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"Experiments on the Composition and Destructive Distillation of Coal."

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THE composition of coal, as determined by the processes of ultimate chemical analysis, has been worked out, more or less, for the best known examples found in the United Kingdom. Very few, however, of such analyses are complete. For instance, most experimenters give the weight of the oxygen and nitrogen collectively and not individually. At the time when many of the published analyses of coal were made, the residuals of coal-gas manufacture, and especially ammonium-salts, had but little value; and it is probably in consequence of this circumstance that the chemists of the time regarded with indifference the determination of the amount of nitrogen in the samples of coal which they submitted to the processes of ultimate analysis. Seeing that the production of ammonia in the destructive distillation of coal is in some degree dependent on the amount of nitrogen present in such coal, it becomes all the more desirable at the present time to have carefully worked out data under this head. Some are given in the Tables attached to this communication.

In addition to the quantitative determination of all the important elementary constituents of each of six samples of coal, a number of observations have been made on the disposition of the elementary constituents of each sample when it is submitted to the process of destructive distillation in a close vessel. With this view complete analyses of the samples of coke produced have been made. This method of inquiry does not appear to have been adopted before. It is not proposed in the present Paper to deal with all the facts brought to light in the course of this inquiry, but to leave the more abstrusive and scientific for consideration elsewhere.

The specimens of coal examined represent all the best known types found in different parts of the United Kingdom, and have been taken from widely separated localities, with the view of making the results as representative as possible. The inquiry having been begun with a particular regard to the character of

the gaseous compounds obtained, the samples have been numbered in the order of their gas-producing qualities. Specimen No. 1 is a Scotch cannel of excellent quality. Such a coal does not "cake" in the retort; the pieces of coke obtained retain the shape of the original masses of coal. No. 2 is an English cannel, though probably not a representative sample of English cannels in general. In fact, its chemical composition and behaviour on the application of heat show that it is more nearly related to the "caking" than to the cannel class. In fracture and appearance it is very like the Scotch cannels, but when heated in the retort the pieces fuse together, though not sufficiently thoroughly to destroy the outlines of the original masses of coal. Nos. 3, 4 and 5 are examples of "caking" coals such as are largely used for gas- and coke-making, and are from collieries favourably known in these industries. Though the quality of the illuminating gas which they yield is much inferior to that of the cannel class, on the other hand, they are capable of furnishing the best descriptions of coke. Nos. 3 and 5 are Yorkshire coals, the former being a coal of remarkably good quality. No. 4 is a Durham coal. No. 6 is a good quality of Welsh anthracite, yielding, as is usual with coals of this class, but little gas, which is devoid of illuminating properties.

RESULTS OF ULTIMATE ANALYSES OF COAL AND COKE.

In Table I. are given the particulars of the average results obtained in the case of each coal, and the coke which it produces when heated in a close vessel until all gaseous matter has ceased to come off. Each element present has been determined in the most approved method, and occasionally different methods have been employed, so as to ensure the greatest possible accuracy. The carbon and hydrogen have been determined by combustion in pure oxygen in the presence of chromate of lead; the nitrogen either by combustion with copper oxide *in vacuo*, or with excess of soda lime; the sulphur by fusion with alkaline carbonate and nitrate; the moisture by absorption by oil of vitriol in a sealed atmosphere; the ash by combustion in a muffle furnace. The oxygen has been ascertained in the ordinary way by difference; that is, after having determined the amounts of all the other elements by the direct methods above named and reduced the results to percentages, the deficiency required to make up one hundred parts is taken as the percentage of oxygen. As there is not a direct method for finding the amount of oxygen of an

organic substance, the accuracy of the usual estimate is entirely dependent on the working of the methods employed in the estimation of each and all of the other elementary constituents. In the case of the analysis of coal, the possible error in the estimate does not show itself so markedly as in that of the coke, because in the latter there is but little oxygen.

PROXIMATE ANALYSES OF COAL.

In order fully to realize all the points brought out by the complete analysis of a sample of coal and of the coke which it produces, it is necessary to have accurate determinations of the amount of coke obtained from a given quantity of the coal. A series of observations has therefore been made with this view, and has been performed under exactly similar conditions. The particulars of the results are given in Table II. In these experiments 5 grams of coal have been placed in a platinum crucible, provided with a neatly fitting cover, and the whole has been strongly heated for thirty minutes by means of a gas-jet of constant size. In about ten minutes the whole of the gas from the coal appears to have escaped, so that it is certain the coke is of a representative description if the heating be maintained for half an hour. The crucible having been quickly cooled has then been weighed, and the percentage of dry coke and volatile matter deduced. Such percentage determinations are absolutely needed for a critical and comprehensive consideration of the disposition of the elements composing the coal. This Paper more particularly deals with the sulphur and nitrogen.

The samples of coke obtained in this way have been employed for the purposes of ultimate analysis. Before being employed in these operations they have been reduced to the finest powder possible, and have been carefully preserved in well-stoppered bottles. In spite of all ordinary precautions the samples of coke have occasionally taken up a tolerably large amount of moisture from the air, and in that respect have shown a more marked tendency to absorb moisture than coal when in a similar condition. The determination of the amount of moisture, whether in the case of coal or of coke, has led to some special observations, the outcome of which is, that it is impossible to rely on the numbers obtained by the usual method of drying the substances at an exalted temperature in a drying oven. Whether it is owing to the action of the components of the coal or coke as a whole, or whether it is entirely due to the sulphur only, no opinion is

offered. The fact still remains that oxidation (which means increase in weight) does occur at an exalted temperature simultaneously with the removal of moisture, which tends to diminish the weight. The former may be entirely prevented, and the moisture correctly ascertained, by allowing a weighed quantity of the material to stand over a surface of oil of vitriol for twenty-four hours in a sealed atmosphere of limited dimensions. This course has been adopted in all the experiments given in Table I. except in that of the Durham coal, No. 4. This particular analysis was made some time ago, and was published last year. The coke which it produces is now added.

DISPOSITION OF THE SULPHUR OF COAL BY DESTRUCTIVE DISTILLATION IN A CLOSE VESSEL.

The actual condition of things revealed by these experiments is unexpected, and in opposition to the ideas prevailing on the subject. For instance it is generally accepted as an axiom that coke contains more sulphur than coal. The strongest popular indictment levelled against the use of gas-coke as a domestic fuel is based on this belief. It is therefore a significant fact that, throughout this series of samples of coal and coke, in no case is the percentage of sulphur in the coke so great as in that of the parent coal; and in several cases it is considerably less. The behaviour of the sulphur of coal may be considered from two standpoints: one that of the gas engineer, the other that of the ironmaster. The former deals particularly with the sulphur, in its various combinations, found in the crude coal-gas, and has no special interest in knowing what amount of sulphur remains in the coke, or its fate. The reverse of these conditions interests the ironmaster, inasmuch as he endeavours to obtain coke as free from sulphur as possible, and with that view not only selects the coal, but goes to the further trouble of picking and washing by machinery, at least in special cases.

The various analytical numbers relating to sulphur given in Table I. have been simplified and arranged in Table III. The behaviour of the sulphur of a particular sample of coal is stated in two ways in two adjacent columns. There is in the first column the amount of sulphur relating to 100 parts of coal which is expelled and found in the crude coal-gas, and beneath these figures are those which denote the amount of sulphur remaining behind in the coke from 100 parts of coal. In the adjacent column the same facts are expressed as percentages on 100 parts

of sulphur present in the original coal. For the purposes of this Paper it will no doubt be conceded that the sulphur, whether of coal-gas or of coke, is a source of mischief, or of expense, or of both. The sulphur found in the coal-gas is more interesting than that remaining in the coke, because the former can be and is removed, although to an extent which varies considerably, according to the legislative enactments relating to the gas supplied by a particular company or corporation.

The sulphur in crude coal-gas may be regarded as being present in two forms: the one sulphuretted hydrogen and the other bisulphide of carbon, together with nondescript sulphur compounds. It is usual to speak of the latter, including the bisulphide of carbon, as the "carbon-sulphur compounds." Where the purification of the coal-gas is strictly limited to the removal of the sulphur existing as sulphuretted hydrogen, this is effected by oxide of iron which entails the minimum expense. Probably the recent attempts of two or three gas engineers to use up the sulphur removed in this way, on the spot, may be attended with profit. No data are, however, available at present. In most cases the coal-gas is specially treated for the removal of the carbon-sulphur compounds, the processes as a whole, not being of the simple and inexpensive nature which especially characterises that for the removal of sulphuretted hydrogen. Therefore, considering the question of sulphur-purification in its broadest sense, and as practised by the London and other gas-companies, it must be regarded as a matter which entails a loss dependent, within certain limits, on the amount of sulphur in all forms present in the crude coal-gas. In order still further to simplify the results expressed in Table III., it will be assumed that 1 ton of each of the first five kinds of coal under notice yields 10,000 cubic feet of gas. The figures for the sulphur in the crude coal-gas expressed in lbs. per 1,000 cubic feet are as follow:—

TABLE SHOWING the AMOUNT of SULPHUR EXPRESSED in lbs. per 1,000 CUBIC FEET of CRUDE COAL-GAS from FIVE DIFFERENT SAMPLES of COAL.

Coal No. 1.	Coal No. 2.	Coal No. 3.	Coal No. 4.	Coal No. 5.
4·233	1·075	0·716	0·515	2·844

The maximum amount of sulphur allowed in the gas supplied by the London companies at the present time (winter months) is 220 grains or 0·031 lb. per 1,000 cubic feet. The removal of

such varying amounts of sulphur as are specified above, so as to reduce the quantity in the manufactured product within the limits defined by law, must be attended with an expense related in some degree to the amounts of sulphur in the crude gas. The most noteworthy feature in connection with this part of the subject is that the coal marked No. 3, which contains such an exceptionally small percentage of sulphur, furnishes a gas containing one and a half time more sulphur than coal No. 4, although the percentage of sulphur in the latter is double that of the former. Further, No. 3 yields more volatile matter by $5\frac{1}{2}$ per cent. than No. 4, and this extra yield may be connected in some way with this increased elimination of sulphur from the coal. Such a view is strengthened by a consideration of the behaviour of coals No. 1 and No. 2, No. 1 in particular furnishing a large amount of volatile matter correspondingly rich in sulphur.

DISPOSITION OF THE NITROGEN OF COAL DURING DESTRUCTIVE DISTILLATION IN A CLOSE VESSEL.

This phase of the work connected with the present researches has been the subject of much experiment extending over the past two years. In the course of a discussion at the annual meeting of the Gas Institute in 1882, an account was given of the behaviour of the nitrogen of Durham coal;¹ and subsequently the same subject was considered in a short Paper by the Author, read before the Chemical Society.² The results referred to in these communications are incorporated in the present Paper and appear in Table IV. under the head of coal No. 4 (Durham). The method adopted in the distillation of the Durham coal was slightly different from that practised in the case of the other samples, namely Nos. 1, 2, 3 and 5. The later experiments have been made by distilling weighed quantities of about $1\frac{1}{2}$ oz. of coal in a cylindrical iron retort, whereas the experiments on the Durham coal were made in glass combustion tubes.

When coal is submitted to destructive distillation in a close vessel, the disposition of its nitrogen may be considered under four heads. According to the experiments about to be described from 11 to 18 per cent. of the total nitrogen takes the form of ammonia-gas or its compounds; from 0.2 to 1.5 per cent. being found as

¹ The Gas Institute. Transactions for 1882, p. 188.

² "The Behaviour of the Nitrogen of Coal during destructive distillation; with some observations on the estimation of nitrogen in coal and coke." Journal of the Chemical Society, No. cexliii., February 1883, p. 105.

cyanogen gas; from 21 to 36 per cent. is unaccounted for, and is believed to be in the crude coal-gas as free nitrogen; and from 48 to 66 per cent. remains behind in the coke. Table IV. gives the figures expressing the disposition of the nitrogen of samples 1 to 5 inclusive arranged under the four heads already named. Double columns are used for each sample of coal. In the first column is the amount of nitrogen in each of the four conditions expressed as a percentage on 100 parts of the original coal, and in the second column the same facts are expressed as percentages on 100 parts of nitrogen. For further simplicity and comparison the ammonia obtained from each specimen has been expressed as lbs. of ammonium sulphate per ton of coal.

AMMONIA IN THE CRUDE COAL-GAS.

The method of obtaining the figures under this head has been to place 40 grams of the coal in a cylindrical 1-inch iron tube about 22 inches long, and to raise the whole to the temperature of distillation as quickly as possible. Each observation has been carried out on the same lines as far as has been practicable. The ammonia of the crude coal-gas has been removed by dilute acid, and this in turn has been distilled with excess of caustic soda, the ammonia having been eventually weighed as platinum ammonium chloride. It is a matter for regret that the most important question of temperature has not received, during the course of these inquiries, that scientific treatment which in the present state of knowledge is so much needed. What has been aimed at is, that the results obtained with the different samples of coal should, as far as possible, be strictly comparable; and the object has been not so much to ascertain what is the greatest amount of ammonia which can be obtained, as to ascertain what is obtained in the ordinary method of conducting the destructive distillation of coal, unaided by modifying conditions. It is believed that the results obtained with coals numbered 1, 2, 3 and 5 are comparable. No. 4 was distilled in a glass tube. Viewing the figures as a whole, the small proportion of nitrogen which is evolved as ammonia is noticeable; this, in the highest case, is 17·8, and in the lowest 11·1 per cent. Curiously enough, the specimen of coal which contains the lowest percentage of nitrogen (1·28 per cent.) yields as much ammonia as any of the other examples, although some of them are much richer in nitrogen. Average results are given in all cases except No. 4. Had the maximum result only been taken, coal No. 1 would have shown almost as

high a yield of ammonia as that accorded to No. 4. Coal No. 1 certainly yields far more volatile matter than any other of the coals experimented with, and therefore the greater yield of ammonia may be related in some way to this circumstance. Clearly this of itself does not appear to be the full explanation, because other coals (and notably No. 4) are nearly as good ammonia producers, though furnishing far less volatile matter. The explanation is undoubtedly to be found in some fundamental difference of nitrogen itself, which, although a gas at ordinary temperatures, is, when in chemical combination with carbon as a solid compound, next to carbon in its power of resisting tendencies to chemical change brought about by mere elevation of temperature. The negative character of nitrogen has always been considered a property favourable to its ready elimination in some gaseous form or other when coal is submitted to destructive distillation, and this idea seems to have been entertained by all writers on the subject.

CYANOGEN PRESENT IN THE CRUDE COAL-GAS.

After the crude coal-gas has been treated with dilute acid so as to remove all ammonia, it can still be made to furnish a much smaller quantity by being passed through highly-heated slaked lime. The method of operating has been to remove all ammonia from the crude gas, and then to pass the latter through a tube about 2 feet long filled with slaked lime, and maintained at a high temperature in a furnace. The gas escaping at the outlet has again been washed with dilute acid, and from the acid liquor the ammonia has been distilled and weighed as platinum ammonium chloride. The substance which is the origin of this second quantity of ammonia is cyanogen or its compounds. The amount is small, and appears to be increased by the employment of high temperatures during the distillation of the coal. The highest yield in the experiments recorded in Table IV. was furnished by the Durham coal, which was distilled in a glass tube; and there is no doubt that a higher average temperature was maintained during this experiment than in the other cases where an iron retort was used. This opinion is based not only on the amount of cyanogen produced, but also on the relatively large amount of nitrogen which was unaccounted for owing to its being in the crude gas in the elementary condition.

NITROGEN UNACCOUNTED FOR.

The greater portion of the nitrogen classed under this head is believed to be present in the crude coal-gas in the elementary condition. Some nitrogen undoubtedly exists in the tar in the form of alkaloidal substances which are not gaseous at ordinary temperatures. The quantity thus found in the tar is assumed to be relatively small. No data are available for computing the actual amount. The cause of the existence of so much free nitrogen in the crude coal-gas is one which is of the greatest importance to the gas-engineer. The Author believes that it is increased within certain limits by increase of temperature, other things being equal. This part of the subject, however, is somewhat obscure. In 1882 a large number of observations was made by the Author on the amounts of ammonia in crude coal-gas at different stages during the process of distillation,¹ and the results then obtained distinctly showed that, in the process as carried on in the works where the experiments were conducted, the coal-gas was particularly poor in ammonia-gas at the latter period of the operation. The Author attributes the existence of free nitrogen in the crude coal-gas not so much to the evolution of the element as such from the coal, but rather to the resolution by the action of heat of the ammonia first evolved from the coal into its two elementary constituents. This opinion is arrived at not only from a consideration of the experiments above cited, but also from the results given in the present Paper in so far as they relate to this point. A careful inquiry as to the influence of temperature in modifying the yield of ammonia (and indirectly of other substances) is much needed. In suggesting this to the attention of the gas-world the following points may be noted: 1, the use of a coal of carefully ascertained composition; 2, the careful determination of the amount of ammonia coming off at different periods of the distillation, and its total; 3, the composition of the coke resulting from each operation; 4, the employment of different temperatures, which should be ascertained, and an average arrived at for each operation of distillation.

NITROGEN REMAINING BEHIND IN THE COKE.

The amount of nitrogen which remains behind in the coke in the case of the five examples in Table IV. ranges from 49 to 66 per cent. of the total nitrogen present in the parent coal. The

¹ The Journal of Gas Lighting, vol. xl., p. 1125.

amount found in the sample of Durham coke, No. 4, has already been published. The most notable features in connection with the remarkable results furnished under this head are those obtained with coal No. 1. This coal contains a considerably lower percentage of nitrogen than any of the other coals in the list; yet, as has been seen, it is almost as good a producer of ammonia as the best of the series. The coke which is produced is also considerably richer in nitrogen than the parent coal. This apparently anomalous result can only be understood on some such hypothesis as has already been put forward; and exceptional as the behaviour of the nitrogen of this particular coal may seem at first, yet when the results of the distribution of the nitrogen under the four heads are considered as percentages on 100 parts of original nitrogen, the anomaly in a great measure disappears.

Having demonstrated that coke from the most varied sources contains so much nitrogen, the next step has been to ascertain its condition and behaviour under circumstances favourable to its elimination in the form of the valuable product ammonia. Much has been written and said on this subject at different times since the publication of the Author's earlier experiments a year and a half ago. It is not possible in this Paper to deal with all the arguments and methods adopted by the many observers whose attention has been attracted to the subject, although it is desirable to notice some. In the first place, it is important to observe that the nitrogen is in a very stable form of chemical combination with the other elements of the coke, and most probably more particularly with the carbon. The nitrogen certainly does not exist in the coke as ammonia, although this has been freely stated to be the case. If finely-powdered coke be treated with any of the ordinary chemical reagents sufficiently energetic to evolve ammonia from a mixture which contains it already existing as such, no indications of the gas in question can be obtained. On the other hand, the usual methods for the determination of the nitrogen of an organic substance apply, with some modification, to the estimation of the nitrogen of coke. All of it can be obtained as ammonia by heating the very finely-powdered coke to dull redness with an intimate admixture of soda lime in excess. But in order that the operation may be completely successful, it is necessary to maintain the application of heat for a longer time than would suffice for the similar treatment of a sample of coal or any ordinary "organic" substance. The chemical stability of the coke is very pronounced, not only in the case of the use of soda lime, but in other operations of a kindred nature.

When coke is maintained at a red heat in a current of steam, the escaping gases, mainly hydrogen and carbonic oxide, contain relatively small quantities of ammonia and sulphuretted hydrogen. As a commercial process this will be considered subsequently. Many experiments have been made on samples of coke obtained from all the first five coals named in the Tables with this general result, that the nitrogen of each is amenable to this treatment with steam. This fact being established, and knowing the large amount of reserve nitrogen in the coke, the possibility of producing considerable quantities of ammonia is a natural sequence. It is, however, unnecessary to relate the many results which have been obtained, since they have been anticipated by the recently published experiments of others.

The action of steam in producing ammonia from coke can be made to furnish some very important evidence which, although somewhat disappointing in the prospects that it foreshadows, defines most clearly the maximum advantage that can be obtained by its use, and also throws some light on the condition of the nitrogen existing in the coke. A quantity of coke was prepared from coal No. 1 (Scotch cannel). It was believed that the richness in nitrogen, and the porous character, of this particular coke made it specially suitable for the following inquiry. A weight of 50 grams perfectly dry was placed in the iron cylindrical retort, the whole was raised to a red heat in the furnace and maintained in that condition, steam largely in excess being then passed through the apparatus for definite and consecutive periods. The gases produced were washed with acid in the ordinary way, and the amount of ammonia absorbed during each period was eventually estimated. At the end of these operations the coke was removed and weighed, though not with the strictest accuracy. Its weight was recorded as about 43 grams, that is, the coke had lost about 14 per cent. in weight by being subjected to the action of steam at a red heat for four and a half hours. The amount of nitrogen in the coke from coal No. 1 (Scotch cannel) is given as 1.47 per cent. in Table I.; consequently, on the assumption that the specimen in question contained this amount of nitrogen, the 50 grams of coke employed would contain 0.735 gram. As 0.1148 gram was obtained in the form of ammonia, this quantity can be expressed as a percentage on the presumed total original nitrogen. It is equal to 15.6, and is almost identical with the maximum quantity possible, unless the action of steam is attended with some special selective influence on the nitrogen of the coke, causing it eventually to be expelled from the retort as free nitrogen.

The result of the foregoing experiment expressed as ammonium sulphate is equal to 24·9 lbs. per ton of coke treated, and that with only a loss of weight of 14 per cent. On the assumption already made, a further loss of 14 per cent. in weight under the influence of steam ought to be attended with another corresponding yield of ammonia. Important as the foregoing experiments are in the lessons they teach, there still remain many points on which it is desirable to have accurate data.

The experiments were therefore repeated, having special regard to the following heads:—1, the quantity of nitrogen in the original coke; 2, the amounts of ammonia produced during different stages of the operation of steaming; 3, the quantity of steam used; 4, the loss in weight of coke by the action of the steam; 5, the quantity of nitrogen remaining in the steamed coke.

The coke used was made in quantities of a few ozs. at a time from the Scotch cannel coal, and the different batches were eventually well mixed. On subjecting some of the mixed specimen to the action of steam, the production of appreciable quantities of tar showed that the coking of the coal had not been complete. One determination of the nitrogen in the well-mixed sample by the soda lime process gave 1·38 as the percentage. This is lower than would have been the case had the coking been pushed further. There were now placed in the experimental retort 50 grams of the coke, the whole being heated to redness and maintained in that condition, and steam passed through in large excess.

The following are the particulars of the two experiments:—

ACTION OF STEAM IN PRODUCING AMMONIA FROM COKE.

Period during which Steam was passing through the Apparatus.		Amount of Nitrogen found as Ammonia.	
First Experiment.	Second Experiment.	First Experiment.	Second Experiment.
Minutes.	Minutes.	Gram.	Gram.
45	45	0·0112	0·1400
90	90	0·0196	0·1204
135	90	0·0840	0·0896
..	90	..	0·0756
Totals 270	315	0·1148	0·4256

The coke on being removed from the retort, at the termination of the second experiment, weighed 29 grams, showing a loss of

42 per cent. on the original. The steam passed into the retort during the whole operation was 500 grams. One determination of the nitrogen remaining in the steamed coke was made by the soda-lime process, and gave 0.831 per cent. From these data important conclusions can be arrived at. The nitrogen present in the 50 grams of original coke is 0.69 gram. The nitrogen actually recovered as ammonia by the operation of steaming is 0.4256 gram, and the difference between these two quantities is 0.2644 gram, and represents the theoretical quantity of nitrogen remaining in the steamed coke. The actual quantity present in the 29 grams as shown by the nitrogen analysis is 0.241 gram. There is therefore some loss of the nitrogen of coke regarded as ammonia, even when coke is heated in a large excess of steam, but it is extremely slight. Calling the quantity of nitrogen in the original coke 100, the following is the disposition of the nitrogen by this operation of steaming:—

Nitrogen obtained as ammonia	61.6
Nitrogen unaccounted for	3.4
Nitrogen remaining in the steamed coke	35.0
	<hr/>
	100.0
	<hr/>

The nitrogen unaccounted for undoubtedly arises from a resolution of some of the ammonia first formed into nitrogen and hydrogen by contact with the heated surface of the iron retort; and the fact that the quantity is small in this instance appears to throw some light on the origin of the unaccounted for nitrogen in the case of the simple distillation of raw coal.

The acquisition of 61.6 per cent. of the total nitrogen of a sample of coke by a loss in weight of the coke of only 42 per cent. demonstrates that steam at a high temperature does exercise some specially selective influence on the nitrogen of the coke, although not to such an extent as could be wished. The foregoing quantity is equal to 90 lbs. of ammonium sulphate per ton of coke treated; and it is obvious from the analysis that the steamed coke is still capable of yielding about 50 lbs. more sulphate on the original ton of coke; in other words, that it is perfectly easy to obtain 140 lbs. of ammonium sulphate from 1 ton of coke containing the particular quantity of nitrogen as set forth in the analysis.

The foregoing data afford a means of comparison between the steam actually used and that theoretically necessary. Assuming that the coke employed is pure carbon, the 21 grams loss of weight

sustained by the 50 grams of original coke would require 31.5 grams of water as steam for the equation

But 500 grams of steam were passed into the retort. Hence in this particular experiment no less than sixteen times the theoretical quantity of steam were employed, while the coke in the retort was maintained at a bright red heat by the application of heat externally. It may therefore fairly be inferred that the conditions of the experiment were in the highest degree favourable to the production of ammonia, and also to the "gasification" of the coke.

The limited dimensions of the apparatus employed have prevented the carrying out of trustworthy experiments in which steam could be used in quantities just sufficient for the purpose of gasification. The Author is aware of the mechanical difficulties which would have to be overcome in order to carry out the process on a commercial scale without undue waste of steam; but he believes that they are not insuperable. It has therefore been assumed, in the course of subsequent considerations, that steam could be employed, not unduly in excess, and that ammonia would be obtained by such treatment in the proportions demonstrated by these experiments.

SOME TECHNICAL POINTS ARISING FROM A CONSIDERATION OF THE FOREGOING ANALYSES AND EXPERIMENTS.

At the present time much attention is being bestowed on the subject of gaseous fuel, and its extension is being promoted. There can be no question that its possibilities in a large number of industries are as yet but imperfectly realized, and a great extension in this direction may reasonably be expected. Earnest attempts are also being made to extend the use of gaseous fuel for domestic purposes. Its cleanliness, the absence of smoke in its use, and the economy attendant on its adoption as an intermittent source of heat, are its chief recommendations. Its promoters may be arranged in two classes: those who recommend the supply of a "producer," or "water-gas" by separate mains to private consumers, and those who would employ coal-gas for both heating and illuminating purposes, making it possible to do so by reducing the cost of the coal-gas to the consumer. The promoters of the extension of coal-gas for this twofold purpose have undeniably a strong case, from the fact that the gas companies are already "in possession" with the plant and appliances in working condition.

By extending the "heating" uses of coal-gas it is further maintained that the consumption of the gas will be more uniform during a greater portion of the twenty-four hours than it now is, and that therefore the capital charges for plant in the works will not be proportional to the increased consumption, if brought about as suggested. One result of the extension of the use of coal-gas is not usually contemplated, namely, the increased production of coke. At present there is some difficulty in London in disposing of gas-coke at a price commensurate with its heating value; and some cities and towns in the United Kingdom are worse circumstanced in this particular than London. It therefore behoves the promoters of the extension of coal-gas for use in domestic fires to take into consideration the contingent increase in the production of coke, and to provide for it; because a depreciation in the market price of the coke would operate unfavourably in the direction of coal-gas being supplied at a lower price. A combination domestic fire, in which gas-coke could be employed with a limited amount of coal-gas to render the whole cheerful, would be a step in the right direction, and would meet the wants of those requiring a fire for short periods at short notice, say in bedrooms and the like. It would also satisfy the requirements of the promoters of smokeless fuel. Sufficient has already been said, under the head of "Sulphur in Coke," to show that coke is a fuel of the best description. It however requires some care and intelligence in its use.

The Author has more particularly concerned himself with the question of applying coke to the production of "water-gas"; and in the first instance was led to hope that the large amount of reserve nitrogen of the coke could in some way be converted into ammonia in the process. That coke can be treated so as to furnish its nitrogen as ammonia has been demonstrated at some length in the foregoing pages; but whether such a process can be conducted on a commercial scale for the supply of "water-gas" for domestic purposes, bearing in mind the present position of the coal-gas industry, is not by any means so easy to demonstrate. Whatever may have been the prospects of the "water-gas" industry (and they have never been very hopeful in this country), it is certain that they were never brighter than at present, seeing that ammonia can be simultaneously produced as a by-product. It has also been found during the course of these experimental inquiries, that the sulphur of coke is evolved as sulphuretted hydrogen when the coke is subjected to the action of steam at a red heat; and as sulphur in this form of chemical combination is readily dealt with and can be turned to profit, especially when produced simultaneously

with ammonia, there is every prospect of the sulphur of coke occupying the position of a second by-product of some little value.

It is important to point out that the possibility of the easy removal of the sulphuretted hydrogen from "water-gas" is a great feature in the scheme for supplying gaseous fuel free from sulphur, for use in a number of industries where the presence of sulphur in the fuel is most objectionable. The Author is convinced that some of the Sheffield and Birmingham industries would greatly profit by the substitution of gaseous fuel free from sulphur for the gas-coke now used, which, though washed and treated at great length, retains its original sulphur, and he believes that the advantages of sulphur-free, smokeless, gaseous fuel will before long be practically realized in these and similar districts.

The chief point aimed at in this portion of the present work has been to ascertain the advantage likely to arise from the recovery of ammonia as a by-product. Given 100 parts of gas-coke, it can be approximately predicted from its percentage amount of nitrogen what will be the amount of ammonia recoverable in the gasification of the coke by the agency of steam. But in the process of gasification fuel is necessary; and therefore the simplest and most accurate method of calculating the possibilities of ammonia-production, and the manufacture of "water-gas," is to consider what portion of the 100 parts of coke will be needed to gasify the remainder, taking as data the usually accepted thermal equivalents of the books and the results of the present inquiry. The condition of things expressed by the chemical equation—

where carbon and steam mutually reacting give rise to carbonic oxide and hydrogen in equal volumes, is that which every producer of gaseous fuel keeps before him as his ideal.

Having steam and carbon at the temperature required for the above decomposition to occur, the 18 parts of steam expressed by the formula H_2O require 68,068 heat-units to be imparted to them before they are completely separated into gaseous hydrogen and oxygen. The combustion of the 12 parts of carbon expressed by the symbol C in the oxygen freed from chemical combination with hydrogen is attended with the production of 29,676 heat-units. The difference between these two quantities is 38,392, and expresses the net amount of heat which must be imparted to bring about the necessary chemical changes. There is still remaining to be considered the amount of heat required to raise the 12 parts of carbon and 18 parts of water from an ordinary temperature to that

of mutual chemical decomposition. If this be regarded as 600° Centigrade, the specific heat of carbon as 0·24, the specific heat of steam as 0·48, and the initial temperature as 10° Centigrade, the heat-units will be as follows:—

Carbon	12 × 0·24 × 590 =	1,699
Water to steam	18 × 626	=11,268
Steam to 600°	18 × 0·48 × 500 =	4,320
Heat-units to effect decomposition at a temperature of 600° C.	} =38,392	
Total.		<u>55,679</u>

The combustion of 12 parts of carbon in oxygen to carbonic acid is attended with the production of 96,960 heat-units, and therefore from the foregoing estimate the necessary heat-units (55,679) would be provided by the combustion of 7 parts of carbon. The amount of heat expended in conducting the operation on a commercial scale would, no doubt, be much in excess of the theoretical quantity. Therefore it is proposed to allow 100 per cent. more fuel for the gasification of coke than is theoretically needed; that is to say, every 12 parts of carbon shall be supposed to require 14 parts of carbon for their gasification. A study of the analysis of coke shows that dry coke contains about 90 per cent. of carbon; and, supposing 42 per cent. of a sample to be gasified, there would remain 48 parts of carbon available for the purposes of fuel for conducting the process. The ratio of 48 to 42 is almost identically that of 14 to 12. It has already been shown that the gasification of 42 per cent. of a sample of coke is attended with the production of 90 lbs. of ammonium sulphate per ton of coke treated; and therefore, if 100 tons of coke were subjected to this limited influence of steam, 4 tons of the ammonium salt could be obtained. Taking the net value of the salt at £10 per ton, there is at once £40 to the credit of this residual.

A simple way of considering the heating value of the gaseous fuel is to compare it with that of the coke employed both in and for the purpose of gasification. An allowance of 14 parts of carbon has been made as fuel for the conversion of 12 parts of carbon into "water-gas," and therefore the computed heat-units must be on a basis of 26 parts of carbon. These 26 parts, if burnt to carbonic acid in the ordinary way, would develop 210,080 heat-units. The total heat-units developed by the combustion of the hydrogen and the carbonic oxide, the results of the gasification of 12 parts of carbon, are 202,636. Therefore, on the above basis, the theoretical value of the "water-gas" as a heating agent is only about 4 per cent.

less than the theoretical heating value of the whole of the coke used in its manufacture, were that coke consumed direct to the condition of carbonic acid.

The greater efficiency of gaseous fuel enables it to be substituted for solid fuel in a large number of operations, and the fact that a larger percentage of the heat developed can be turned into useful effect in many special cases is the cause of its wide-spread adoption. Any process, therefore, which tends to reduce its cost of production, whether directly or indirectly, can only tend to augment the advantages it is known to possess when employed in certain industrial operations.

The natural field for the manufacture of "water-gas" is an ordinary gasworks. Coke is often a residual of little value in the district, and occasionally, from a number of circumstances, it has to be sold at a remarkably low price. The more advanced large works are gradually, as circumstances permit, adopting gaseous fuel for the purpose of heating the retorts. There is, therefore, every opportunity of introducing the manufacture of the best description of "water-gas," if only for consumption on the premises. In this way the ammonia obtainable could be saved, and the whole process submitted to a thoroughly practical test. If successful, the manufacture could be extended so as to supply external demands as they arose. The advance would be a natural and an easy one. At present the gasworks supply the great bulk of the material used in artificial illumination. They are also large producers of solid fuel in the shape of coke. Further, they are the producers of the material for the manufacture of ammonium salts for the world generally. The propositions now made are therefore not calculated to disturb the existing order of things, and it is believed that their adoption would prove a step in the right direction, and in accordance with the spirit of the times. The utilization of the nitrogen of coke would enable a gasworks to keep up its revenue from the sale of ammonia owing to the reduction in the price of ammonium salts, and to maintain a fair position in the face of the existing competition with the owners of collieries. The agriculture of this and continental countries needs all the ammonium salts likely to be produced.

It is twenty years since the late Sir William Siemens introduced gaseous fuel for the heating of retorts in the Paris gasworks, with perfect success. Gaseous fuel has not been employed for the same purpose in this country for more than three or four years. The most advanced engineers now admit its superiority to solid fuel, and are adapting their appliances for its employment as opportuni-

ties offer. In fact, they have adopted it after the lengthened experience of other industries—a strictly safe course. Will a similar series of events attend the progress of the “water-gas” industry?

It is not possible here to do more than barely notice the labours and writings of several gentlemen who have been engaged on some of the subjects discussed in this Paper. Since the publication of the Author’s discovery of the relatively large amount of the nitrogen of coal which remains behind in the coke, earnest attempts have been made to win it for useful purposes. The first to do so in point of time was Mr. William Young; and he has been followed by Mr. Scheurer Kestner, Mr. Beilby, Mr. Tervet, and several others, all of whom have contributed to a knowledge of what is, confessedly, a difficult subject.

APPENDIX.

TABLE I.—RESULTS OF ULTIMATE ANALYSES OF SAMPLES OF COAL AND COKE.

Elementary Components.	No. 1. Scotch Cannel.		No. 2. English Cannel.		No. 3. Yorkshire.		No. 4. Durham.		No. 5. Yorkshire.		No. 6. Welsh Anthracite.	
	Coal.	Coke.	Coal.	Coke.	Coal.	Coke.	Coal.	Coke.	Coal.	Coke.	Coal.	Coke.
Carbon	75.42	86.75	81.46	87.64	84.10	88.45	84.34	87.32	82.18	84.04	89.17	88.64
Hydrogen	6.18	1.37	5.02	1.31	4.93	1.41	5.30	1.67	5.31	1.51	3.50	1.37
Nitrogen	1.28	1.47	1.66	1.36	1.67	1.60	1.73	1.13	1.75	1.59	0.91	0.99
Sulphur	2.18	0.65	0.95	0.74	0.55	0.35	0.78	0.75	2.00	1.06	0.96	0.63
Oxygen (by difference)	8.70	0.48	5.00	0.48	5.35	1.67	4.29	1.07	3.66	0.68	1.56	0.60
Moisture	4.00	4.53	2.07	2.67	2.20	4.82	1.14	4.36	1.34	4.08	1.78	5.60
Ash	2.24	4.75	3.84	5.80	1.20	1.70	2.42	3.70	3.76	7.04	2.12	2.17
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE II.—PROXIMATE ANALYSES OF COAL.

Volatile matter	57.02	37.02	34.44	29.00	33.66	7.88
Coke (dry)	42.98	62.98	65.56	71.00	66.34	92.12
	100.00	100.00	100.00	100.00	100.00	100.00

TABLE III.—DISPOSITION OF THE SULPHUR OF COAL BY DESTRUCTIVE DISTILLATION IN A CLOSE VESSEL.

Sulphur present in the crude coal-gas	1.89	86.7	0.48	50.5	0.32	58.1	0.23	29.5	1.27	63.5	0.30	31.3
Sulphur remaining in the coke	0.29	13.3	0.47	49.5	0.23	41.9	0.55	70.5	0.73	36.5	0.66	68.7
	2.18	100.0	0.95	100.0	0.55	100.0	0.78	100.0	2.00	100.0	0.96	100.0

TABLE IV.—DISPOSITION OF THE NITROGEN OF COAL BY DESTRUCTIVE DISTILLATION IN A CLOSE VESSEL.

Description of Sample.	No. 1. Scotch Cannel.		No. 2. English Cannel.		No. 3. Yorkshire.		No. 4. Durham.		No. 5. Yorkshire.	
Nitrogen evolved as ammonia (average results, except No. 4)	0.227	17.8	0.192	11.6	0.209	12.5	0.251	14.5	0.195	11.1
Nitrogen evolved as cyanogen	0.005	0.4	Unknown		0.006	0.4	0.027	1.5	0.001	0.2
Nitrogen unaccounted for. The greater portion is believed to be in the gas as free nitrogen	0.387	30.2	0.593	35.7	0.351	21.2	0.610	35.3	0.452	25.9
Nitrogen remaining in the coke in chemical combination	0.661	51.6	0.875	52.7	1.101	65.9	0.842	48.7	1.099	62.8
	1.280	100.0	1.660	100.0	1.670	100.0	1.730	100.0	1.750	100.0
Lbs. of ammonium sulphate from 1 ton of coal	23.96		20.27		22.06		20.40		20.50	

DISCUSSION.