

calories for a gram of protein, the same for a gram of carbohydrates, and 9.3 per gram of fats.

It will be observed that arrowroot gives the widest nutrient ratio, 1 : 20, showing how largely starch enters into its composition; it is also an expensive food, costing sixteen pence per pound. Fine grain farola is prepared as a substitute costing only sixpence per pound, with a nutrient ratio, 1 : 43, and ought to prove a nourishing food for ordinary invalids.

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THE AVAILABLE HYDROGEN OF COAL.

BY S. W. PARR.

Received January 17, 1907.

The volatile constituents of coal being the subject of special attention on the part of the Illinois State Geological Survey the following study has been made in connection with that work.

The available hydrogen of coal is that part of the total hydrogen which may enter into combination with oxygen for the production of heat. The carbon, sulphur and available hydrogen constitute the actual combustible matter. While methods for the determination of carbon and sulphur are direct and accurate, there is no direct method applicable for available hydrogen.

The usual procedure is one of calculation, and it is indicated in Dulong's formula for determining the heat value from analytical data thus, calories = $8080 C + 34460(H - \frac{O}{8}) + 22.50S$. The accuracy of the factor for the available hydrogen, therefore, depends upon the accuracy attending the determination of oxygen. But the oxygen factor is subject to error. It is determined by difference and includes, therefore, the sum of all the errors that may have attended the work on the other constituents. This is of considerable moment in the case of coal high in sulphur. If the sulphur is all in the pyritic form, and if we assume the iron only to be an ash constituent, the ash will be too high by reason of the oxidation of the iron, the added oxygen increasing the ash factor by $\frac{3}{8}$ of the sulphur constituent. This error falls upon the oxygen making the percentage of that element too low or too high, depending on the basis of calculation. Nor can this difficulty be easily obviated by correcting the ash, since coals are very frequently met with high in sulphur and practically free from iron.

In the results published by Lord & Haas¹ on 50 coals of the Pennsylvania and Ohio region the results from calorific determinations compared with calculations by the Dulong formula were in such close agreement as

¹ Trans. Am. Inst. Eng., Vol. 27.

to warrant the inference that the available hydrogen was correctly represented by the total hydrogen minus $\frac{1}{8}$ of the oxygen. The same reasoning does not apply so well, however, to other regions. Take for example, the results on the first ten coals found in the last report from the Fuel Testing Plant of the United States Geological Survey¹. With one exception, these are all Illinois coals, and variations in calorific values between the calorimeter and calculated results show that on the average the results by the calorimeter are 70 calories higher than those calculated by the formula. This if computed to available hydrogen would indicate a calculated factor for that constituent averaging 0.2 per cent. too low. A still wider variation is found in a number of instances; for example, North Dakota No. 9A is 0.73 per cent. too low; West Virginia No. 18 is 0.80 per cent. too low, and four or five others are given with an indicated error of $\frac{1}{2}$ of one per cent. In these instances the variations cannot be ascribed to sulphur.

It is not the purpose of this paper primarily to offer a more accurate method of arriving at the factor for available hydrogen, but to suggest a different one which may also have the advantage of indicating other properties depending upon the structure and composition of coal.

The fundamental conception is based on the idea that the original substance from which coal has resulted was made up of substantially the same sort of material, and that the products of decomposition represent a progression, which at any given stage in any case bear a constant likeness of composition to the same stage in another case. Many facts suggest this hypothesis which need not be enumerated here. We have cellulose, brown and black lignites, bituminous coals of many varieties, semi-bituminous coals, semi-anthracites, anthracites, and graphites. How are they related?

If we take a number of coals of the bituminous type, and of widely differing characteristics as to their content of volatile matter, and reassemble their products of decomposition by destructive distillation into a sort of hypothetical molecule, we can arrange the series of equations which follow. These, of course, are intended as illustrative merely, though it should be said that they have their actual counterparts in respect to percentage composition².

TABLE I.

Bituminous Coal.	Carbon.	Hydrocarbons.	Water.	$\frac{vc}{C} \times 100$	$\frac{H}{vc} \times 100$
(a) $C_{24}H_{18}O_3$	= C_{20}	+ C_4H_{10} + 2H	+ 3 H_2O ;--	20%	25%
(b) $C_{18}H_{18}O_3$	= C_{13}	+ C_5H_{12}	+ 3 H_2O ;--	27.7%	20%
(c) $C_{22}H_{20}O_3$	= C_{16}	+ C_6H_{14}	+ 3 H_2O ;--	29.2%	19.4%
(d) $C_{18}H_{22}O_3$	= C_{11}	+ C_7H_{16}	+ 3 H_2O ;--	39%	16.5%

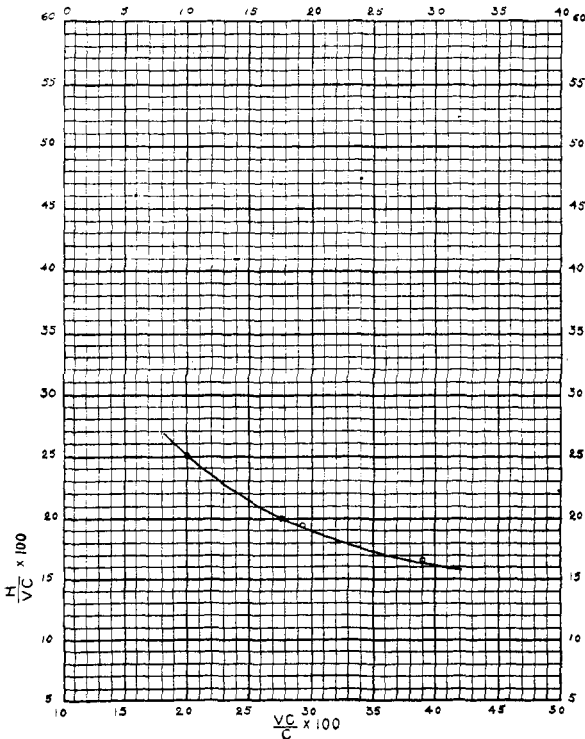
¹ Bulletin 290, U. S. Geol. Survey.

² vc = carbon of the volatile matter. C = total carbon. H = available hydrogen.

There is little suggestion of a progression here until we put them upon some common basis for comparison. This has been done in the last two columns. The basis in the first case is that of the ratio between the volatile carbon, or that which is joined with hydrogen, as a volatile hydrocarbon, (total carbon minus fixed carbon) and the total carbon of the coal. The ratio is further multiplied by 100 to bring it to the form of a whole number and we have for the ratio the expression $\frac{VC}{C} \times 100$.

The last column expresses the ratio between the hydrogen thus joined with the carbon, and the volatile carbon. We therefore have the expression for this column of $\frac{H}{VC} \times 100$.

Now, if we locate these points, taking the first ratio for the abscissas and the second for the ordinates, and draw the curve through the points as indicated, we shall have the following:



CARBON AND HYDROGEN RATIOS

Fig. 1.

The final adjustment and location of this curve has not been, however, so simple as might appear, but has involved a large amount of rather

tedious calculation¹. After trial of almost every possible ratio, the one represented by the expression $\frac{vc}{C} \times 100$ was adopted as the fundamental element in the case. Its concordant relationship to the other constituents justifies its adoption. This characteristic indeed suggested the scheme of classification of coals recently proposed by the writer². It may be argued in its favor that of its constituent parts the denominator is a relatively large quantity and presumably accurate as to its determined value; the numerator has whatever error is incident to the determination of the fixed carbon or volatile matter, but its effect is divided and practically eliminated by the character of the denominator just described. It has an especial advantage over any ratios based on the values for volatile and fixed constituents where both terms are susceptible of marked variation and error in their determination.

The curve as finally decided upon is given in Fig. 2. A brief explanation of the curve is as follows: For ratios of $\frac{vc}{C} \times 100$, which are less than 20 no location of the curve should be attempted. First, for the reason that there are no coals having ratios which fall between 12 or 13 and 20, at least, they are so rare as to be negligible, and second, because below a ratio of 20, no sufficient uniformity exists to make the ratio applicable. It should be further noted that with the ratios in the higher numbers another factor enters into the account, *viz.*, that of inert volatile matter, chiefly composed of water of composition, the main curve "A" being applicable to coals of the true bituminous type having a content of from 12 per cent. to 16 per cent. of this material. This variation is easily cared for as follows. The available hydrogen is first calculated by means of the main curve A. The sum of the sulphur, available hydrogen and the carbon to which it is attached (vc) is subtracted from the volatile matter³, as determined by proximate analysis.

This remainder is the inert or non-combustible volatile matter. It should be reduced to the "ash and water-free" basis to avoid the abnormal effect of high ash and moisture. (Dividing by 100 — (ash + moisture)). If the result shows a factor for this constituent between 16 and 20 per cent., it indicates a black lignite, and the hydrogen reading should be made from the accessory curve "c." Similarly, the use of the sub-curves "b" and "d" is indicated by a preliminary calculation roughly made, it being only necessary to ascertain the type of coal in hand. So far as present ex-

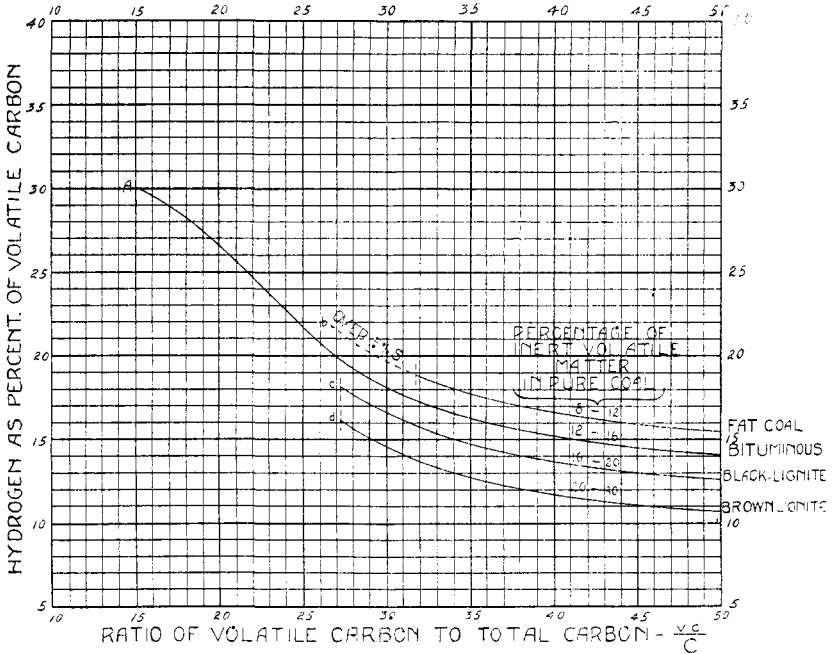
¹ Special recognition of assistance in this connection is due Mr. F. F. Grout, formerly of the Illinois Geological Survey, and Mr. F. K. Ovitz, of the Engineering Experiment Station, University of Illinois.

² This Journal, 28, 1425.

³ Usually called "volatile combustible matter." It does not include water lost at 100°.

perience goes, the application of these subsidiary curves does not extend to lower ratios than is indicated by the dotted lines at the left, except in the case of a few Michigan coals with over 5 per cent. sulphur.

AVAILABLE HYDROGEN CURVES.



(Fig. 2.)

The curve, therefore, is an empirical one, and is of value only as it fits the case of other data not involved in its location. For verification, therefore, a large number of results have been assembled which give the ultimate analysis as well as the calorific values, and such factors tabulated as are necessary for illustrating the method. In the table below the volatile carbon of the second column is the total carbon minus the fixed carbon.

The ratio of $\frac{VC}{C}$ of the third column indicates the location on the curve where may be read as ordinate the percentage ratio of the available hydrogen to the volatile carbon. By multiplying, therefore, the volatile carbon by this percentage factor we have the per cent. of available hydrogen in the coal. This is the first column under "Hydrogen Values." The second column of hydrogen values is derived from the ultimate analysis factors, and corresponds to the expression from Dulong's formula

$(H - \frac{O}{8})$ The last column is derived from the indicated calories by means of the formula

$$H = \frac{\text{Indicated calories} - (8080 C + 2250 S)}{34460}$$

The first ten samples only have been taken as being sufficiently illustrative of the total of 54 analyses.

TABLE II.
Comparison of Derived Values for Available Hydrogen.¹

Description.	Total Carbon C	Vol. Carbon vc	Ratio $\frac{vc}{C}$	Reading from Curve.	Hydrogen Values		
					H calc. from Curve.	H from Ult. Anal.	H from Ind. Cals.
1. Alabama, No. 1.....	72.16	18.45	25.56	21.1	3.90	3.98	3.92
2. Alabama, No. 2.....	69.24	17.50	25.27	21.6	3.78	3.43	3.77
6. Colorado, No. 1.....	61.13	18.10	29.60	16.9	3.05	2.63	3.02
7. Illinois, No. 1.....	62.01	20.93	33.73	16.8	3.52	3.36	3.64
8. Illinois, No. 2.....	54.06	18.82	32.96	17.0	3.03	3.05	2.92
9. Illinois, No. 3.....	67.30	15.14	22.50	24.4	3.69	3.49	3.62
10. Illinois, No. 4.....	61.79	17.49	28.3	19.0	3.32	3.02	3.14
11. Illinois, No. 5.....	58.02	17.35	29.9	18.2	3.16	3.02	3.32
12. Illinois, No. 6.....	60.51	13.05	21.5	25.2	3.30	3.11	3.51
13. Indiana, No. 1.....	62.20	19.53	31.4	17.6	3.44	3.33	3.63
14. Indiana, No. 2.....	62.97	20.21	32.09	17.3	3.50	3.54	3.53
15. Ind. Ter., No. 1.....	69.85	19.80	28.34	19.0	3.76	3.72	3.84
16. Ind. Ter., No. 2.....	71.49	21.70	30.35	18.0	3.90	3.89	4.04
17. Ind. Ter., No. 3.....	68.18	20.36	29.86	18.2	3.71	3.54	3.87
18. Ind. Ter., No. 4.....	63.21	19.31	30.54	17.9	3.46	3.20	3.27
19. Ind. Ter., No. 5.....	52.39	15.34	29.28	18.6	2.85	2.63	2.54
20. Iowa, No. 1.....	61.80	15.29	24.74	22.1	3.38	3.25	3.54
21. Iowa, No. 2.....	60.36	18.62	30.85	17.8	3.31	3.45	3.53
22. Iowa, No. 3.....	60.62	21.63	35.68	16.2	3.52	3.54	3.65
23. Iowa, No. 4.....	61.25	20.03	32.70	17.1	3.41	3.24	3.45
Average					3.39	3.28	3.42

If we summarize the results on these 54 coals of the Fuel Testing Plant at St. Louis, we shall have a comparison of factors as follows, counting in units of $\frac{1}{10}$ of a per cent. above or below the standard which is taken as the hydrogen from indicated calories.

TABLE III.
Available Hydrogen : Variations in units of $\frac{1}{10}$ of one per cent.

	Available Hydrogen from Curve.	From Ultimate Analysis.
Total plus error.....	11	7
Total minus error.....	84	128
Highest plus error.....	3	1.5
Lowest minus error.....	7	7
Average of all variations.....	1.8	2.5

Since the above tabulations were made, analyses have been published

¹ Calculations based on data contained in Bulletin No. 261, United States Geological Survey, 1904.

from the Fuel Testing Plant of the Government Geological Survey¹, covering 70 additional coals fairly well distributed throughout the United States. The first 20 of these results are tabulated below showing the available hydrogen as derived by these three methods. Following the table is a summary showing variations above and below the standard which is taken as the available hydrogen calculated from the indicated calories as in Table No. 3.

TABLE IV.
Comparison of Derived Values for Available Hydrogen.²

Description.	Total Carbon C	Vol. Carbon vc	Ratio $\frac{vc}{C}$	Reading from Curve	Hydrogen Values.		
					H calc. from Curve	H from Ult. Anal.	H from Ind. Cals.
1. California, No. 1.....	47.34	16.67	35.2	14.7	2.45	2.49	2.42
2. Illinois, No. 6.....	56.94	13.04	22.9	23.9	3.12	2.91	2.98
3. Illinois, No. 7 B.....	54.56	18.31	33.5	16.7	3.06	2.83	3.07
4. Illinois, No. 7 D.....	58.59	18.84	32.2	17.1	3.22	3.18	3.37
5. Illinois, No. 8... ..	57.25	17.31	30.2	18.00	3.12	2.71	3.21
6. Illinois, No.9 A.....	58.69	18.66	31.8	17.3	3.23	3.22	3.39
7. Illinois, No. 9 B.....	58.95	19.23	32.6	17.0	3.27	3.25	3.44
8. Illinois, No. 10.....	63.83	16.75	26.20	20.50	3.43	3.23	3.49
9. Illinois, No. 11 A.....	66.55	16.36	24.60	22.10	3.62	3.34	3.54
10. Illinois, No. 11 B.....	64.29	16.06	24.90	21.70	3.49	3.36	3.63
11. Illinois, No. 11 C.....	65.14	16.81	24.7	22.0	3.70	3.40	3.60
12. Illinois, No. 12.....	62.52	15.93	25.5	21.3	3.38	3.23	3.43
13. Illinois, No. 13.....	65.83	16.27	24.7	22.00	3.58	3.24	3.36
14. Illinois, No. 14.....	58.74	17.97	30.60	17.90	3.22	3.15	3.29
15. Illinois, No. 15.....	59.64	17.58	29.50	18.40	3.23	3.13	3.43
16. Illinois, No. 16.....	67.33	15.44	22.90	23.90	3.69	3.37	3.43
17. Illinois, No. 18.....	61.29	19.49	31.80	17.30	3.37	3.47	3.75
18. Illinois, No. 19 A.....	62.76	13.26	21.1	25.6	3.39	2.79	2.82
19. Illinois, No. 19 B.....	66.74	16.68	25.0	21.7	3.62	3.26	3.14
20. Indiana, No. 3.....	54.52	15.25	28.0	19.3	2.94	3.03	3.07
Average.....					3.306	3.178	3.293

TABLE V.

Summary of Comparative Factors Showing Variations in Units of 1/10 per cent.

	Available Hydrogen from Curve.	From Hydrogen Analysis.
Total plus errors	26	4
Total minus errors	69	142
Highest plus error.....	5.5	1.3
Lowest minus error.....	5.5	9.5
Average of all errors per sample .	1.4	2.1

¹ U. S. Geol. Survey, Bulletin No. 290.

² Calculations based on data contained in Bulletin No. 290, United States Geological Survey, 1905.

A further comparison may be made by tabulating the averages from the various data made use of in the above computations.

TABLE VI.

	H From Curve	H From Ult. Anal.	H From Ind. Calories.
Average of first 20 (Table No. 2)	3.39	3.28	3.42
Average of 50 from Bulletin No. 261, U. S. Geol. Survey	3.51	3.46	3.69
Average of 50 from report of Lord and Haas	3.96	3.95	3.90
Average of 12 from Mich. Geol. Survey	4.09	4.06	4.16
Average of first 20, as in Table No. 4 . .	3.30	3.17	3.29
Average of 70 from Bulletin No. 290. U. S. Geol. Survey	3.54	3.41	3.61

It will be seen from the above that out of 180 coals the extreme of error by use of the curve is much within that resulting from the ultimate analysis; and that on the average the error represented by the former is less than that resulting from use of Dulong's formula. There is here opened up the possibility of making the essential factors as derived by ultimate analysis equally accessible with those of the proximate method, the real value of chemical work on coal being greatly enhanced thereby. Further interest in this connection would center in the derivation of the factor for total and fixed carbon, a discussion of which must be reserved for another time.

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[CONTRIBUTION FROM THE OFFICE OF PUBLIC ROADS, U. S. DEPARTMENT OF AGRICULTURE¹.]

AIR ELUTRIATION OF FINE POWDERS.

BY ALLERTON S. CUSHMAN AND PREVOST HUBBARD.

Received February 4, 1907.

In recent years the production of extremely fine ground material for use in the various arts has made it highly desirable to obtain a standard method for separating and measuring particles which will readily pass through the finest meshed sieves. All the methods heretofore used depend upon the elutriation of the material with water flowing at different velocities, each velocity allowing the sedimentation of particles within the range of certain definite dimensions. Various forms of apparatus have been constructed on these principles, among which the best known are those of Schoene² and Hilgard³. Recently an improved form has been described by Binns⁴. In all the methods of water elutriation, however, it

¹ Published by permission of the Secretary of Agriculture.

² Bulletin de la société impériale des naturalistes de Moscou (1867), Part I, 324.

³ Bulletin 38, Bureau of Chemistry, Department of Agriculture, 60.

⁴ Trans. Am. Ceram. Soc., 8, 244 (1906).