466·68	143	538·0	681·0
9	33·86	42·86	54	203·15	257·15	99	372·44	471·44	144	541·7	685·7
10	37·62	47·62	55	206·91	261·91	100	376·20	476·20	145	545·5	690·5
11	41·38	52·38	56	210·67	266·67	101	379·96	480·96	146	549·2	695·2
12	45·14	57·14	57	214·43	271·43	102	383·72	485·72	147	553·0	700·0
13	48·91	61·91	58	218·19	276·19	103	387·49	490·49	148	556·8	704·8
14	52·67	66·67	59	221·96	280·96	104	391·25	495·25	149	560·5	709·5
15	56·43	71·43	60	225·72	285·72	105	395·01	500·01	150	564·3	714·3
16	60·19	76·19	61	229·48	290·48	106	398·77	504·77	151	568·1	719·1
17	63·95	80·95	62	233·24	295·24	107	402·53	509·53	152	571·8	723·8
18	67·72	85·72	63	237·01	300·00	108	406·30	514·30	153	575·6	728·6
19	71·48	90·48	64	240·77	304·77	109	410·06	519·06	154	579·3	733·3
20	75·24	95·24	65	244·53	309·53	110	413·82	523·82	155	583·1	738·1
21	79·00	100·00	66	248·29	314·29	111	417·58	528·58	156	586·9	742·9
22	82·76	104·76	67	252·05	319·05	112	421·34	533·34	157	590·6	747·6
23	86·53	109·53	68	255·82	323·82	113	425·11	538·11	158	594·4	752·4
24	90·29	114·29	69	259·58	328·58	114	428·87	542·87	159	598·2	757·2
25	94·05	119·05	70	263·34	333·34	115	432·63	547·63	160	601·9	761·9
26	97·81	123·81	71	267·10	338·10	116	436·39	552·39	161	605·7	766·7
27	101·57	128·57	72	270·86	342·86	117	440·15	557·15	162	609·4	771·4
28	105·34	133·34	73	274·63	347·63	118	443·92	561·92	163	613·2	776·2
29	109·10	138·10	74	278·39	352·39	119	447·68	566·68	164	617·0	781·0
30	112·86	142·86	75	282·15	357·15	120	451·44	571·44	165	620·7	785·7
31	116·62	147·62	76	285·91	361·91	121	455·2	576·2	166	624·4	790·4
32	120·38	152·38	77	289·67	366·67	122	459·0	581·0	167	628·2	795·2
33	124·15	157·15	78	293·44	371·44	123	462·7	585·7	168	632·0	800·0
34	127·91	161·91	79	297·20	376·20	124	466·5	590·5	169	635·8	804·8
35	131·67	166·67	80	300·96	380·96	125	470·2	595·2	170	639·5	809·5
36	135·43	171·43	81	304·72	385·72	126	474·0	600·0	171	643·3	814·3
37	139·19	176·19	82	308·48	390·48	127	477·8	604·8	172	647·1	819·1
38	142·96	180·96	83	312·24	395·24	128	481·5	609·5	173	650·8	823·8
39	146·72	185·72	84	316·01	400·00	129	485·3	614·3	174	654·6	828·6
40	150·48	190·48	85	319·77	404·77	130	489·1	619·1	175	658·3	833·3
41	154·24	195·24	86	323·53	409·53	131	492·8	623·8	176	662·1	838·1
42	158·00	200·00	87	327·29	414·29	132	496·6	628·6	177	665·9	842·9
43	161·77	204·77	88	331·06	419·06	133	500·2	633·2	178	669·6	847·6
44	165·53	209·53	89	334·82	423·82	134	504·0	638·0	179	673·4	852·4
45	169·29	214·29	90	338·58	428·58	135	507·8	642·8	180	677·2	857·2

O.	N.	Air.	O.	N.	Air.	O.	N.	Air.	O.	N.	Air.
181	680·9	861·9	232	872·8	1104·8	283	1065	1348	334	1257	1591
182	684·7	866·7	233	876·6	1109·6	284	1068	1352	335	1260	1595
183	688·4	871·4	234	880·3	1114·3	285	1072	1357	336	1264	1600
184	692·2	876·2	235	884·1	1119·1	286	1076	1362	337	1268	1605
185	696·0	881·0	236	887·8	1123·8	287	1080	1367	338	1271	1609
186	699·7	885·7	237	891·6	1128·6	288	1083	1371	339	1275	1614
187	703·5	890·5	238	895·4	1133·4	289	1087	1376	340	1279	1619
188	707·2	895·2	239	899·1	1138·1	290	1091	1381	341	1283	1624
189	711·0	900·0	240	902·9	1142·9	291	1095	1386	342	1287	1629
190	714·8	904·8	241	906·6	1147·6	292	1098	1390	343	1290	1633
191	718·5	909·5	242	910·4	1152·4	293	1102	1395	344	1294	1638
192	722·3	914·3	243	914·2	1157·2	294	1106	1400	345	1298	1643
193	726·1	919·1	244	917·9	1161·9	295	1110	1405	346	1302	1648
194	729·8	923·8	245	921·7	1166·7	296	1114	1410	347	1305	1652
195	733·6	928·6	246	925·5	1171·5	297	1117	1414	348	1309	1657
196	737·5	933·5	247	929·2	1176·2	298	1121	1419	349	1313	1662
197	741·1	938·1	248	933·0	1181·0	299	1125	1424	350	1317	1667
198	744·9	942·9	249	936·7	1185·7	300	1129	1429	351	1321	1672
199	748·6	947·6	250	940·5	1190·5	301	1132	1433	352	1324	1676
200	752·4	952·4	251	944·3	1195·3	302	1136	1438	353	1328	1681
201	756·2	957·2	252	948·0	1200·0	303	1140	1443	354	1332	1686
202	759·9	961·9	253	951·8	1204·8	304	1144	1448	355	1335	1690
203	763·7	966·7	254	955·6	1209·6	305	1147	1452	356	1339	1695
204	767·4	971·4	255	959·3	1214·3	306	1151	1457	357	1343	1700
205	771·2	976·2	256	963·1	1219·1	307	1155	1462	358	1347	1705
206	774·9	980·9	257	966·8	1223·8	308	1159	1467	359	1350	1709
207	778·7	985·7	258	970·6	1228·6	309	1162	1471	360	1354	1714
208	782·5	990·5	259	974·4	1233·4	310	1166	1476	361	1358	1719
209	786·2	995·2	260	978·1	1238·1	311	1170	1481	362	1362	1724
210	790·0	1000·0	261	981·9	1242·9	312	1174	1486	363	1366	1729
211	793·8	1004·8	262	985·6	1247·6	313	1177	1490	364	1369	1733
212	797·5	1009·5	263	989·4	1252·4	314	1181	1495	365	1373	1738
213	801·3	1014·3	264	993·2	1257·2	315	1185	1500	366	1377	1743
214	805·1	1019·1	265	996·9	1261·9	316	1189	1505	367	1381	1748
215	808·8	1023·8	266	1000	1266	317	1193	1510	368	1384	1752
216	812·6	1028·6	267	1004	1271	318	1196	1514	369	1388	1757
217	816·3	1033·3	268	1008	1276	319	1200	1519	370	1392	1762
218	820·1	1038·1	269	1012	1281	320	1204	1524	371	1396	1767
219	823·9	1042·9	270	1016	1286	321	1208	1529	372	1400	1772
220	827·6	1047·6	271	1019	1290	322	1211	1533	373	1403	1776
221	831·4	1052·4	272	1023	1295	323	1215	1538	374	1407	1781
222	835·2	1057·2	273	1027	1300	324	1219	1543	375	1411	1786
223	838·9	1061·9	274	1030	1304	325	1223	1548	376	1414	1790
224	842·7	1066·7	275	1034	1309	326	1226	1552	377	1418	1795
225	846·4	1071·4	276	1038	1314	327	1230	1557	378	1422	1800
226	850·2	1076·2	277	1042	1319	328	1234	1562	379	1426	1805
227	854·0	1081·0	278	1046	1324	329	1238	1567	380	1430	1810
228	857·7	1085·7	279	1050	1329	330	1241	1571	381	1433	1814
229	861·5	1090·5	280	1053	1333	331	1245	1576	382	1437	1819
230	865·3	1095·3	281	1057	1338	332	1249	1581	383	1441	1824
231	869·0	1100·0	282	1061	1343	333	1253	1586	384	1444	1828

O.	N.	Air.	O.	N.	Air.	O.	N.	Air.	O.	N.	Air.
385	1448	1833	436	1640	2076	487	1832	2319	538	2024	2562
386	1452	1838	437	1644	2081	488	1836	2324	539	2028	2567
387	1456	1843	438	1648	2086	489	1840	2329	540	2031	2571
388	1460	1848	439	1651	2090	490	1843	2333	541	2035	2576
389	1463	1852	440	1655	2095	491	1847	2338	542	2039	2581
390	1467	1857	441	1659	2100	492	1851	2343	543	2043	2586
391	1471	1862	442	1663	2105	493	1855	2348	544	2046	2590
392	1475	1867	443	1667	2110	494	1858	2352	545	2050	2595
393	1478	1871	444	1670	2114	495	1862	2357	546	2053	2599
394	1482	1876	445	1674	2119	496	1866	2362	547	2058	2605
395	1486	1881	446	1678	2124	497	1870	2367	548	2061	2609
396	1490	1886	447	1682	2129	498	1873	2371	549	2065	2614
397	1493	1890	448	1685	2133	499	1877	2376	550	2069	2619
398	1497	1895	449	1689	2138	500	1881	2381	551	2073	2624
399	1501	1900	450	1693	2143	501	1885	2386	552	2076	2628
400	1505	1905	451	1697	2148	502	1888	2390	553	2080	2633
401	1509	1910	452	1700	2152	503	1892	2395	554	2084	2638
402	1512	1914	453	1704	2157	504	1896	2400	555	2087	2642
403	1516	1919	454	1708	2162	505	1900	2405	556	2092	2648
404	1520	1924	455	1712	2167	506	1904	2410	557	2095	2652
405	1524	1929	456	1715	2171	507	1907	2414	558	2099	2657
406	1527	1933	457	1719	2176	508	1911	2419	559	2103	2662
407	1531	1938	458	1723	2181	509	1915	2424	560	2107	2667
408	1535	1943	459	1727	2186	510	1919	2429	561	2110	2671
409	1539	1948	460	1730	2190	511	1922	2433	562	2114	2676
410	1542	1952	461	1734	2195	512	1926	2438	563	2118	2681
411	1546	1957	462	1738	2200	513	1930	2443	564	2122	2686
412	1549	1961	463	1742	2205	514	1934	2448	565	2125	2690
413	1554	1967	464	1746	2210	515	1937	2452	566	2129	2695
414	1557	1971	465	1749	2214	516	1941	2457	567	2133	2700
415	1561	1976	466	1753	2219	517	1945	2462	568	2137	2705
416	1565	1981	467	1757	2224	518	1949	2467	569	2140	2709
417	1569	1986	468	1761	2229	519	1952	2471	570	2144	2714
418	1572	1990	469	1764	2233	520	1956	2476	571	2148	2719
419	1576	1995	470	1768	2238	521	1960	2481	572	2152	2724
420	1580	2000	471	1772	2243	522	1964	2486	573	2155	2728
421	1584	2005	472	1776	2248	523	1967	2490	574	2159	2733
422	1588	2010	473	1779	2252	524	1971	2495	575	2163	2738
423	1591	2014	474	1783	2257	525	1975	2500	576	2167	2743
424	1595	2019	475	1787	2262	526	1979	2505	577	2171	2748
425	1599	2024	476	1791	2267	527	1983	2510	578	2174	2752
426	1603	2029	477	1794	2271	528	1986	2514	579	2178	2757
427	1606	2033	478	1798	2276	529	1990	2519	580	2182	2762
428	1610	2038	479	1802	2281	530	1994	2524	581	2186	2767
429	1614	2043	480	1806	2286	531	1997	2528	582	2189	2771
430	1618	2048	481	1809	2290	532	2001	2533	583	2193	2776
431	1621	2052	482	1813	2295	533	2005	2538	584	2197	2781
432	1625	2057	483	1817	2300	534	2008	2542	585	2201	2786
433	1629	2062	484	1821	2305	535	2013	2548	586	2204	2790
434	1633	2067	485	1825	2310	536	2016	2552	587	2208	2795
435	1636	2071	486	1828	2314	537	2020	2557	588	2212	2800

O.	N.	Air.	O.	N.	Air.	O.	N.	Air.	O.	N.	Air.
589	2216	2805	640	2408	3048	691	2599	3290	742	2791	3533
590	2220	2810	641	2412	3053	692	2603	3295	743	2795	3538
591	2223	2814	642	2415	3057	693	2607	3300	744	2799	3543
592	2227	2819	643	2419	3062	694	2611	3305	745	2803	3548
593	2231	2824	644	2423	3067	695	2615	3310	746	2806	3552
594	2234	2828	645	2426	3071	696	2618	3314	747	2810	3557
595	2238	2833	646	2430	3076	697	2622	3319	748	2814	3562
596	2242	2838	647	2434	3081	698	2626	3324	749	2818	3567
597	2246	2843	648	2438	3086	699	2630	3329	750	2821	3571
598	2250	2848	649	2441	3090	700	2633	3333	751	2825	3576
599	2253	2852	650	2445	3095	701	2637	3338	752	2829	3581
600	2257	2857	651	2449	3100	702	2641	3343	753	2833	3586
601	2261	2862	652	2453	3105	703	2645	3348	754	2836	3590
602	2265	2867	653	2457	3110	704	2648	3352	755	2840	3595
603	2268	2871	654	2460	3114	705	2652	3357	756	2844	3600
604	2272	2876	655	2464	3119	706	2656	3362	757	2848	3605
605	2276	2881	656	2468	3124	707	2660	3367	758	2852	3610
606	2280	2886	657	2472	3129	708	2663	3371	759	2855	3614
607	2283	2890	658	2475	3133	709	2667	3376	760	2859	3619
608	2287	2895	659	2479	3138	710	2671	3381	761	2863	3624
609	2291	2900	660	2483	3143	711	2675	3386	762	2867	3629
610	2295	2905	661	2487	3148	712	2678	3390	763	2870	3633
611	2299	2910	662	2490	3152	713	2682	3395	764	2874	3638
612	2302	2914	663	2494	3157	714	2686	3400	765	2878	3643
613	2306	2919	664	2498	3162	715	2690	3405	766	2882	3648
614	2309	2923	665	2502	3167	716	2694	3410	767	2885	3652
615	2314	2929	666	2505	3171	717	2697	3414	768	2889	3657
616	2317	2933	667	2509	3176	718	2701	3419	769	2893	3662
617	2321	2938	668	2513	3181	719	2705	3424	770	2897	3667
618	2325	2943	669	2517	3186	720	2709	3429	771	2900	3671
619	2329	2948	670	2520	3191	721	2712	3433	772	2904	3676
620	2332	2952	671	2524	3195	722	2716	3438	773	2908	3681
621	2336	2957	672	2528	3200	723	2720	3443	774	2912	3686
622	2340	2962	673	2532	3205	724	2724	3448	775	2916	3691
623	2344	2967	674	2536	3210	725	2727	3452	776	2919	3695
624	2347	2971	675	2539	3214	726	2731	3457	777	2923	3700
625	2351	2976	676	2543	3219	727	2735	3462	778	2927	3705
626	2355	2981	677	2546	3223	728	2739	3467	779	2931	3710
627	2359	2986	678	2550	3228	729	2742	3471	780	2934	3714
628	2364	2992	679	2554	3233	730	2746	3476	781	2938	3719
629	2366	2995	680	2558	3238	731	2750	3481	782	2942	3724
630	2370	3000	681	2562	3243	732	2754	3486	783	2946	3729
631	2374	3005	682	2566	3248	733	2757	3490	784	2949	3733
632	2378	3010	683	2569	3252	734	2761	3495	785	2953	3738
633	2381	3014	684	2573	3257	735	2765	3500	786	2957	3743
634	2385	3019	685	2577	3262	736	2769	3505	787	2961	3748
635	2389	3024	686	2581	3267	737	2773	3510	788	2964	3752
636	2393	3029	687	2584	3271	738	2776	3514	789	2968	3757
637	2396	3033	688	2588	3275	739	2780	3519	790	2972	3762
638	2400	3038	689	2592	3281	740	2784	3524	791	2976	3767
639	2404	3043	690	2596	3286	741	2788	3529	792	2979	3771

O.	N.	Air.	O.	N.	Air.	O.	N.	Air.	O.	N.	Air.
793	2983	3776	845	3179	4024	897	3374	4271	949	3570	4519
794	2987	3781	846	3183	4029	898	3378	4276	950	3574	4524
795	2991	3786	847	3186	4033	899	3382	4281	951	3578	4529
796	2995	3791	848	3190	4038	900	3386	4286	952	3581	4533
797	2998	3795	849	3194	4043	901	3390	4291	953	3585	4538
798	3002	3800	850	3198	4048	902	3393	4295	954	3589	4543
799	3006	3805	851	3201	4052	903	3397	4300	955	3593	4548
800	3009	3809	852	3205	4057	904	3401	4305	956	3596	4552
801	3013	3814	853	3209	4062	905	3405	4310	957	3600	4557
802	3017	3819	854	3213	4067	906	3408	4314	958	3604	4562
803	3021	3824	855	3216	4071	907	3412	4319	959	3608	4567
804	3024	3828	856	3220	4076	908	3416	4324	960	3611	4571
805	3028	3833	857	3224	4081	909	3420	4329	961	3615	4576
806	3032	3838	858	3227	4085	910	3423	4333	962	3619	4581
807	3036	3843	859	3231	4090	911	3427	4338	963	3623	4586
808	3040	3848	860	3235	4095	912	3431	4343	964	3627	4591
809	3043	3852	861	3239	4100	913	3435	4348	965	3630	4595
810	3047	3857	862	3243	4105	914	3438	4352	966	3634	4600
811	3051	3862	863	3247	4110	915	3442	4357	967	3638	4605
812	3055	3867	864	3250	4114	916	3446	4362	968	3641	4609
813	3058	3871	865	3254	4119	917	3450	4367	969	3645	4614
814	3062	3876	866	3258	4124	918	3453	4371	970	3649	4619
815	3066	3881	867	3262	4129	919	3457	4376	971	3653	4624
816	3070	3886	868	3265	4133	920	3461	4381	972	3657	4629
817	3074	3891	869	3269	4138	921	3465	4386	973	3660	4633
818	3077	3895	870	3273	4143	922	3469	4391	974	3664	4638
819	3081	3900	871	3277	4148	923	3472	4395	975	3668	4643
820	3085	3905	872	3280	4152	924	3476	4400	976	3672	4648
821	3088	3909	873	3284	4157	925	3480	4405	977	3675	4652
822	3092	3914	874	3288	4162	926	3484	4410	978	3679	4657
823	3096	3919	875	3292	4167	927	3487	4414	979	3683	4662
824	3100	3924	876	3296	4172	928	3491	4419	980	3687	4667
825	3103	3928	877	3299	4176	929	3495	4424	981	3690	4671
826	3107	3933	878	3303	4181	930	3499	4429	982	3694	4676
827	3111	3938	879	3307	4186	931	3502	4433	983	3698	4681
828	3115	3943	880	3311	4191	932	3506	4438	984	3702	4686
829	3119	3948	881	3314	4195	933	3510	4443	985	3705	4690
830	3122	3952	882	3318	4200	934	3514	4448	986	3709	4695
831	3126	3957	883	3322	4205	935	3517	4451	987	3713	4700
832	3130	3962	884	3326	4210	936	3521	4457	988	3717	4705
833	3134	3967	885	3329	4214	937	3525	4462	989	3720	4709
834	3137	3971	886	3333	4219	938	3529	4467	990	3724	4714
835	3141	3976	887	3336	4223	939	3532	4471	991	3728	4719
836	3145	3981	888	3341	4229	940	3536	4476	992	3732	4724
837	3149	3986	889	3344	4233	941	3540	4481	993	3736	4729
838	3152	3990	890	3348	4238	942	3544	4486	994	3739	4733
839	3156	3995	891	3352	4243	943	3548	4491	995	3743	4738
840	3160	4000	892	3356	4248	944	3551	4495	996	3747	4743
841	3164	4005	893	3359	4252	945	3555	4500	997	3751	4748
842	3167	4009	894	3363	4257	946	3558	4504	998	3754	4752
843	3171	4014	895	3367	4262	947	3562	4509	999	3758	4757
844	3175	4019	896	3371	4267	948	3566	4514	1000	3762	4762

TABLE FOR DETERMINING THE CARBON CONTENT OF GASES, AND GAS VOLUMES CONTAINING 1 KILOGRAMME C FROM THE RESULTS OF GAS ANALYSES.

C Content of Gases and Gas Volumes.

Multiples of 0·538 and Gas Volume containing 1 Kilogramme C.

C-containing Gas per cent.	Kg. C in 100 cbm. Gas.	Amount of Gas from 1 kg. C.	C-containing Gas per cent.	Kg. C in 100 cbm. Gas.	Amount of Gas from 1 kg. C.
1·0	0·538	186cbm.	5·6	3·013	
1·1	0·592		5·7	3·067	
1·2	0·646		5·8	3·120	
1·3	0·699		5·9	3·174	
1·4	0·753		6·0	3·228	31·0cbm
1·5	0·807		6·1	3·282	
1·6	0·861		6·2	3·336	
1·7	0·915		6·3	3·389	
1·8	0·968		6·4	3·443	
1·9	1·022		6·5	3·497	
2·0	1·076	93·0	6·6	3·551	
2·1	1·130		6·7	3·605	
2·2	1·184		6·8	3·658	
2·3	1·237		6·9	3·712	
2·4	1·291		7·0	3·766	26·5
2·5	1·345		7·1	3·820	
2·6	1·399		7·2	3·874	
2·7	1·453		7·3	3·927	
2·8	1·506		7·4	3·981	
2·9	1·560		7·5	4·035	
3·0	1·614	62·1	7·6	4·089	
3·1	1·668		7·7	4·142	
3·2	1·721		7·8	4·196	
3·3	1·775		7·9	4·250	
3·4	1·829		8·0	4·304	23·2
3·5	1·883		8·1	4·358	
3·6	1·937		8·2	4·412	
3·7	1·991		8·3	4·465	
3·8	2·044		8·4	4·519	
3·9	2·098		8·5	4·573	
4·0	2·152	46·5	8·6	4·627	
4·1	2·206		8·7	4·681	
4·2	2·260		8·8	4·734	
4·3	2·313		8·9	4·788	
4·4	2·367		9·0	4·842	20·7
4·5	2·421		9·1	4·896	
4·6	2·475		9·2	4·950	
4·7	2·529		9·3	5·003	
4·8	2·582		9·4	5·057	
4·9	2·636		9·5	5·111	
5·0	2·690	37·2	9·6	5·165	
5·1	2·744		9·7	5·219	
5·2	2·798		9·8	5·272	
5·3	2·851		9·9	5·326	
5·4	2·905		10·0	5·380	18·6
5·5	2·959				

C-containing Gas per cent.	Kg. C in 100 cbm. Gas.	Amount of Gas from 1 kg. C.	C-containing Gas per cent.	Kg. C in 100 cbm. Gas.	Amount of Gas from 1 kg. C.
10·1	5·434		15·1	8·124	
10·2	5·488		15·2	8·178	
10·3	5·541		15·3	8·231	
10·4	5·595		15·4	8·285	
10·5	5·649		15·5	8·339	
10·6	5·703		15·6	8·393	
10·7	5·757		15·7	8·447	
10·8	5·810		15·8	8·500	
10·9	5·864		15·9	8·554	
11·0	5·918	17·0 cbm.	16·0	8·608	11·6 cbm.
11·1	5·972		16·1	8·662	
11·2	6·026		16·2	8·716	
11·3	6·079		16·3	8·769	
11·4	6·133		16·4	8·823	
11·5	6·187		16·5	8·877	
11·6	6·241		16·6	8·931	
11·7	6·295		16·7	8·985	
11·8	6·348		16·8	9·038	
11·9	6·402		16·9	9·092	
12·0	6·456	15·5	17·0	9·146	10·9
12·1	6·510		17·1	9·200	
12·2	6·564		17·2	9·254	
12·3	6·617		17·3	9·307	
12·4	6·671		17·4	9·361	
12·5	6·725		17·5	9·415	
12·6	6·779		17·6	9·469	
12·7	6·833		17·7	9·523	
12·8	6·886		17·8	9·576	
12·9	6·940		17·9	9·630	
13·0	6·994	14·3	18·0	9·684	10·3
13·1	7·048		18·1	9·738	
13·2	7·102		18·2	9·792	
13·3	7·155		18·3	9·845	
13·4	7·209		18·4	9·899	
13·5	7·263		18·5	9·953	
13·6	7·317		18·6	10·007	
13·7	7·371		18·7	10·061	
13·8	7·424		18·8	10·114	
13·9	7·478		18·9	10·168	
14·0	7·532	13·3	19·0	10·222	9·79
14·1	7·586		19·1	10·276	
14·2	7·640		19·2	10·330	
14·3	7·693		19·3	10·383	
14·4	7·747		19·4	10·437	
14·5	7·801		19·5	10·491	
14·6	7·855		19·6	10·545	
14·7	7·909		19·7	10·599	
14·8	7·962		19·8	10·652	
14·9	8·016		19·9	10·706	
15·0	8·070	12·4	20·0	10·760	9·30

C-containing Gas per cent.	Kg. C in 100 cbm. Gas.	Amount of Gas from 1 kg. C.	C-containing Gas per cent.	Kg. C in 100 cbm. Gas.	Amount of Gas from 1 kg. C.
20·1	10·814		25·1	13·50	7·41 cbm.
20·2	10·868		25·2	13·56	7·38
20·3	10·921		25·3	13·61	7·35
20·4	10·975		25·4	13·66	7·32
20·5	11·029		25·5	13·72	7·29
20·6	11·083		25·6	13·77	7·26
20·7	11·137		25·7	13·83	7·23
20·8	11·190		25·8	13·88	7·20
20·9	11·244		25·9	13·93	7·17
21·0	11·298	8·86 cbm.	26·0	13·99	7·15
21·1	11·352	8·81	26·1	14·04	7·12
21·2	11·406	8·77	26·2	14·09	7·09
21·3	11·459	8·73	26·3	14·15	7·06
21·4	11·513	8·69	26·4	14·20	7·04
21·5	11·567	8·65	26·5	14·26	7·01
21·6	11·621	8·61	26·6	14·31	6·98
21·7	11·675	8·57	26·7	14·36	6·96
21·8	11·728	8·53	26·8	14·42	6·93
21·9	11·782	8·49	26·9	14·47	6·91
22·0	11·836	8·45	27·0	14·53	6·89
22·1	11·890	8·41	27·1	14·58	6·86
22·2	11·944	8·38	27·2	14·63	6·84
22·3	11·997	8·34	27·3	14·69	6·82
22·4	12·051	8·30	27·4	14·74	6·79
22·5	12·105	8·27	27·5	14·79	6·76
22·6	12·159	8·23	27·6	14·85	6·74
22·7	12·213	8·19	27·7	14·90	6·71
22·8	12·266	8·15	27·8	14·96	6·68
22·9	12·320	8·12	27·9	15·01	6·66
23·0	12·374	8·09	28·0	15·06	6·64
23·1	12·428	8·05	28·1	15·12	6·62
23·2	12·482	8·02	28·2	15·17	6·59
23·3	12·535	7·98	28·3	15·22	6·57
23·4	12·589	7·95	28·4	15·28	6·55
23·5	12·643	7·91	28·5	15·33	6·52
23·6	12·697	7·87	28·6	15·39	6·50
23·7	12·751	7·84	28·7	15·44	6·48
23·8	12·804	7·81	28·8	15·49	6·46
23·9	12·858	7·78	28·9	15·55	6·43
24·0	12·912	7·75	29·0	15·60	6·41
24·1	12·966	7·71	29·1	15·66	6·39
24·2	13·020	7·68	29·2	15·71	6·37
24·3	13·073	7·65	29·3	15·76	6·34
24·4	13·127	7·62	29·4	15·82	6·32
24·5	13·181	7·59	29·5	15·87	6·30
24·6	13·235	7·56	29·6	15·92	6·28
24·7	13·289	7·52	29·7	15·98	6·26
24·8	13·424	7·50	29·8	16·03	6·24
24·9	13·396	7·47	29·9	16·09	6·22
25·0	13·45	7·44	30·0	16·14	6·20

C-containing Gas per cent.	Kg. C in 100 cbm. Gas.	Amount of Gas from 1 kg. C.	C-containing Gas per cent.	Kg. C in 100 cbm. Gas.	Amount of Gas from 1 kg. C.
30·1	16·19	6·17 cbm.	35·1	18·88	5·29 cbm.
30·2	16·25	6·15	35·2	18·94	5·28
30·3	16·30	6·13	35·3	18·99	5·27
30·4	16·36	6·11	35·4	19·04	5·25
30·5	16·41	6·09	35·5	19·10	5·23
30·6	16·46	6·08	35·6	19·15	5·22
30·7	16·52	6·06	35·7	19·21	5·20
30·8	16·57	6·04	35·8	19·26	5·19
30·9	16·62	6·02	35·9	19·31	5·18
31·0	16·68	6·00	36·0	19·37	5·17
31·1	16·73	5·98	36·1	19·42	5·15
31·2	16·78	5·96	36·2	19·48	5·13
31·3	16·84	5·94	36·3	19·53	5·12
31·4	16·89	5·92	36·4	19·58	5·10
31·5	16·95	5·90	36·5	19·64	5·09
31·6	17·00	5·88	36·6	19·69	5·08
31·7	17·05	5·86	36·7	19·74	5·06
31·8	17·11	5·84	36·8	19·80	5·05
31·9	17·16	5·82	36·9	19·85	5·04
32·0	17·22	5·81	37·0	19·91	5·03
32·1	17·27	5·79	37·1	19·96	
32·2	17·32	5·77	37·2	20·01	
32·3	17·38	5·75	37·3	20·06	
32·4	17·41	5·73	37·4	20·12	
32·5	17·48	5·72	37·5	20·17	
32·6	17·54	5·70	37·6	20·22	
32·7	17·59	5·68	37·7	20·28	
32·8	17·65	5·66	37·8	20·33	
32·9	17·70	5·65	37·9	20·39	
33·0	17·75	5·64	38·0	20·44	4·89
33·1	17·81	5·62	38·1	20·50	
33·2	17·86	5·60	38·2	20·55	
33·3	17·91	5·59	38·3	20·60	
33·4	17·97	5·57	38·4	20·66	
33·5	18·02	5·55	38·5	20·71	
33·6	18·08	5·53	38·6	20·77	
33·7	18·13	5·51	38·7	20·82	
33·8	18·18	5·50	38·8	20·87	
33·9	18·24	5·48	38·9	20·93	
34·0	18·29	5·47	39·0	20·98	4·77
34·1	18·34	5·45	39·1	21·03	
34·2	18·39	5·43	39·2	21·09	
34·3	18·45	5·41	39·3	21·14	
34·4	18·51	5·40	39·4	21·20	
34·5	18·56	5·38	39·5	21·25	
34·6	18·61	5·37	39·6	21·30	
34·7	18·67	5·35	39·7	21·36	
34·8	18·72	5·34	39·8	21·41	
34·9	18·78	5·32	39·9	21·46	
35·0	18·83	5·31	40·0	21·52	4·65

C-containing Gas per cent.	Kg. C in 100 cbm. Gas.	Amount of Gas from 1 kg. C.	C-containing Gas per cent.	Kg. C in 100 cbm. Gas.	Amount of Gas from 1 kg. C.
40·1	21·57		45·1	24·26	
40·2	21·63		45·2	24·31	
40·3	21·68		45·3	24·37	
40·4	21·73		45·4	24·42	
40·5	21·79		45·5	24·48	
40·6	21·84		45·6	24·53	
40·7	21·90		45·7	24·58	
40·8	21·95		45·8	24·64	
40·9	22·00		45·9	24·69	
41·0	22·06	4·54 cbm.	46·0	24·75	4·04 cbm.
41·1	22·11		46·1	24·80	
41·2	22·16		46·2	24·86	
41·3	22·22		46·3	24·91	
41·4	22·27		46·4	24·96	
41·5	22·33		46·5	25·01	
41·6	22·38		46·6	25·07	
41·7	22·43		46·7	25·12	
41·8	22·49		46·8	25·17	
41·9	22·54		46·9	25·23	
42·0	22·59	4·43	47·0	25·29	3·95
42·1	22·65		47·1	25·34	
42·2	22·70		47·2	25·39	
42·3	22·76		47·3	25·45	
42·4	22·81		47·4	25·50	
42·5	22·86		47·5	25·55	
42·6	22·92		47·6	25·60	
42·7	22·97		47·7	25·66	
42·8	23·03		47·8	25·71	
42·9	23·08		47·9	25·77	
43·0	23·14	4·32	48·0	25·82	3·87
43·1	23·19		48·1	25·88	
43·2	23·24		48·2	25·93	
43·3	23·29		48·3	25·98	
43·4	23·35		48·4	26·04	
43·5	23·40		48·5	26·09	
43·6	23·46		48·6	26·14	
43·7	23·51		48·7	26·20	
43·8	23·56		48·8	26·25	
43·9	23·62		48·9	26·31	
44·0	23·67	4·22	49·0	26·36	3·79
44·1	23·73		49·1	26·41	
44·2	23·78		49·2	26·47	
44·3	23·83		49·3	26·52	
44·4	23·88		49·4	26·57	
44·5	23·94		49·5	26·63	
44·6	24·00		49·6	26·68	
44·7	24·05		49·7	26·74	
44·8	24·10		49·8	26·79	
44·9	24·16		49·9	26·85	
45·0	24·21	4·13	50·0	26·90	3·72

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