

XXX.—*The Composition of Coal and Cannel Gas in Relation to their Illuminating Power.*

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HAVING had occasion during the past two or three years to investigate the composition of several kinds of illuminating gas, it has occurred to me that, as published analyses of coal-gas are by no means numerous, it might be interesting to examine in detail the nature of the gas supplied to some of the more important towns of the United Kingdom. I have been more especially induced to undertake this investigation in order to illustrate practically some of the results which I have recently arrived at in studying the laws to which the illuminating power of gas is subject.

In the year 1851, the metropolitan gases were examined by my father, and 25 years later, in 1876, by Dr. Humpidge, and the results of their analyses are recorded in the *Journal of the Chemical Society*, 1877, p. 624. As the analytical methods employed in their examinations were the same as those which I have also made use of, the three sets of results are interesting for comparison, and show the result of 33 years' experience on the manufacture of gas.

The constituents of the gas which have been individually determined, are:—The hydrocarbons absorbed by fuming sulphuric acid, carbonic anhydride, oxygen, nitrogen, hydrogen, carbonic oxide, and marsh-gas. In all cases, also, the carbon-density of the hydrocarbons has been determined, and in many cases also their hydrogen-density; the carbon and hydrogen densities together representing the average molecular formula of the hydrocarbons present.

The carbon-density is determined by exploding some of the gas with excess of oxygen, and then absorbing with caustic potash to ascertain the amount of carbonic anhydride formed. This total carbonic anhydride is then calculated for 100 vols. of gas, and then from this percentage is subtracted the sum of the CO_2 , due to the com-

bustion of marsh-gas and carbonic oxide, together with any CO_2 that may be present as such in the gas; the residual CO_2 is then due only to the combustion of the hydrocarbons in 100 vols. of gas. If this percentage is divided by the percentage of hydrocarbons, the quotient is the carbon-density, whilst the percentage of residual carbonic anhydride, divided by 2, indicates the percentage of ethylene to which the hydrocarbons are equivalent, since 1 vol. of C_2H_4 produces 2 vols. of CO_2 .

The hydrogen-density, on the other hand, is determined by ascertaining the total amount of oxygen required for the complete combustion of 100 vols. of gas, and then subtracting from that the oxygen required for the combustion of hydrogen, carbonic oxide, marsh-gas, and carbon of the hydrocarbons; the remaining oxygen is that required for the hydrogen of the hydrocarbons in 100 vols. of gas.

Now, since 1 vol. of oxygen combines with 2 vols. of hydrogen, and since the molecule of oxygen occupies 2 vols., therefore the molecule of oxygen corresponds to 4 atoms of hydrogen; consequently the volume of residual oxygen must be multiplied by 4, and the product divided by the percentage of heavy hydrocarbons, when the quotient will indicate the number of hydrogen-atoms in the molecule of average hydrocarbons.

The process may be expressed by means of the following formula:—

$$\frac{A \times 4}{C} = \text{hydrogen-density.}$$

A = volume of oxygen consumed by hydrogen of hydrocarbons in 100 vols. of gas.

C = volume of hydrocarbons in 100 vols. of gas.

The reputed illuminating power is also recorded for each gas; also the ratio of the illuminating power to the proportion of ethylene to which the heavy hydrocarbons are equivalent.

On turning attention, in the first place, to the illuminating constituents of the gases, it will be seen from the average formulæ of the hydrocarbons, that the C_nH_{2n} or olefine series composes by far the greater part of the hydrocarbons; and since the carbon-density is almost invariably less than 3, the first and second terms of that series, or ethylene and propylene, must be the predominant hydrocarbons. That ethylene by itself, however, would be quite incapable of yielding the illuminating power indicated, is demonstrated, not only by my experiments with mixtures of ethylene and the several diluents of coal-gas, but also by actually adding ethylene to coal-gas disilluminated by bromine. Thus, I find that no less than 13 per cent. of ethylene must be added to the disilluminated gas of the Gaslight and Coke

Company, in order that it shall yield a light of 16 candles, whilst the same illuminating power is attained by the hydrocarbons actually present in the gas, although equivalent to only 6·58 per cent. of ethylene. Similarly, to make this gas produce a light of 28 candles, it is necessary to add no less than 31 per cent. of ethylene, whilst the St. Andrew's gas of 27 candles contains only the equivalent of 13·71 per cent. of ethylene. This clearly indicates how much of the actual illuminating power of gas is due to denser hydrocarbons, although they are present only in comparatively insignificant proportions.

Thus, I also find that if the disilluminated gas of the Gaslight and Coke Company be saturated with the vapour of benzene, 3 per cent. of benzene vapour, equivalent to 9 per cent. of ethylene, already imparts to the gas an illuminating power of about 23 candles, a light which is greatly in excess of that yielded when 13 per cent. of ethylene itself is added to the disilluminated gas. These determinations are recorded in the following table:—

Percentage composition of gas.		Observed illuminating power in standard candles.	Rate.		Candle-power calculated to 5 cubic feet of gas, and 120 grains of spermaceti.
			Cubic feet of gas consumed per hour.	Grains of spermaceti consumed per hour.	
Disilluminated gas.	C_2H_4 .				
86·59	13·41	18·68	5·60	116·2	16·84
68·98	31·02	24·94	4·32	118·1	28·40
Disilluminated gas.	C_6H_6 .				
96·91	3·09*	13·06	2·60†	109·3	22·92
96·70	3·30†	10·20	2·11‡	120·0	24·17

Taking the gases in groups, the members of each group having the same illuminating power, it will be seen that the same light is produced by hydrocarbons which are equivalent to considerably different proportions of ethylene. Thus:—

* Temperature of benzoliser 15·5° C.

† Temperature of benzoliser 17·0° C.

‡ Cubic feet of disilluminated gas consumed per hour, the benzoliser being placed between the meter and the burner.

Illuminating power in standard candles.	C_nH_m per cent. maximum and minimum.	Equivalent to C_2H_4 , maximum and minimum.	Value of 1 per cent. of C_2H_4 in standard candles.
30 (?)	12·23	16·55	1·81
27	10·04—10·00	13·40—13·71	1·97—2·01
21·5	7·90	9·50	2·26
20	6·22	8·41	2·38
18·5	5·63	8·24	2·25
18	7·28—6·28	10·64—8·78	1·69—2·05
17·25	4·76	6·28	2·75
17	4·58	7·77	2·19
16	4·95—2·92	7·10—4·42	2·25—3·62
15	4·53	5·67	2·65
14	4·53—3·09	5·82—4·60	2·40—3·04
			Average (cannel) 2·02
			„ (coal) 2·71

A glance at this table shows that the gases of high illuminating power, and these are all cannel-gases, have a considerably lower candle value for each per cent. of ethylene-equivalent than the coal-gases of lower illuminating power. From the average formulæ of the hydrocarbons in these cannel-gases it will be seen that they belong almost exclusively to the C_nH_{2n} or olefine series, whilst the coal-gases contain larger proportions of hydrocarbons belonging to the more condensed series.

On comparing the analyses of coal-gas made in 1851 with those in 1876 and 1883, it will be seen that some changes have taken place. In the first place the carbon-density has undergone progressive diminution, being greater in 1851 than in 1876, greater in 1876 than in 1883. The high carbon-density of the cannel coal in 1876 is especially noticeable, being considerably greater than that of any of the coal-gases.

The samples of gas analysed in 1851 appear to have been practically free from nitrogen, other than that present as atmospheric air, whilst some of the samples analysed in 1876, and by myself, contain a very considerable percentage of nitrogen, over and above that present as atmospheric air. This excess of nitrogen in the later analyses must necessarily have been derived from the atmosphere, and become deprived of its oxygen in the process of manufacture. For taking the percentage of nitrogen in coal as 2, which is certainly considerably above the truth, it appears, from a paper recently read by Mr. Foster before the Institute of Civil Engineers, that from 21 to 36 per cent. of the nitrogen present in the coal is unaccounted for, either in the residual coke or in the nitrogenous compounds formed on distillation. Now 21—36 per cent. of the nitrogen in coal corresponds to 127—

Town.	Reputed illuminating power in standard candles.	Composition of coal and cannel gases, 1882-4.										Ratio:—		Coal used.
		Hydrocarbons, C_nH_m .	Equivalent of C_nH_m in C_2H_4 .	Average formula of C_nH_m .		CO_2 .	O.	N.	H.	CO.	CH_4 .	Equivalent of C_2H_4 per cent. C_2H_4 in standard candles.	Illuminating-power or	
				C.	H.									
Edinburgh	(30?)	12.23	16.55	2.71	5.38	0.35	1.00	3.64	33.24	6.61	42.93	1.81	Cannel.	
Glasgow	27	10.00	13.40	2.68	5.09	0.29	0.06	3.07	39.18	7.14	40.26	2.01	"	
St. Andrews	27	10.04	13.71	2.73	—	2.73	0.48	2.83	36.63	5.16	42.13	1.97	"	
Liverpool	21.5	7.90	9.50	2.41	—	1.70	0.19	6.10	36.44	3.39	44.28	2.26	"	
Preston	20	6.22	8.41	2.70	—	0.84	0.25	4.79	43.95	4.62	39.33	2.38	"	
Nottingham	18.5	5.63	8.24	2.93	—	0.81	0.24	2.51	45.52	5.63	39.66	2.25	Coal.	
Leeds	18	7.28	10.64	2.92	—	0.34	0.07	4.32	40.23	5.02	42.74	1.69	Cannel.	
Sheffield	18	6.28	8.78	2.79	—	0.24	0.10	2.56	43.05	4.72	43.05	2.05	"	
Birmingham	17.25	4.76	6.28	2.64	4.29	1.50	0.36	10.10	40.23	4.05	39.00	2.75	Coal.	
Bristol	17	4.58	7.77	3.39	—	none	0.27	5.11	44.57	4.77	40.70	2.19	"	
London	—	—	—	—	—	—	—	—	—	—	—	—	"	
Gas Light and Coke Co.	16	4.41	6.58	2.98	4.32	none	0.26	5.95	47.99	3.75	37.64	2.43	"	
South Metropolitan	16	2.92	4.42	3.03	5.16	0.09	none	3.19	53.14	4.11	36.55	3.62	"	
Redhill	16	4.40	5.91	2.69	4.58	0.74	0.49	3.37	48.18	3.41	39.41	2.71	"	
Gloucester	(16?)	4.95	7.10	2.87	—	0.03	0.51	2.73	48.89	4.64	38.25	2.25	"	
Newcastle-on-Tyne	16	3.62	5.00	2.76	—	0.28	0.23	5.29	50.50	3.37	36.71	3.20	"	
Newcastle, Staffordshire.	15	4.53	5.67	2.47	—	0.08	0.11	6.22	46.31	3.74	39.01	2.65	"	
Brighton	14	3.76	4.60	2.45	4.62	0.03	0.23	2.07	51.62	4.14	38.15	3.04	"	
Southampton	14	3.09	4.90	3.17	5.20	0.07	0.39	2.53	53.59	3.59	36.74	2.86	"	
Ipswich	14	4.53	5.82	2.57	3.77	0.06	0.12	10.84	43.26	2.46	38.73	2.40	"	
Norwich	(14?)	3.26	4.85	2.97	3.40	0.27	0.14	3.03	53.79	3.40	36.11	2.89	"	

217 cubic feet of nitrogen from 1 ton of coal, and taking the gas produced from 1 ton of coal as 10,000 cubic feet, the nitrogen in the coal-gas would amount to from 1·27 to 2·17 per cent. by volume. To this must be added the nitrogen which is occluded in the coal, which from the researches of Mayer (*J. pr. Chem.*, 1872, **113**, 407) averages, in the English coal examined by him, 48 per cent. of the total occluded gases. The mean volume of occluded gases amounts to 25 cubic inches in 1 lb. of coal, or 32 cubic feet in 1 ton, so that the nitrogen from this source would be 15 cubic feet per ton, or, taking 10,000 cubic feet as the total yield of gas per ton of coal carbonised, 0·15 per cent. of nitrogen by volume in the coal-gas, an amount which is, therefore, quite insignificant. There can be no doubt that the larger quantities of nitrogen found in the later analyses of coal-gas, are due to the replacement of the iron retorts, which were almost exclusively used before, by the porous fire-clay retorts, which are also more liable to fissure, together with the increased exhaustion of the retorts during distillation. A certain amount of atmospheric air or furnace gas is thus sucked in, deprived of its oxygen in the retort; the carbonic anhydride formed is of course removed in the process of purification, and the nitrogen only remains in the final product. Moreover, the same result would be attained if air were aspirated into the gas at any other point before passing through the purifiers, since in the latter it would be deprived of its oxygen by the reducing action of the calcium and iron sulphides, the nitrogen alone remaining in the purified gas.
