price reagents that will give accurate results when put to the ordinary uses.

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THE CLASSIFICATION OF COALS.[1]

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THE fundamental properties of coal are directly involved in the decomposition products which are in evidence as a result of geological processes. These products have certain characteristics which manifest themselves in practical every-day use under the two notions of behavior and quality. A scheme of classification, therefore, to have any intelligent significance should be an expression of these two ideas. But while it should be susceptible of practical or commercial interpretation, it should have for its fundamental and ultimate basis, correct analytical facts and scientific data. The methods of classification thus far proposed have seemed to the writer deficient in one or the other of these two phases: either they were devised wholly with industrial ends in view and gave little heed to scientific considerations or they were too profoundly scientific to be capable of translation into any everyday meaning. The work here outlined has been done in connection with the State Geological Survey of Illinois and the effort has been made to embody both of these phases in the consideration of the topic.

The scheme of classification at present most widely recognized is that proposed by Frazer.[2] It has the merit of being intelligible from the industrial standpoint. It does not, however, embody certain phases that seem desirable if any meaning attaches to our discussion of the essentials from a scientific basis as above set forth. Indeed in his recent admirable defense of this classification,[3] Frazer recognizes the lack of data which at the present time would be embodied in the ordinary results of proximate analysis.

It is proposed by Campbell[4] to base a classification on the ratio of the total carbon divided by the total hydrogen. The argument

[1] Read at the Ithaca Meeting of the American Chemical Society.

[2] Trans. Am. Inst. Min. Eng. 6, 430.

[3] Bull. Am. Inst. Min. Eng. March, 1905.

[4] Report of Coal Testing Plant, U. S. Geol. Survey, St. Louis, Professional Paper U. S. G. S. No. 48, Part I, pp. 156–173.

for the use of the total hydrogen in such a ratio seems illogical and at variance with all the facts attending the property of coals. Especially is this true at the lignitic end of the series. Certain it is that the hydrogen there has a different meaning from what it has at the semi-bituminous end. To include the hydrogen of the moisture is to build on a variable that would make it impossible for any one else to reproduce the classification who could not duplicate the exact method of sampling and transmission. With the finely drawn distinctions in the resulting ratios a sample of coal might fall into as many different classes as there were analysts who examined it. It fails also to make use of one valuable fact developed by the usual method of proximate analysis, and that is, the relation of the volatile hydrocarbons to the total carbonaceous material. This, it would seem, comprises such fundamental properties, both with reference to its chemical structure as well as its performance in actual use, that no system of classification could have much value that ignores it. These objections all become accentuated when samples approach the lignitic type. It does not seem possible that these divisions can be properly considered without taking into account the factor for combined water, the "residual cellulose," if we may so designate it. On this point again we quote from Frazer:[1] "It may well be that other factors than carbon and hydrogen will some day furnish the means of a further differentiation of lignites, brown coals, peats and cannel coals."

It is certain that in any careful study of the composition, especially of bituminous coals and lignites, there is truly another factor which seems to have been entirely ignored or overlooked and it is this factor which seems to be primarily the one to be made use of for further differentiating between not only the various sorts of bituminous coals, but especially between the bituminous coals and lignites, as well as between the lignites themselves. Reference has already been made to this constituent, which is the "water of hydration" or that part of the volatile matter which is non-combustible or inert, so far as fuel value is concerned. There is no part of the ordinary proximate analysis that refers to it and its only recognition so far seems to be in that part of Dulong's formula which represents the available hydrogen as consisting

[1] Bull. Am. Inst. Min. Eng. March, 1906, pp. 244-245.

of $H - \frac{O}{8}$, which in reality means the total hydrogen less the hydrogen required to combine with the oxygen of the coal. But here again this particular factor is obscured for the reason that the usual ultimate analysis combines in its factors the ordinary moisture as well as this water of composition, and it seems to be not altogether an easy matter to establish a recognition of this constituent of coal as a part of the volatile matter which should receive separate mention and report.

Another difficulty in the case has been the almost universal use of the term "volatile combustible" for "volatile matter," when as a matter of fact, it is not strictly a volatile combustible for the reason that in average bituminous coal approximately one-third of the volatile matter is really non-combustible. This may be further illustrated by putting into molecular form the pure coal of an average bituminous sample, considered as free from moisture and ash, as follows:

				Volatile matter.		
$C_{22}H_{20}O_3$	=	C_{16}	+	C_6H_{14}	+	$3H_2O$.
Coal.		Fixed carbon.		Volatile combustible.		Inert.
Per cent.		Per cent.		Per cent.		Per cent.
100		58		26		16

This type molecule represents an actual example of Illinois coal and the right-hand member of the equation represents the percentage constituents of the products resulting from destructive distillation. It is not, of course, intended that these formulas represent actual compounds.

Now the point here made is that the two last constituents which are ordinarily reported as "volatile combustible," or still worse as "volatile carbon," are in fact composed of volatile hydrocarbons and hydrogen which are combustible and an inert constituent consisting essentially of hydrogen and oxygen in the proportion to form water, and hence designated as the inert portion of the volatile matter.

Furthermore, if we examine a lignite in the same way, we shall find the proportion of inert volatile matter much greater than in the case of bituminous coals and similarly, the semi-bituminous type will be found to have relatively less of this constituent.

The method of classification herein proposed, therefore, makes prominent use of that part of the volatile matter which has been variously designated as inert or non-combustible, or as "water of composition."

But still another factor even more fundamental must be taken into the account. It has already been referred to as the fact of chief value developed by the process of proximate analysis; this is the ratio existing between the forms of carbon. The amount of fuel constituent which assumes the volatile condition is as much a scientific item as it is a matter of practical importance. This is best expressed in the form of a ratio or percentage and while it may be argued that one ratio is as good as another, a thorough examination of the one here employed will bear out the argument that it best expresses that feature of the composition of coal which recognizes a certain percentage of the fuel as of the volatile sort. The ratio thus employed is designated by the expression $vc \times \frac{100}{C}$ in which "vc" is the volatile carbon unassociated with hydrogen, and "C" is the total carbon as determined by analysis.

Briefly outlined, the plan of classification proposes to retain the old nomenclature but to base the first or fundamental divisions upon the ratio $vc \times \frac{100}{C}$. Upon applying this principle it will be found that coals in general divide themselves first into two distinct classes. Those of the anthracitic and those of the bituminous type. In the first division (of the one hundred coals tabulated), no carbon ratio as above expressed is found greater than 15 per cent. In the second division, no carbon ratio falls below 20 per cent. This certainly has the virtue of differentiating between these two types in a manner which demands respectful consideration for this suggested ratio. As to further classification, also, this ratio seems to be all that is needed to differentiate among the members of the first general division. Three main classes are thus indicated: First, anthracites proper with a ratio of $vc \times \frac{100}{C}$ of less than 4; second, semi-anthracites with ratios falling between 4 and 8; and third, semi-bituminous with ratios grouping very closely around 10 and 12, but in no case exceeding 15.

In the second general division, designated as the bituminous type, we have again three general classes. But here there enters into the account the factor for the inert portion of the volatile matter. Moreover, in order to make one coal comparable with another, this constituent has been reduced to the pure coal or "ash and water free" basis and expressed in percentage.

The three divisions, therefore, are designated as follows:

First, the bituminous proper with carbon ratios exceeding 20 and with inert volatile content not exceeding 15 per cent.

Second, black lignites with carbon ratios exceeding 27 and with inert volatile ratios falling between 16 and 20 per cent.

Third, brown lignites with carbon ratios above 27, but with inert volatile matter above 20 per cent.

The tabular presentation of this outline will make these relations more clear.

CLASSIFICATION OF COALS.

Coals				
Anthracitic..	Anthracite proper.....		vc × 100/C below 4 per cent.	
Anthracitic..	Semi-anthracite.........		vc × 100/C between 4 and 8 per cent.	
Anthracitic..	Semi-bituminous.......		vc × 100/C from 10 to 15 per cent.	
Bituminous..	Bituminous proper	A	vc × 100/C from 20 to 32 per cent.	Inert volatile matter from 5 to 10 per cent.
Bituminous..	Bituminous proper	B	vc × 100/C from 20 to 27 per cent.	Inert volatile matter from 10 to 15 per cent.
Bituminous..	Bituminous proper	C	vc × 100/C from 32 to 44 per cent.	Inert volatile matter from 5 to 10 per cent.
Bituminous..	Bituminous proper	D	vc × 100/C from 27 to 44 per cent.	Inert volatile matter from 10 to 15 per cent.
Bituminous..	Black lignites...........		vc × 100/C from 27 per cent. up.	Inert volatile matter from 16 to 20 per cent.
Bituminous..	Brown lignites..........		vc × 100/C from 27 per cent. up.	Inert volatile matter from 20 to 30 per cent.

One further subdivision is necessary: the bituminous group is large and is susceptible of further separation. These sub-classes are designated for the present by the letters A, B, C, and D. A and B have the characteristic of a lower percentage of volatile carbon, using that term correctly, with a "fat" and a "lean" feature as indicated by the percentage of inert volatile matter, being from 5 to 10 per cent. under A, and from 10 to 15 per cent. under B. In exactly the same way C and D are characterized by having a high ratio of volatile carbon but sub-class C has the lower percentage of inert volatile matter, thus allying it closely with the cannels or gas coals, and D has the higher percentage of inert matter, thus bringing it nearer the lignites.

Before illustrating this method of classification by tabulating a series from analytical data, one point further should be discussed. That is the element of intrinsic value or relative merit. This enters slightly into the expression for the carbon ratios, but a coal with a high percentage of its fuel content in the fixed form may still be inferior in fuel content to one with a high ratio of volatile combustible.

So also something more of relative value is expressed by the percentage of inert volatile matter but this factor alone should not be made to carry the burden of indicating the grade. Concerning the element of worth it should not dominate in the idea of classification, and in the scheme here proposed this feature is considered as having been given its due weight by arranging particular coals in their ultimate classes in the order of their fuel ratios. Here again is proposed something of an innovation in the use of terms. If we recognize the true fuel of a coal to be all comprised in the total carbon, available hydrogen, and the sulphur, then the reciprocal of the sum of these percentages expressed in hundreds will be a fuel ratio that indicates directly the number of pounds of that particular coal required to make one hundred pounds of true combustible or "fuel," and to avoid confusion of terms, we designate this factor as the "gross coal index." For example, a West Virginia coal has carbon 78.31 per cent., hydrogen 4.31 per cent., and sulphur 0.90 per cent.; total fuel 83.5 per cent. Then the gross coal index $= \frac{100}{0.835}$ or 120, which means that 120 pounds of this coal would be required to make 100 pounds of actual fuel. Or again illustrating by a sample of Dakota lignite: if we have carbon 52.66 per cent., hydrogen 1.83 per cent., and sulphur 2.02 per cent., total 56.51 per cent., the expression for the gross coal index would be $\frac{100}{0.565}$ or 175, which means that 175 pounds of this material would be required to make 100 pounds of true combustible matter.

In the following table, use is made of the analytical results as obtained at the United States Geological Survey Coal-Testing Plant at St. Louis. The ultimate order of the samples is arranged according to their fuel ratios as above described, while the location in the respective classes is determined by the carbon ratios and the inert volatile percentages as already outlined.

It may be said in conclusion that the analytical results from fifty coals by Lord and Haas previously made[1] and by Williams[2] have been subjected to the same method of classification with equally satisfactory results.

CLASSIFICATION OF COALS, ST. LOUIS TESTING PLANT, FIRST REPORT.

Anthracites.

$vc \times \frac{100}{C}$ below 4 per cent.

Semi-Anthracites.

$vc \times \frac{100}{C}$ between 4 and 8 per cent.

Arkansas No. 5	4.66
Arkansas No. 2	7.96

Semi-Bituminous.

$vc \times \frac{100}{C}$ from 10 to 15 per cent.

	Carbon ratio, vc × 100/C.	Gross coal index.
West Virginia No. 10	11.63	110.0
West Virginia No. 6	13.26	113.0
West Virginia No. 7	10.68	113.5
West Virginia No. 11	10.55	120.0
West Virginia No. 5	11.06	120.0
Arkansas No. 3	11.41	123.0
Arkansas No. 1	10.00	124.5

[1] Trans. Am. Inst. Min. Eng. Vol. XXVII.

[2] Mich. Geol. Report, Vol. VIII.

BITUMINOUS.

CLASS A.

vc × 100/C 20 to 32 per cent.
Inert volatile matter 5 to 10 per cent.

	Carbon. Ratio.	Inert vol. matter.	Gross coal index.
West Va., No. 9 ...	21.02	8.46	118.5
West Va., No. 8 ...	25.18	7.78	119.0
West Va., No. 5 ...	21.46	6.33	120.0
West Va., No. 4 ...	20.89	8.03	120.0
West Va., No. 1 ...	29.30	9.53	120.0
Kansas, No. 5	23.54	8.75	120.5
West Va., No. 3 ...	23.30	8.22	123.0
Kansas, No. 3	25.80	7.51	127.0
Kansas, No. 4	28.02	7.97	129.5
Kansas, No. 1	26.69	8.27	131.5
Kentucky, No. 4 ...	29.63	9.73	134.0
Kansas, No. 2	24.56	7.88	136.5

CLASS B.

vc × 100/C 20 to 27 per cent.
Inert volatile matter 10 to 15 per cent.

	Carbon. Ratio.	Inert vol. matter.	Gross coal index.
Kentucky, No. 1 ...	27.11	10.54	120.0
Alabama, No. 1.....	25.56	10.51	130.0
Alabama, No. 2.....	25.27	12.77	135.0
Illinois, No. 3	22.50	11.75	137.0
Iowa, No. 1	24.74	10.08	142.0
Illinois, No. 6	21.50	14.83	146.5
Iowa, No. 5	25.66	13.84	150.0

CLASS C.

vc × 100/C 32 to 44 per cent.
Inert volatile matter 5 to 10 per cent.

Missouri, No. 4.....	38.61	7.41	121.0
West Va., No. 2 ...	32.16	9.44	121.5
Missouri, No. 1.....	32.05	9.53	145.5

CLASS D.

vc × 100/C 27 to 44 per cent.
Inert volatile matter 10 to 15 per cent.

	Carbon. Ratio.	Inert vol. matter.	Gross coal index.
Indian Terr., No. 2...	30.35	11.53	130.0
Indian Terr., No. 3...	29.86	11.36	132.5
Indian Terr., No. 1...	28.34	11.86	132.5
Kentucky, No. 2......	31.59	11.91	133.0
Kentucky, No. 3......	29.64	11.76	135.0
Indiana, No. 2.........	32.09	11.44	140.5
Iowa, No. 3	35.68	11.23	141.0
Indian Terr., No. 4..	30.54	13.46	141.5
Illinois, No. 1.........	33.73	12.77	143.5
Illinois, No. 4	28.30	13.41	145.5
Iowa, No. 2.............	30.85	12.56	145.5
Indiana, No. 1.........	31.40	12.00	146.5
Iowa, No. 4	32.70	11.93	147.0
Illinois, No. 5	29.90	14.15	154.0
Missouri..................	30.63	12.12	155.0
Missouri, No. 3........	28.61	13.05	162.0
Illinois, No. 2	32.96	12.95	163.0
Indian Terr., No. 5...	29.28	13.44	168.0

BLACK LIGNITES.

vc × 100/C 27 per cent. and above.
Inert volatile matter 16 to 20 per cent.

N. Mexico, No. 1...	27.10	16.88	147.0
Montana, No. 1.....	28.77	18.25	153.5
Colorado, No. 1.....	29.60	19.19	155.0
Wyoming, No. 2...	32.36	17.00	160.5
Wyoming, No. 1...	32.27	19.99	161.0
N. Mexico, No. 2..	33.29	16.18	164 0

BROWN LIGNITES.

vc × 100/C 27 per cent. and above.
Inert volatile matter 20 to 30 per cent.

Texas, No. 2.........	30.00	23.90	165.0
N. Dakota, No. 2..	28.40	23.79	172.0
N. Dakota, No. 1..	36.17	21.09	175.0
Texas, No. 1.........	44.20	22.39	180.0