Designation: D388 – 17

Standard Classification of Coals by Rank[1]

This standard is issued under the fixed designation D388; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This standard covers the classification of coals by rank, that is, according to their degree of metamorphism, or progressive alteration, in the natural series from lignite to anthracite.

1.2 This classification is applicable to coals that are composed mainly of vitrinite.

NOTE 1—Coals rich in inertinite or liptinite (exinite), or both, cannot be properly classified because, in those macerals, the properties that determine rank (calorific value, volatile matter, and agglomerating character) differ greatly from those of vitrinite in the same coal. Often such coals can be recognized by megascopic examination. In North America, these coals are mostly nonbanded varieties that contain only a small proportion of vitrain and consist mainly of attrital materials. The degree of metamorphism of nonbanded and other vitrinite-poor coals can be estimated by determining the classification properties of isolated or concentrated vitrinite fractions, or by determining the reflectance of the vitrinite (see Test Method D2798 and Appendix X1 of this classification). However, in the use of these vitrinite-poor coals, some properties normally associated with rank, such as rheology, combustibility, hardness, and grindability (as well as the rank determining properties) may differ substantially from those of vitrinite-rich coals of the same degree of metamorphism.

The precision of the classification of impure coal may be impaired by the effect of large amounts of mineral matter on the determination of volatile matter and calorific value, and on their calculation to the mineral-matter-free basis.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard. The values given in parentheses are for information only.

1.3.1 *Exception*—The values stated in British thermal units per pound (Btu/lb) are to be regarded as the standard. The SI equivalents of Btu/lb are provided for information only and are not considered standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D121 Terminology of Coal and Coke
D720 Test Method for Free-Swelling Index of Coal
D1412 Test Method for Equilibrium Moisture of Coal at 96 to 97 Percent Relative Humidity and 30 °C
D2013 Practice for Preparing Coal Samples for Analysis
D2234/D2234M Practice for Collection of a Gross Sample of Coal
D2798 Test Method for Microscopical Determination of the Vitrinite Reflectance of Coal
D3172 Practice for Proximate Analysis of Coal and Coke
D3173 Test Method for Moisture in the Analysis Sample of Coal and Coke
D3174 Test Method for Ash in the Analysis Sample of Coal and Coke from Coal
D3175 Test Method for Volatile Matter in the Analysis Sample of Coal and Coke
D3302 Test Method for Total Moisture in Coal
D4239 Test Method for Sulfur in the Analysis Sample of Coal and Coke Using High-Temperature Tube Furnace Combustion
D4596 Practice for Collection of Channel Samples of Coal in a Mine
D5016 Test Method for Total Sulfur in Coal and Coke Combustion Residues Using a High-Temperature Tube Furnace Combustion Method with Infrared Absorption
D5192 Practice for Collection of Coal Samples from Core
D5865 Test Method for Gross Calorific Value of Coal and Coke

3. Terminology

3.1 *Definitions:*

[1] This classification is under the jurisdiction of ASTM Committee D05 on Coal and Coke and is the direct responsibility of Subcommittee D05.18 on Classification of Coals.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.1.1 For additional definitions of terms used in this classification, refer to Terminology D121.

3.1.2 *agglomerating, adj*—as applied to coal, the property of softening when it is heated to above about 400 °C in a nonoxidizing atmosphere, and then appearing as a coherent mass after cooling to room temperature.

3.1.3 *apparent rank, n*—of coal, the rank designation obtained on samples other than channel samples or core samples with 100 % recovery, but otherwise conforming to procedures of Classification D388.

3.1.4 *coal seam, n*—the stratum, layer, or bed of coal that lies between two other rock layers whose compositions differ significantly from that of coal.

3.2 *Abbreviations:*

3.2.1 Where it is desired to abbreviate the designation of the ranks of coal, the following abbreviations shall be used:

ma—meta-anthracite
an—anthracite
sa—semianthracite
lvb—low volatile bituminous
mvb—medium volatile bituminous
hvAb—high volatile *A* bituminous
hvBb—high volatile *B* bituminous
hvCb—high volatile *C* bituminous
subA—subbituminous *A*
subB—subbituminous *B*
subC—subbituminous *C*
ligA—lignite *A*
ligB—lignite *B*

3.3 *Symbols:*

3.3.1 *Descriptive Symbols (symbols used for describing quantities, all in lowercase, roman)*

d—dry basis
f—free basis (e.g., mineral-matter-free and sulfur-trioxide-free)
im—inherent moisture basis

3.3.2 *Simple Quantity Symbols (calculated quantities with units, all in upper case, italicized)*

A—ash, %
FC—fixed carbon, %
FSI—free swelling index
GCV—gross calorific value, Btu/lb
IM—inherent moisture, %
MM—mineral matter, %
S—total sulfur, %
SO_3:*A*—sulfur trioxide in the ash, %
SO_3:*C*—sulfur trioxide in the ash, expressed as a percentage of the coal, %
VM—volatile matter, %

3.3.3 *Complex Quantity Symbols (simple quantity symbols with roman subscripts)*

A_d—ash, dry basis (possibly sulfate-bearing), %
A_{im}—ash, inherent-moisture basis, %
A_{im,SO_3f}—ash, inherent-moisture basis, sulfur-trioxide-free basis, %
FC_d—fixed carbon, dry basis, %
$FC_{d,MMf}$—fixed carbon, dry basis, mineral-matter-free basis, %
FC_{im}—fixed carbon, inherent-moisture basis, %
FC_{im,SO_3f}—fixed carbon, inherent-moisture basis, sulfur-trioxide-free basis, %
GCV_d—gross calorific value, dry basis, Btu/lb
GCV_{im}—gross calorific value, inherent-moisture basis, Btu/lb
$GCV_{im,MMf}$—gross calorific value, inherent-moisture basis, mineral-matter-free basis, Btu/lb
MM_{d,SO_3f}—mineral matter, dry basis, sulfur-trioxide-free basis, %
MM_{im,SO_3f}—mineral matter, inherent-moisture basis, sulfur-trioxide-free basis, %
S_d—total sulfur, dry basis, %
S_{im}—total sulfur, inherent-moisture basis, %
SO_3: A_d—sulfur trioxide in the ash, dry basis, %
SO_3:C_{im}—sulfur trioxide in the ash, expressed as a percentage of the coal, inherent moisture basis, %
VM_d—volatile matter, dry basis, %
$VM_{d,MMf}$—volatile matter, dry basis, mineral-matter-free basis, %
VM_{im}—volatile matter, inherent moisture basis, %

4. Significance and Use

4.1 This classification establishes categories of coal based on gradational properties that depend principally on the degree of metamorphism to which the coal was subjected while buried. These categories indicate ranges of physical and chemical characteristics that are useful in making broad estimates of the behavior of coal in mining, preparation, and use.

5. Basis of Classification

5.1 Classification is according to fixed carbon and gross calorific value (expressed in British thermal units per pound, Btu/lb) calculated to the mineral-matter-free basis. The higher-rank coals are classified according to fixed carbon on the dry basis; the lower-rank coals are classified according to gross calorific value on the moist basis. Agglomerating character is used to differentiate between certain adjacent groups.

6. Classification by Rank

6.1 *Fixed Carbon and Gross Calorific Value*—Coals shall be classified by rank in accordance with Table 1. Classify coals having gross calorific values of 14 000 Btu/lb or more on the inherent-moisture, mineral-matter-free basis, and coals having fixed carbon of 69 % or more on the dry, mineral-matter-free basis, according to fixed carbon on the dry, mineral-matter-free basis. Classify coals having gross calorific values less than 14 000 Btu/lb on the inherent-moisture, mineral-matter-free basis according to gross calorific value on the inherent-moisture, mineral-matter-free basis, provided the fixed carbon on the dry, mineral-matter-free basis is less than 69 %.

6.2 *Agglomerating Character*—Classify coals having 86 % or more fixed carbon on the dry, mineral-matter-free basis, if agglomerating, in the low volatile group of the bituminous class. Classify coals having gross calorific values in the range from 10 500 to 11 500 Btu/lb on the inherent-moisture, mineral-matter-free basis according to their agglomerating character (Table 1).

TABLE 1 Classification of Coals by Rank[A]

Class/Group	$FC_{d,MMf}$ Limits, %		$VM_{d,MMf}$ Limits, %		$GCV_{im,MMf}$ Limits[B]				Agglomerating Character
					Btu/lb		MJ/kg[C]		
	Equal or Greater Than	Less Than	Greater Than	Equal or Less Than	Equal or Greater Than	Less Than	Equal or Greater Than	Less Than	
Anthracitic:									
Meta-anthracite	98	. . .	. . .	2	. . .	. . .	. . .	. . .	non-agglomerating
Anthracite	92	98	2	8	. . .	. . .	. . .	. . .	
Semianthracite[D]	86	92	8	14	. . .	. . .	. . .	. . .	
Bituminous:									
Low volatile bituminous coal	78	86	14	22	. . .	. . .	. . .	. . .	commonly agglomerating[E]
Medium volatile bituminous coal	69	78	22	31	. . .	. . .	. . .	. . .	
High volatile *A* bituminous coal	. . .	69	31	. . .	14 000[F]	. . .	32.557	. . .	
High volatile *B* bituminous coal	. . .	. . .	. . .	. . .	13 000[F]	14 000	30.232	32.557	
High volatile *C* bituminous coal	. . .	. . .	. . .	. . .	11 500	13 000	26.743	30.232	
					10 500	11 500	24.418	26.743	agglomerating
Subbituminous:									
Subbituminous *A* coal	. . .	. . .	. . .	. . .	10 500	11 500	24.418	26.743	non-agglomerating
Subbituminous *B* coal	. . .	. . .	. . .	. . .	9 500	10 500	22.09	24.418	
Subbituminous *C* coal	. . .	. . .	. . .	. . .	8 300	9 500	19.30	22.09	
Lignitic:									
Lignite *A*	. . .	. . .	. . .	. . .	6 300	8 300	14.65	19.30	
Lignite *B*	. . .	. . .	. . .	. . .	. . .	6 300	. . .	14.65	

[A] This classification does not apply to certain coals, as discussed in Section 1.
[B] Refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.
[C] Megajoules per kilogram. To convert British thermal units per pound to megajoules per kilogram, multiply by 0.0023255.
[D] If agglomerating, classify in low volatile group of the bituminous class.
[E] It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and that there are notable exceptions in the high volatile *C* bituminous group.
[F] Coals having 69 % or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of gross calorific value.

6.3 *Supplemental Information*—A correlation of the ranking property, volatile matter (100–fixed carbon), with the mean-maximum reflectance of the vitrinite group macerals in coals tested in one laboratory over a period of several years is shown in Appendix X1.

7. Sampling

7.1 *Samples*—Classify a coal seam, or part of a coal seam, in any locality based on the average analysis and gross calorific value (and agglomerating character where required) of not less than three and preferably five or more whole seam samples, either face channels or cores, taken in different and uniformly distributed localities, either within the same mine or closely adjacent mines representing a continuous and compact area not greater than approximately 10 km^2 (4 square miles) in regions of geological uniformity. In regions in which conditions indicate that the coal probably varies rapidly in short distances, the spacing of sampling points and grouping of analyses to provide average values shall not be such that coals of obviously different rank will be used in calculating average values.

7.1.1 Take channel samples by excluding mineral partings more than 1 cm (⅜ in.) and lenses or concretions (such as sulfur balls) more than 1.25 cm (½ in.) thick and 5 cm (2 in.) wide, as specified in Practice D4596.

7.1.2 A drill core sample may be used provided it was collected as specified in Practice D5192 and meets the following provisions: core recovery is 100 % of the seam, the major mineral partings and concretions are excluded as specified in 7.1.1, and drilling mud is removed from the core (see also 7.1.6).

7.1.3 Place all samples in metal or plastic cans with airtight lids, or heavy vapor impervious bags, properly sealed to preserve inherent moisture.

7.1.4 Analyses of samples from outcrops or from weathered or oxidized coal shall not be used for classification by rank.

7.1.5 In case the coal is likely to be classified on the *moist* basis, that is, inclusive of its natural complement of inherent moisture, take samples in a manner most likely to preserve inherent moisture for purposes of analysis. Because some of the moisture in a freshly collected sample condenses on the inside of the sample container, weigh both the container and the coal before and after air drying, and report the total loss in mass as air-drying loss.

7.1.6 If the sample is a core or if it is impossible to sample the coal without including visible surface moisture, or if there may be other reasons to question the accuracy of inherent moisture content determinable from the sample, and the coal is likely to be classified on the *moist* basis, the sampler shall include the following statement in the description: *Moisture questionable*. Samples so marked shall not be used for classification on a moist basis unless brought to a standard condition of moisture equilibrium at 30 °C in a vacuum desiccator containing a saturated solution of potassium sulfate (97 % humidity) as specified in Test Method D1412. Analyses of such samples that have been treated in this manner shall be designated as *samples equilibrated at 30 °C and 97 % humidity*.

7.2 *Other Types of Samples*—A standard rank determination cannot be made unless samples have been obtained in accordance with 7.1. However, the relation to standard determinations may be usefully given for other types of samples taken under unspecified conditions, providing the same standards of analysis and computation are followed. Designate these comparative indications as *apparent rank,* which indicates the correct relative position for the sample analyzed but does not imply any standards of sampling. Whenever apparent rank is stated, give additional information as to the nature of the sample.

7.2.1 The apparent rank of the coal product from a mine shall be based on representative samples taken in accordance with the Organization and Planning of Sampling Operations section (Section 7) of Practice D2234/D2234M.

7.2.2 In case the coal is likely to be classed on the *moist* basis, take samples at the tipple or preparation plant and seal the sample to prevent loss of moisture.

8. Methods of Analysis and Testing

8.1 *Laboratory Sampling and Analysis*—Prepare coal in accordance with Test Method D2013 and analyze it in accordance with Test Methods D3173, D3174, D3175, D4239, D3302, and Practice D3172. Determine its gross calorific value in accordance with Test Method D5865. Determine the sulfur trioxide (SO_3) retained in the ash in accordance with Test Method D5016 and express the result on a dry basis. Inherent moisture is reported as as-received (AR) moisture if the sample was collected according to 7.1.1 or as equilibrium moisture if 7.1.6 (Test Method D1412) applies.

8.2 Adjust the ash value determined in accordance with Test Method D3174 to be free of sulfur trioxide as follows:[3]

$$A_{\mathrm{im,SO_3f}} = A_d\left(1 - \frac{\mathrm{SO_3{:}}A_\mathrm{d}}{100}\right)\left(1 - \frac{IM}{100}\right) \quad (1)$$

Add to the value of fixed carbon that is determined in accordance with Practice D3172 the value of the SO_3 determined in the ash to obtain the value fixed carbon to be used in Eq 2.

8.3 *Agglomerating Character*—The test carried out by the examination of the residue in the platinum crucible incident to the volatile matter determination shall be used.[4] Coals which, in the volatile matter determination, produce either an agglomerate button that will support a 500 g mass without pulverizing, or a button showing swelling or cell structure, shall be considered agglomerating from the standpoint of classification. In addition, a result of 1.0 or more on the Free Swelling Index test (Test Method D720) may also be used to indicate the coal is agglomerating; a result of 0.5 or 0 indicates the coal is nonagglomerating.

9. Calculation to Mineral-Matter-Free Basis

9.1 *Calculation of Fixed Carbon and Calorific Value*—For classification of coal according to rank, calculate fixed carbon to the dry, mineral-matter-free basis and gross calorific value to the inherent-moisture, mineral-matter-free basis in accordance with the Parr formulas,[4,5] Eq 2-4. Background information concerning the development of the Parr formulas, including explanations of the embedded factors, as well as other ranking considerations and examples of the calculations (Table 1), are provided in Appendix X2.

9.2 Calculate to mineral-matter-free basis as follows:

9.2.1 *Parr Formulas:*

$$FC_{\mathrm{d,MMf}} = \frac{100\left(FC_{\mathrm{im,SO_3f}} - 0.15S_{\mathrm{im}}\right)}{\left(100 - \left(IM + 1.08A_{\mathrm{im,SO_3f}} + 0.55S_{\mathrm{im}}\right)\right)} \quad (2)$$

$$VM_{\mathrm{d,MMf}} = 100 - FC_{\mathrm{d,MMf}} \quad (3)$$

$$GCV_{\mathrm{im,MMf}} = \frac{100\left(GCV_{\mathrm{im}} - 50S_{\mathrm{im}}\right)}{\left(100 - \left(1.08A_{\mathrm{im,SO_3f}} + 0.55S_{\mathrm{im}}\right)\right)} \quad (4)$$

10. Keywords

10.1 anthracite; bituminous; coal; lignite; rank

[3] To perform the calculations in this standard, the percentage values (rather than their decimal equivalent) should be entered in the equations. The result is the value expressed as a percentage (Except for calculations of gross calorific value, which is expressed as Btu/lb). For example, a value of 40 % should be entered into the calculation as "40" and a result of 90 should be expressed as 90 %. The use of the factor "100" allows the conversion to %.

[4] Gilmore, R. E., Connell, G. P., and Nicholls, J. H. H., "Agglomerating and Agglutinating Tests for Classifying Weakly Caking Coals," *Transactions*, American Institute of Mining and Metallurgical Engineers, Coal Division, Vol 108, 1934, p. 255.

[5] Parr, S. W., "The Classification of Coal," *Bulletin No. 180*, Engineering Experiment Station, University of Illinois, 1928.

APPENDIXES

(Nonmandatory Information)

X1. CORRELATION OF VOLATILE MATTER WITH MEAN-MAXIMUM REFLECTANCE OF VITRINITE

X1.1 The reflectance of vitrinite in a sample of coal, as determined by Test Method D2798, provides a useful guide to the rank of the coal. The correlation of the mean-maximum reflectance of all varieties of vitrinite with volatile matter, expressed on a dry and mineral-matter-free basis, is given in Fig. X1.1. Data are plotted for 807 coal samples that contained less than 8 % ash from many different coal fields in North America. All data were determined by a single laboratory, with several different analysts over a period of several years. The plot shows a range of reflectances for three important rank groups:

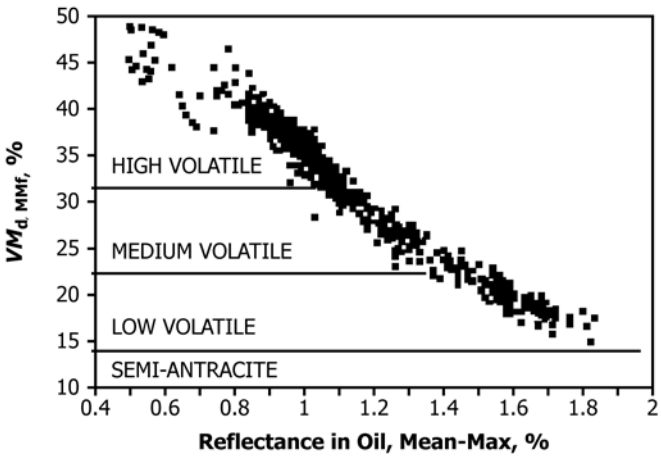

FIG. X1.1 Relation Between the Rank of U.S. Coals and Vitrinite Reflectance

Reflectance Range in Oil, Mean-Max, %	Distribution Midpoints	Rank
<1.15	<1.1	hvb
1.02–1.55	1.10–1.45	mvb
1.35–2.0 (?)	1.45–2.0 (?)	lvb

NOTE X1.1—Coals with the same vitrinite reflectance and similar maceral compositions may have different rheological and fluorescence properties and even burn and carbonize differently. These differences may be due to such diverse factors as their geologic age, environment, or mode of accumulation (time, temperature, and pressure), or a combination thereof, and even differences in the plants that contributed to their formation. Thus, the use of vitrinite reflectance for selecting coals for use may need additional qualifications to predict their utilization potential. This is particularly important in selecting coals for coke production since vitrinites with the same reflectance but different fluorescence properties are known to produce different carbon forms that have different physical (strength) and chemical (reactivity) properties.

X1.2 The midpoints given above are the midpoints of the distribution for the lower and upper boundary points on the reflectance scale for the indicated rank. Of the 807 coals, those that contain greater than a volume fraction of 25 % inertinites tend to plot on the lower side of the distribution range than do the others that contain more vitrinites and liptinites.

X2. BACKGROUND INFORMATION ON THE PARR EQUATIONS AND OTHER RANKING CONSIDERATIONS

X2.1 *Introduction*—Coals are ranked according to Classification D388 on a mineral matter-free, dry or inherent-moisture basis, depending on the parameter that applies. The rank parameters—either volatile matter (or fixed carbon) or gross calorific values—are commonly reported by laboratories on the as-received (AR), dry, and ash-free basis. These reported values must be converted to the mineral-matter-free basis for ranking purposes. Thus converted, the properties of the maceral (carbonaceous) material are used as ranking criteria, and the effects of variable mineral matter contents, which are unrelated to rank, are eliminated. In essence, only the "pure coal" fraction of a given sample is being ranked. The Parr formula is used to estimate the original mineral matter (on the inherent-moisture and sulfur-trioxide-free basis) in the coal by using the ash content (on the inherent-moisture and sulfur-trioxide-free basis) and total sulfur content (on the inherent-moisture basis) determined on that coal as follows:

$$MM_{\mathrm{im,SO_3f}} = 1.08A_{\mathrm{im,SO_3}} + 0.55S_{\mathrm{im}}$$

This formula assumes that clay minerals, with an average water of hydration content of 8 %, and pyrite, which contains essentially all the sulfur, are the only mineral groups present. Furthermore, the following reactions are assumed to occur during ashing: (1) the hydroxyl groups from the clay minerals are lost to the atmosphere; (2) the sulfur converts to sulfur dioxide, which also is lost; and (3) pyrite decomposes to iron oxide and iron is retained in the ash. The Parr formula attempts to correct the measured ash and sulfur for these reactions by adjusting their mass back to that of the original minerals in the coal. By using this formula, the varying amounts of mineral matter can be factored out of the ranking of coals. For example, Samples A and B in Table X2.1 are both ranked as Lignite A because they have similar gross calorific values, when calculated to an inherent-moisture, mineral-matter-free basis, in contrast to their gross calorific values, which are quite different on an as-received (AR) basis. In this example, differing mineral contents are thus factored out for the purposes of ranking.

TABLE X2.1 Example Calculations of Coal Rank According to Classification D388[A]

	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F
As-Received (AR) Basis[B]						
IM, %	34.79	32.45	14.94	9.85	9.20	1.88
A_{im}, %	5.65	11.93	7.57	6.00	7.54	11.86
VM_{im}, %	30.32	28.07	33.89	32.81	31.69	25.27
FC_{im}, %	29.24	27.55	43.60	51.34	51.57	60.99
S_{im}, %	0.71	1.15	0.66	3.07	1.14	0.33
GCV_{im}, Btu/lb	7676	7093	10 178	10 178	12 077	13 045
Dry Basis						
A_d, %	8.66	17.66	8.90	6.66	8.30	12.09
VM_d, %	46.50	41.55	39.84	36.39	34.90	25.75
FC_d, %	44.84	40.78	51.26	56.95	56.80	62.16
S_d, %	1.09	1.70	0.78	3.41	1.26	0.34
GCV_d, Btu/lb	11 771	10 500	11 966	11 290	13 301	13 295
Other Results						
FSI	0	0	0	2	4	2.5
SO_3 : A_d, %	11.00	10.57	9.75	2.17	2.18	2.27
SO_3: C_{im}, %[C]	0.62	1.26	0.74	0.13	0.16	0.27
$A_{im,SO_3}f$, %[D]	5.03	10.67	6.83	5.87	7.38	11.59
$MM_{im,SO_3}f$, %	5.82	12.16	7.74	8.03	8.59	12.70
$FC_{im,SO_3}f$, %	29.86	28.81	44.34	51.47	51.73	61.26
Rank Determining Values[E]						
$GCV_{im,MMf}$, Btu/lb	8113	8009	10 996	10 899	13 150	14 924
$VM_{d,MMf}$, %	49.90	48.30	42.78	37.89	37.28	28.34
$FC_{d,MMf}$, %	50.10	51.70	57.22	62.11	62.72	71.66
Agglomerating character	Non.	Non.	Non.	Aggl.	Aggl.	Aggl.
Rank (Classification D388)	lig A	lig A	sub A	hvCb	hvBb	mvb

[A] Footnote. [6]
[B] The as-received (AR) basis is equivalent to the inherent-moisture-containing basis only for samples collected and preserved as described in Section 7. For samples not meeting those criteria, data should be adjusted from the as-received (AR) basis to the inherent-moisture-containing basis.
[C] SO_3:C_{im} is an artificial construct needed to adjust the FC_{im} to be free of SO_3 (FC_{im,SO_3f}). There is no actual SO_3 in coal.
[D] Values corrected to sulfur-trioxide-free ash basis per Classification D388, Section 8.2. These adjusted parameters are used to calculate rank-determining values.
[E] Parameters used for ranking each sample using Classification D388, Table 1 are shown in bold type. The other values are shown for informational and comparison purposes only.

Section X2.3 provides useful equations that enable the ranking parameters to be calculated from laboratory results on the dry basis for volatile matter, ash, and sulfur.

X2.2 *Explanation of Analytical Bases for Ranking Properties:*

X2.2.1 *Dry, Mineral-Matter-Free Basis*—The basis to which chemical properties are to be calculated for samples of coal of ranks medium volatile bituminous and higher. Mineral matter (noncoal) in North American coals is best approximated by the Parr formula[4,5]

$$MM_{d,SO_3f} = A_d + \left(\frac{5}{8}\right) S_d + 0.08\left(A_d - \left(\frac{10}{8}\right) S_d\right) \quad (X2.1)$$

Quoting Parr[4,5] (except for the subscript$_d$ and parentheses around the fractions, added for clarity):

> "(5/8)S_d restores the Fe_2O_3 as weighed in the ash to FeS_2, as weighed in the coal, 3 oxygens or 48 in the ash having been originally 4 sulfurs or 128 in the coal;
> (10/8)S_d represents the equivalent of Fe_2O_3 as weighed in the ash, that is, the Fe_2O_3 molecule, 160, is 10/8 of the sulfur present in the coal;
> (A_d – (10/8)S_d) is the ash as weighed minus the Fe_2O_3;
> 0.08 is a constant applied to the iron free ash to restore the water of hydration to the earthy matter less iron pyrites, thus representing the true amount of earthy constituent as weighed in the original coal."

The above reduces to: $MM_{d,SO_3f} = 1.08A_d + 0.525S_d$

and simplifies to: $MM_{d,SO_3f} = 1.08A_d + 0.55S_d$

where the coefficient of sulfur is arbitrarily adjusted up by the value 0.025 (to give results that do not statistically differ from those of other proposed formulas).[6]

X2.2.2 *Inherent Moisture, Mineral-Matter-Free Basis*—The basis to which calorific value is calculated for determining coal rank for samples of coal of ranks high volatile *A* bituminous and lower.[6] This is the mineral-matter-free, inherent-moisture basis, which is equivalent to the as-received (AR) basis for samples collected and preserved as described in 7. In Eq 4, the calorific value is corrected for the estimated heat of combustion of pyrite (–50*S*), expressed as units of (Btu/lb)/% sulfur, and then calculated to the inherent-moisture, mineral-matter-free basis by the factor (100 – MM_{im,SO_3f}), equivalent to (100 – (1.08A_{im,SO_3f} + 0.55S_{im})). All data are on the inherent-moisture basis.

X2.3 Useful Equations—The ranking equation (Eq 3 of 9.2.1) can be simplified for cases when data are available on the dry basis: ash, volatile matter, sulfur, and the sulfur trioxide content of the ash.[7] In such cases, Eq 3 of 9.2.1 can be expressed so as to yield the ranking parameter directly, the

[6] Fieldner, A. C., Selvig, W. A., and Gibson, F. H., "Application of Ash Corrections to Analyses of Various Coals," *Transactions*, American Institute of Mining and Metallurgical Engineers, Coal Division, Vol 101, 1932, pp. 223–246.
[7] Hoeft, A. P., Harvey, R. D., and Luppens, J. A., "Notes on the Determination of ASTM Coal Rank," *Journal of Coal Quality*, Vol 12, No. 1, 1993, pp. 8–13.

volatile matter on the dry, mineral-matter-free basis:

$$VM_{dMMf} = \frac{VM_d - 0.08A_d\left(1 - \frac{SO_3{:}A_d}{100}\right) - 0.4S_d}{1 - 0.0108A_d\left(1 - \frac{SO_3{:}A_d}{100}\right) - 0.0055S_d} \quad \text{(X2.2)}$$

For a coal of rank high volatile *A* bituminous or lower and for which the inherent moisture (or equivalent as-received moisture) and dry values for gross calorific value, and the ash and sulfur contents are given, the ranking equation (Eq 4, 9.2.1) gross calorific value on the inherent-moisture, mineral-matter-free basis is equivalent to:

$$GCV_{im,MMf} = \frac{100(GCV_d - 50S_d)}{100\left(\frac{100}{100 - IM}\right) - 1.08A_d\left(1 - \frac{SO_3{:}A_d}{100}\right) - 0.55S_d} \quad \text{(X2.3)}$$

Table X2.1 provides helpful example calculations for samples with widely different ranks to demonstrate some of the important considerations for classifying coals. These examples also demonstrate the effects of the correction factor for sulfur retained in the ash during the ashing process per 8.2 and its importance to rank determination.

Samples A and B are both ranked as Lignite A because they have similar gross calorific values when calculated to an inherent-moisture, mineral-matter-free basis, in contrast to their quite different gross calorific values, when calculated on an as-received (AR) basis. In this example, differing mineral contents are thus factored out for the purposes of ranking.

Samples C and D have essentially the same gross calorific value on an inherent-moisture, mineral-matter-free basis, but are not ranked the same because of their differing agglomerating properties. An important, but sometimes unclear consideration with higher rank coals is their agglomerating character. Since 1934, the agglomerating character of the sample has been used to distinguish subbituminous A from high volatile C bituminous coals. It was recognized that the calorific value of the two ranks overlapped. In earlier versions of the standard, "examination of the residue in the platinum crucibles incident to the volatile matter determination..." was the required procedure to determine agglomerating character. These versions go on to read "Coals which, the volatile matter determination, produce either an agglomerate button that will support a 500-g weight without pulverizing, or a button showing swelling or cell structure, shall be considered agglomerating... ." However, for over 25 years, the standard test for the Free-Swelling Index (Test Method D720) has included the provision to test the pulverizing nature of the button under a "500-g weight." It has been the practice for many years to use the results of the Free-Swelling test to determine the agglomerating character of a coal as outlined in 8.3 of this standard.

Sample F demonstrates the need to use fixed carbon and volatile matter contents (on a dry, mineral-matter-free basis) since the fixed carbon exceeds 69 % irrespective of the gross calorific value on an inherent-moisture, mineral-matter-free basis. In Samples E and F, gross calorific values on a dry, mineral-free basis are very similar, but, because Sample F contains greater than 69 % fixed carbon on a dry, mineral-matter-free basis, these two samples are not given the same rank. Sample E is a high volatile B bituminous coal and Sample F is ranked as a medium volatile bituminous coal.