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REPRINTED FROM THE

JOURNAL OF THE FRANKLIN INSTITUTE,

For April, 1878.

PHILADELPHIA:
WM. P. KILDARE, PRINTER, 734 & 736 SANSOM STREET.
1878.

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By ROBT. BRIGGS, C.E.

COMMON COAL GAS—ITS COMPOSITION, AND RESULTS OF COMBUSTION.—Some forty or more distinct gaseous chemical components are well known to have existence in the ordinary coal gas of the gas works, in four several groups: the first of which are gases which burn in air without, or with slight, emission of light; the second, gases which, when burned with the first for supply of heat, evolve carbon, which, becoming incandescent before burning itself, emits light; the third, incombustible gases; and the fourth, gases which are considered impurities. The first group is over four-fifths of the volume of coal gas, and is composed of only three substances or compounds, to wit: hydrogen, marsh gas and carbonic oxide; the second, which is only 7 to 9 per cent., comprises an almost endless list of hydro-carbon compounds, which are diffused, as gases or vapors, into the gases of the other groups; for the purpose of this paper this group will be considered as if composed entirely of olefiant gas (possibly most of these hydro-carbons are of the olefine series of compounds); the third comprises the carbonic acid, aqueous vapor and air, and is always 3 to 6 per cent. of coal gas; while the fourth, the impurities—ammonia and sulphur compounds; obnoxious as they are in quality, in any tolerably well purified gas the percentage of them in volume is so small, that in a discussion of results of combustion they do not become an element.

With this explanation to qualify the following statements and calculations, it is proper to say that common coal gas, of 14 to 15 candles illuminating power, has the following constituents in volumes per hundred parts: Hydrogen, H, 44 to 48; marsh gas, CH_4, 34 to 38; olefiant gas, C_2H_4, and other hydro-carbons, etc., 6 to 9; carbonic oxide, CO, 5 to 7; carbonic acid, CO_2, 1 to 3; air, $4N+O$, 1 to 3; aqueous vapor, H_2O (saturation at 40° to 60°), 1 to 2. The specific gravity of coal gas is about 0·426, which makes the volume of a pound of gas at 70° (barometer 29·9 in.) equal to 31·3 cubic feet (neglecting fractions, too small to be of consequence in this estimate) = 0·0319 lb. per cubic foot. Taking an average of the constituents of coal gas by weight, they can be reduced to 21·8 parts of hydrogen, 51·3 parts of carbon, and 13·6 parts of carbonic oxide, which are combustible; leaving 13·3 parts of non-combustible substances. The figures of the reduction of volumes to weights are as follows:

	Constituents.	Volumes per ct.	Do. average.	Specific Gravity.		H.	C.			Wt. per ct.
H	Hydrogen,	44 @ 48	45	0·0692 =	3·114	3·114		H	9·266	21·8
CH_4	Marsh gas,	34 @ 38	36	0·559 =	20·124	5·031	15·093			
C_2H_4	Olefiant gas,	6 @ 9	8	0·981 =	7·848	1·121	6·727	C	21·820	51·3
CO	Carbonic oxide,	5 @ 7	6	0·967 =	5·802				5·802	13·6
CO_2	Carbonic acid,	1 @ 3	2	1·524 =	3·048				3·048	7·2
4N+O	Air,	1 @ 3	2	1·000 =	2·000				2·000	1·6
H_2O	Vapor of water,	1 @ 2	1	0·622 =	0·622				0·622	1·5
			100		42·558	9·266	21·820		42·558	100·

From these data, the heat given out by *complete* combustion can be calculated—hydrogen gas will evolve in its chemical change to vapor of water (including the latent heat of the vapor) 62,000 units of heat, while carbon, in becoming carbonic acid, evolves 14,500 units, and carbonic oxide, in changing to the same form, evolves 4330 units—with the following result:

COMBUSTION OF 100 POUNDS OF COAL GAS.

Combustion.		Oxygen required.	Air required to supply oxygen.	Air required to effect complete combustion.	Units of heat per lb. of combustible	Units of heat total evolved.	Product.	
							H_2O	CO_2
H	21·8	174·4	785	1570	62000	1351600	196·2	
C	51·3	136·8	616	1232	14500	743850		188·1
CO	13·6	7·8	35	70	4330	58890		21·1
CO_2	7·2	0·						7·2
4N+O	4·6	0·						
H_2O *	1·5	0·					1·5	
	100·	319·	1436	2872		2154550	198·	217·
Deduct latent heat of 196·2 lbs. vapor of 70° @ 1065°,						208950		
Total units of heat from 100 lbs. coal gas (86·7 combustible + 13·3 of non-combustible)						1945400		

[* This ratio of vapor of water corresponds to the condition of vapor in saturated air at the temperature of 43° or 41 per cent. humidity at 70°—perhaps a little dry for summer tests.]

Accepting these quantities for the products of combustion of 100 pounds of coal gas, the absolute temperature attained may be estimated. Three different hypotheses present themselves: the first supposes the absolute heat to be that derived from the capacity of the product to take up the entire heat generated. The second limits the expenditure of heat in producing intensity, to the air needed to supply oxygen; while the third supposes the ultimate maximum intensity to be that derived from the chemical combination of oxygen and carbon, and of oxygen and hydrogen. The last is probably the correct value for the *intensity* of the source of radiating heat from a gas light. The following table gives the three computations in the order named:

	Pounds × Specific heat	= Sum of weight multiplied by Specific heat.		Pounds	sum, etc.		Pounds	sum, etc.
H_2O	198 × 0·478	= 94·050	H_2O	198;	94·050	H_2O	198;	94·050
N	1117 × 0·245	= 273·665	N ·	1117;	273·665			
4N+O	1436 × 0·238	= 341·768						
CO_2	217 × 0·217	= 47·089	CO_2	217;	47·089	CO_2	217;	47·089
Total	2968 × 0·255	= 756·572		1532;	414·808		415;	141·139

If now the total number of units of heat, which resulted from the burning of 100 pounds of coal gas, be divided by the sum of weights of products of combustion, multiplied by their specific heat, the increment of heat to the products will be given by the result; which, added to the original or normal heat of the gas and air (here taken at 70°), will give the absolute temperature of the products as they are assumed to exist in the three suppositions.

Supposed absolute temperature of flame of coal gas, where the products of combustion are taken to include the volume of air, which is the requisite for complete combustion:

$$= \frac{1945000}{756{\cdot}572} + 70^\circ = 2641^\circ.$$

Supposed absolute temperature of flame of coal gas, where the products of combustion are taken to include the air needed to supply oxygen of chemical combination:

$$= \frac{1945000}{418{\cdot}804} + 70^\circ = 4760^\circ.$$

Supposed absolute temperature of flame of coal gas, where only the oxygen of chemical combination is taken into the estimate:

$$= \frac{1945000}{141{\cdot}139} + 70^\circ = 13885^\circ.$$

At the same time we are discussing the absolute temperatures of coal gas flames, it may prove interesting to examine, separately, those of the three gases which compose it, as follows:

	Weight, pounds.	Oxygen. pounds.	Product of com.	Weight, pounds.	Specific heat.		Units heat.		Intens. of flame.
Hydrogen, H	1	8	H_2O	9	× 0·475	= 4·275)	52447(	12268° + 70°	= 12338°
Carbon, C	1	2 2-3	CO_2	3 2-3	× 0·217	= 0·796)	14500(	18223° + 70°	= 18293°
Carb. ox., CO	1	4-7	CO_2	1 4-7	× 0·217	= 0·341)	4329(	12694° + 70°	= 12764°

The value for the heat effect of one pound of hydrogen is derived in the same way as was used in the estimate for coal gas, as follows:

Total heat effect of 1 lb. of hydrogen, = 62,032 units.
Deduct latent heat of 9 lbs. vapor of 70°, 1065°, ... = 9,585 "

Heat effect of 1 lb. of hydrogen, without condensation of vapor, . = 52,447 "

These estimates of the heat of the flame of gases have taken for granted the constancy of the relative values of specific heats at high temperatures, and the results may therefore be considered as only approximations of the truth; still they give, probably, the most nearly correct estimate of the values of intensity possible.

The heat evolved by the burning of coal gas is dispersed in two ways—as radiant, and as convected or imparted heat. With the open burner, it is fair to assume that a large portion of the heat is dispersed as radiant heat. According to Peclet, 50 per cent. of the heat of a flame of burning wood or coal is dispersed as radiant heat, and it does not seem to be an improper assumption, that one-half the heat of burning of coal gas will be dispersed as radiant heat, and the other will be communicated to the gases of combustion, and disseminated by convection and intermixture with the surrounding air. The limited base from which the flame of a gas burner emerges, as compared to the magnitude of the flame or burning surface, prevents the loss or expenditure of radiant heat upon the fuel (which would again impart its heat to air in contact before burning), and thus reduces the convected heat to its least quantity. The supposition appears the more reasonable when we consider the enormous intensity of the heat of chemical combination; nearly 14000°, as above indicated, when unmixed with other gases to absorb its heat. If we proceed on this supposition, it follows that the convected heat of 100 pounds of coal gas becomes one-half of 1945400 = 972700 units; and this heat imparted to the products of combustion, when they are taken to include the volume of air necessary to effect complete combustion, gives the temperature of these products:

$$= \frac{972500}{756{\cdot}572} + 70° = 1356°.$$

The relations of volumes of the products of combustion of coal gas to the weights as ascertained, can be seen by the following table—estimated at 70°:

Product.	Spec. grav.	Wt. per cu. ft.	Cubic ft. per pound.		Wt. of product.		Cu. ft. of product.	Cu. ft. per ft. of gas.	Vol. per ct. of product.
H_2O	0·622	0·0466	21·45	×	198	=	4247	1·355	10·45
N	0·972	0·0729	13·73	×	1117	=	15332	4·891	37·73
4N+O	1·000	0·0750	13·34	×	1436	=	19158	6·111	47·15
CO_2	1·524	0·1142	8·754	×	217	=	1900	0·606	4·67
					2968	=	40637	12·963	100·00
Gas	0·426	0·0319	31·35	×	100	=	3135	1	7·71
Oxygen*	1·106	0·0829	12·07	×	319	=	3849	1·228	9·47
Air	1·000	0 0750	13·34	×	1432	=	19103	6·094	47·01
Dbl. Air	1·000	0·0750	13·34	×	2868	=	38259	12·204	94·15
Heat total, units			1945400					622	
Heat convected, units			972700					311	

[* The oxygen taken is that of actual combination, and represents the quantity needed, with coal gas, when used for the lime light or Bunsen burner.]

The preceding computation can be verified by another arrangement of data, in which volumes alone appear, taking the second column from the table of reduction of volumes to weight:

	100 vols. × spec. grav.	H.	C.	O.	N.	Result of combustion of hydrogen and carbon with definite proportion of oxyg.	
Hydrogen, H	3·114	3·114					
Marsh gas, CH_2	20·124	5·031	15·093				
Olefines, C_2H_4	7·848	1·121	6·727				
Carbonic oxide, CO	5·802		2·487	3·315			
Carbonic acid, CO_2	3·048		0·831	2·217			
Air, 4N+O	2·000			0·414	1·556		
Aqueous vapor, H_2O	0·622	0·069		0·536			
100 vols. × spec. grav , totals	42·558	9·335	25·138	6·529	1·556	H_2O	CO_2
Per cu. ft. gas, weights, lbs.	0·0319	0·0070	0·0188	0·0049	0·0012	0·063	0 069
" " volumes, cu. ft.	1·000	1·349		0·059	0·017	1·351	0·605

In general, the combustion of all substances, oils, fat acids, or gases used for illuminating purposes, is unquestionably perfect combustion of the carbon and hydrogen elements into carbonic acid and aqueous vapor. Neither smoke nor carbonic oxide, nor hydrogen in free or combined state, other than water, can be found in the air of any room where the lighting is at all satisfactory to the occupants, and the production of heat, as has been estimated, becomes one of the positive facts in physics beyond question as to existence and quantity. With the case of the open gas burner, it is possible that one-half the heat of the flame is dispersed as radiant heat, but this dispersal does not, however, get rid of the heat in a room; it merely transfers it to solid bodies of less temperature, more or less remote from the flame, which again are cooled in great measure by contact of the air of room, which takes up their excess of warmth, so that the heat emanating from a burner really is nearly all expended in the air. But when the burners are shaded by glass or other shades, and particularly for argand burners with chimneys, the larger part of the radiant heat is cut off by the shade or chimney, or both together, and imparted to an unknown volume of air which accompanies the air for or of combustion. As a practical application, it may be well to consider what volumes of air are requisite to disperse the heat of gas lights if the air in any part of a room is limited to some definite temperature.

The following table exhibits the effect of gas burning from a single burner of the usual sizes:

(All figures refer to quantities per hour—air of room and gas at 70°.)

Gas burned, cu. ft.,	1	3	3½	4	4½	5	6	8
Carbonic acid evolved, cu. ft.,	0·606	1·82	2·12	2·42	2·73	3·03	4·21	4·84
Aqueous vapor " " "	1·355	4·07	4·74	5·42	7·10	7·78	8·13	10·81
" " " lbs.,	0·063	0·19	0·221	0·253	0·285	0·317	0·38	0·506
Oxygen removed, cu. ft.,	1·228	3·68	4·30	4·91	5·52	6·14	7·37	8·60
Heat produced, units,	622	1866	2177	2488	2799	3110	3732	4976
Coal to produce equal heat, lbs.	0·062	0·19	0·22	0·25	0·28	0·31	0·37	0·50
Air supply = 10 cu. ft. per min. per cu. ft. gas, cu. ft.,	600	1800	2100	2400	2700	3000	3600	4800

With the supply of air to each gas burner given by the preceding table, the temperature of the current ascending from open burners, where one-half the heat is supposed to be radiated away, becomes 99°; while the temperature of the same current arising from an argand burner, where the glass chimney will have intercepted the radiant heat, becomes 128°.

The figures for this temperature are thus obtained: The weight of air at 70° is 0·075 pound per cubic foot, which, multiplied by 0·238, the specific heat of air, gives 0·01785 unit as the capacity of one cubic foot of air for each degree Fahr.; with 600 feet of air supply per hour to 1 foot of gas, the capacity of the 600 feet becomes 10·71 units for each degree of elevation of temperature ; and to absorb 622 units by the 600 cubic feet of air, the latter will become heated

$$\frac{622}{10{\cdot}71} = 58^\circ,$$

which, added to the 70° of primary temperature, give 128° as the final one when all the heat is taken up by the air. When but half the heat is assumed to be given to the air, we have $29^\circ + 70^\circ = 99^\circ$.

The computation of the temperature to accompany any other volume of air supply is easy. Thus, if for each cubic foot of gas burned per hour—normal temperature 70° :

Air supply per minute, cu. ft.,	5	10	15	20	25	30
Corresponding air supply per hour, cu. f.,	300	600	900	1200	1500	1800
Temperature of air ascending from open burners.	128°	99°	89°	84½°	81½°	79½°
Temperature of air ascending from argand burners,	187°	128°	118°	99°	93°	89°

The estimate of weight of coal, the consumption of which will produce an equal effect in warming a room with gas burning, is not based on the theoretical value of coal as a producer of heat, but upon average usual results from heating apparatus, as steam or hot water apparatus, hot air furnaces of best construction, or close stoves, in utilizing the heat of the fuel. That is, 10,000 units of heat have been assumed to be given out efficiently by the consumption of one pound of good anthracite coal.

The capacity of the air requisite for dispersal of the heat of a gas flame, to take up the moisture generated by the process of burning, can be investigated. According to the best authority (Regnault, from Guyot's tables), saturated air has the following quantities of moisture per cubic foot of air :

Temperature of air,	70°	75°	80°	85°	90°	95°	100°	105°
Weight of moisture, lbs.,	0·0011	0·0013	0·0016	0·0018	0·0021	0·0024	0·0028	0·0032

If it is assumed that the air of supply is 70°, and has 60 per cent. of saturation, then such air has 0·0007 pound of water to each cubic foot, whence the capacity of this air, to take up moisture in becoming saturated, is :

0·0004	0·0006	0·0009	0·0011	0·0014	0·0017	0·0021	0·0025

and there will be needed to carry off the 0·063 lb. of moisture which the burning of each cubic foot of gas per hour evolves :

Air at given temperatures, cu. ft.,	158	105	70	57	45	37	30	25

Comparison of these quantities, with the volume of air supply, and corresponding resulting temperatures as given in the previous table, demonstrates that the moisture generated by gas burning will be absorbed, in all cases, into the air for dispersal of heat.

While it appears to be impossible to discern any error in the method and data of this inquiry, and the mathematical accuracy (errors of computation excepted) of the results seems to be unquestionable, yet their application to practice is found to need great qualification. The material products of combustion, *i. e.*, aqueous vapor and carbonic acid, and the corresponding abstraction of oxygen from the air of a room, are established facts, but it is very difficult to account for the dispersion of the heat. Great allowance is needful for conductivity of the enclosing surfaces—floors, walls, ceilings, windows and doors—and also for fresh air currents, surreptitious or otherwise, before the heat imparted to the air, as derived from these computations, will conform to what is really found to be the heat effect of gas lighting. For instance, a 4 ft. gas burner would be held to be ample for lighting a small bed-room, and such a burner is frequently permitted to remain burning all night in a room of, not to exceed, 800 cubic feet capacity. This burner, by the computation, would produce 2488 units of heat each hour. In moderate weather no considerable loss of heat from the surfaces enclosing the room is supposable, and the figures give 7200 cubic feet of air per hour (or 120 feet per minute) as the indispensable necessity to keep down the temperature to 19° above the normal one. To be sure, the current of gases ascending from the burner will reach the ceiling of the room at a greatly elevated temperature, perhaps 140° even, and a stratum of hot air next the ceiling be formed (unless some arrangement of ventilation removes the hot air at once), and then the conductivity of the ceiling will be brought into action, but yet it is hard to feel satisfied that this means is sufficient to account for all the loss of heat apparently demanded.

It must be admitted that further inquiry and experiment are wanted to elucidate the subject of the dispersal of heat of gas lights, and perhaps to review the entire subject of the quantity of heat produced by them.