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## Standard Test Method for Calculating Refuse-Derived Fuel Analysis Data from As- Determined to Different Bases<sup>1</sup>

This standard is issued under the fixed designation E 791; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

### 1. Scope

1.1 This test method gives equations to enable analytical data from the application of RDF analyses procedures to be expressed on various different bases in common use. Such bases are: as-received; dry; dry, ash-free; and others (see 2.1.12).

1.2 *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.*

### 2. Terminology

#### 2.1 Definitions of Terms Specific to This Standard:

2.1.1 *ash*—inorganic residue remaining after ignition of combustible substances, determined by definite prescribed methods. Ash may not be identical, in composition or quantity, with the inorganic substances present in the material before ignition.

2.1.2 *as-determined basis*—experimental data obtained from the analysis sample of RDF. These data represent the numerical values obtained for a particular moisture or ash content, or both, in the sample at the time of measurement.

2.1.3 *air drying*—a process of partial drying of RDF to bring its moisture content near to equilibrium with the atmosphere in which further reduction, division, and characterization of the sample are to take place. In order to bring about this equilibrium, the RDF is usually subjected to drying under controlled temperature conditions ranging from 30 to 40°C.

2.1.4 *air dry loss*—the decrease in mass presumed to be moisture of a sample due to air drying.

2.1.5 *as-received basis*—experimental data calculated to the moisture condition of the sample as it arrived in the laboratory and before any laboratory processing or conditioning. The total moisture value that is calculated from the air dry loss and residual moisture value is used to convert data from the dry basis to the as-received basis (see *dry ash-free basis*).

2.1.6 *dry ash-free basis*—the experimental data calculated to a theoretical base of no moisture or ash associated with the sample. Numerical values (air-dry loss, residual moisture values, and ash content) are used for converting the as-determined data to a moisture and ash-free basis.

2.1.7 *dry basis*—the experimental data calculated to a theoretical base of no moisture associated with the sample. The numerical value (residual moisture value) is used for converting the as-determined data to a dry basis.

2.1.8 *fixed carbon*—the ash-free carbonous material that remains after volatile matter is driven off during the proximate analysis of a dry sample.

2.1.9 *gross calorific value* (gross heat of combustion at constant volume)  $Q_v$  (gross)—the heat produced by combustion of a unit quantity of solid fuel, at constant volume, in an oxygen bomb calorimeter under specified conditions such that all water in the products remains in liquid form.

NOTE 1—The conditions are: initial oxygen pressure of 20 to 40 atm (2 to 4 MPa), initial and final temperatures between 68 and 95°F (20 and 35°C).

NOTE 2—The gross calorific value is closely related to the internal energy of combustion for the same reaction at constant standard temperature and pressure ( $\Delta v$  comb.). It is of opposite sign and differs by a small amount due to energy effects resulting from compression, temperature differences, and solution effects that vary with combustion conditions. Because of the variation of conditions allowed in Note 1, the definition of gross calorific value does not lead to a unique value for any given fuel. However, the specified conditions limit the possible value to a narrow range for which approximate limits can be calculated for a given fuel.

2.1.10 *higher heating value*—synonym for *gross calorific value*.

2.1.11 *proximate analysis*—the determination, by prescribed methods, of moisture, volatile matter, fixed carbon (by difference), and ash. Unless otherwise specified, the term proximate analysis does not include determinations of chemical elements or any determinations other than those named.

2.1.12 *refuse-derived fuels*—solid forms of refuse-derived fuels from which appropriate analytical samples may be prepared are defined as follows in *ASTM STP 832*:<sup>2</sup>

RDF-1—Wastes used as a fuel in as-discarded form with only bulky wastes removed.

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee D34 on Waste Management and is the direct responsibility of Subcommittee D34.06 on Recovery and Reuse.

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<sup>2</sup> *Thesaurus on Resource Recovery Terminology, ASTM STP 832, ASTM, 1983, p. 72.*

RDF-2—Wastes processed to coarse particle size with or without ferrous separation.

RDF-3—Combustible waste fraction reduced to particle sizes, 95 % passing 2 in. square screening.

RDF-4—Combustible waste fraction processed into powder form, 95 % passing 10-mesh screening.

RDF-5—Combustible waste fraction densified (compressed) into the form of pellets, slugs, cubettes, or briquettes.

2.1.13 *residual moisture*—the moisture content remaining in an RDF sample after it has been milled down to an analysis sample. Prior to milling, the RDF sample should have been subjected to either a total moisture determination (single stage), or an air drying procedure.

2.1.14 *total moisture*—the weight loss resulting from drying a sample to constant weight in an oven usually maintained between 103 and 107°C.

2.1.15 *ultimate analysis*—the determination of the percentages of carbon, hydrogen, sulfur, nitrogen, chlorine, ash, and oxygen in a dry sample. The percentage of oxygen may be obtained by calculating the difference between 100 % and the other determined elemental analyses.

2.1.16 *volatile matter*—those products, exclusive of moisture, given off by a material as gas or vapor, determined by definite prescribed methods which may vary according to the nature of the material.

2.2 *Symbols: Symbols:*

2.2.1 The symbols used in this test method are as follows:

- $M$  = moisture, weight %,
- $M_{ar}$  = moisture as-received (total moisture), weight %,
- $M_{ad}$  = moisture as-determined (residual moisture, weight %,
- $ADL$  = air-dry loss, weight %,
- $P$  = any analysis parameter listed in 4.1, weight % (except gross calorific value in Btu/lb),
- $H$  = hydroxygen, weight %,
- $O$  = oxygen, weight %, and
- $A$  = ash, weight %.

2.2.2 Subscripts used in this test method are as follows:

- $_{ad}$  = as-determined,
- $_{ar}$  = as-received,
- $_d$  = dry, and
- $_{daf}$  = dry, ash-free (equivalent to moisture and ash-free, maf).

**3. Significance and Use**

3.1 This test method is available to producers and users of RDF to use in converting laboratory data from one basis to another.

**4. Applicable Parameters**

4.1 The calculation procedures defined in 6.1.3, 6.2.2, and 6.3.2 are applicable to the following analysis parameters when expressed as a weight percent (except gross calorific value as Btu/lb).

- 4.1.1 Ash,
- 4.1.2 Carbon,

- 4.1.3 Chloride, water-soluble,
- 4.1.4 Chlorine, total,
- 4.1.5 Calorific value (gross),
- 4.1.6 Fixed carbon,
- 4.1.7 Nitrogen,
- 4.1.8 Sulfur, and
- 4.1.9 Volatile matter.

**5. Sampling**

5.1 Sampling techniques are not directly applicable to this test method. However, sampling procedures are identified in the respective methods of analyses.

**6. Methods for Calculating Data**

6.1 Converting from the as-determined analysis sample basis to the as-received basis:

6.1.1 *Moisture:*

$$M_{ar} = [M_{ad} \times (100 - ADL)/100] + ADL \quad (1)$$

6.1.2 *Hydrogen and Oxygen*—Inasmuch as hydrogen and oxygen values may be reported on the basis of containing or not containing the hydrogen and oxygen in water (moisture) associated with the sample, alternate conversion procedures are defined as follows:

6.1.2.1 Hydrogen and oxygen reported include hydrogen and oxygen in water:

$$H_{ar} = \left[ (H_{ad} - 0.1119 M_{ad}) \times \frac{100 - M_{ar}}{100 - M_{ad}} \right] + 0.119 M_{ar} \quad (2)$$

$$O_{ar} = \left[ (O_{ad} - 0.8881 M_{ad}) \times \frac{100 - M_{ar}}{100 - M_{ad}} \right] + 0.881 M_{ar} \quad (3)$$

where:

- 0.1119 = ratio of the weight of hydrogen in water to the molecular weight of water, and
- 0.8881 = ratio of the weight of oxygen in water to the molecular weight of water.

6.1.2.2 Hydrogen and oxygen reported do not include hydrogen and oxygen in water:

$$H_{ar} = (H_{ad} - 0.1119 M_{ad}) \times \frac{100 - M_{ar}}{100 - M_{ad}} \quad (4)$$

$$O_{ar} = (O_{ad} - 0.881 M_{ad}) \times \frac{100 - M_{ar}}{100 - M_{ad}} \quad (5)$$

6.1.3 *Other Parameters*—The following equation is applicable to all parameters,  $P$ , listed in 4.1:

$$P_{ar} = P_{ad} \times \frac{100 - M_{ar}}{100 - M_{ad}} \quad (6)$$

6.2 Converting from the as-determined analysis sample basis to the dry basis:

6.2.1 *Hydrogen and Oxygen:*

$$H_d = (H_{ad} - 0.1119 M_{ad}) \times \frac{100}{100 - M_{ad}} \quad (7)$$

$$O_d = (O_{ad} - 0.881 M_{ad}) \times \frac{100}{100 - M_{ad}} \quad (8)$$



6.2.2 *Other Parameters*—The following equation is applicable to all parameters,  $P$ , listed in 4.1:

$$P_d = P_{ad} \times 100 / (100 - M_{ad}) \quad (9)$$

6.3 Converting from the as-determined analysis sample basis to the dry, ash-free basis (see Note Note 3).

6.3.1 *Hydrogen and Oxygen*:

$$H_{daf} = (H_{ad} - 0.1119 M_{ad}) \times \frac{100}{100 - M_{ad} - A_{ad}} \quad (10)$$

$$O_{daf} = (O_{ad} - 0.8881 M_{ad}) \times \frac{100}{100 - M_{ad} - A_{ad}} \quad (11)$$

6.3.2 *Other Parameters*—The following equation is applicable to all parameters,  $P$ , listed in 4.1:

$$P_{daf} = P_{ad} \times \frac{100}{100 - M_{ad} - A_{ad}} \quad (12)$$

NOTE 3—It may not always be practical to report some parameters on a dry, ash-free basis due to oxidation of constituents as well as some elements being retained in the ash. The data calculated are to a theoretical base of no moisture or ash present in the sample.

**7. Conversion Chart**

7.1 To convert any of the analysis values for the parameters listed in 4.1 from one basis to another, multiply the given value by the value shown in the appropriate column in Table 1.

7.2 Hydrogen and oxygen on the as-determined basis include hydrogen and oxygen in free water (moisture) associated with the analysis sample. However, hydrogen and oxygen values reported on other moisture-containing bases may be reported either as containing or not containing the hydrogen and oxygen in water (moisture) reported on that basis. Conversion procedures are shown in Table 2.

**8. Sample Calculations**

8.1 An example of analysis data tabulated for a hypothetical RDF on various bases is shown in Table 3.

**9. Reporting of Results**

9.1 Report the results of the proximate and ultimate analysis based on the example shown in Table 3.

9.2 To avoid ambiguity and to provide a means for conversion of data to other than the reported basis, it is essential that an appropriate moisture and ash content be given in the data report.

9.3 If hydrogen or oxygen data, or both, are reported on an as-received basis (or any other moisture basis), a footnote or some other means shall be employed in the report to indicate whether the values reported do or do not include hydrogen and oxygen in the moisture associated with the sample.

**TABLE 1 Conversion Chart**

NOTE 1— To convert any of analyses values for the parameters listed in 4.1 from one basis to another, multiply the given value by the value shown in the appropriate column.

To convert from	Conversion Factor				
	Multiply by	As-Determined (ad)	As-Received (ar)	Dry (d)	Dry, Ash-Free (daf)
As-determined (ad)	...	...	$\frac{100 - M_{ar}}{100 - M_{ad}}$	$\frac{100}{100 - M_{ad}}$	$\frac{100}{100 - (M_{ad} - A_{ad})}$
As-received (ar)	$\frac{100 - M_{ad}}{100 - M_{ar}}$	...	...	$\frac{100}{100 - M_{ar}}$	$\frac{100}{100 - (M_{ar} - A_{ar})}$
Dry (d)	$\frac{100 - M_{ad}}{100}$	$\frac{100 - M_{ar}}{100}$	...	...	$\frac{100}{100 - A_d}$
Dry, ash-free (daf)	$\frac{100 - (M_{ad} - A_{ad})}{100}$	$\frac{100 - (M_{ar} - A_{ar})}{100}$	$\frac{100 - A_d}{100}$	...	...



**TABLE 2 Procedures for Converting As-Determined Values to Other Bases**

Parameter	As-Determined	As Received		Dry Basis	Dry, Ash-Free Basis
		$H_{ar}$ and $O_{ar}$ include $H$ and $O$ in $M_{ar}$	$H_{ar}$ and $O_{ar}$ do not include $H$ and $O$ in $M_{ar}$		
$P$ (ash, carbon, nitrogen, sulfur, chlorine)	no corrections (see standard method)	$P_{ar} = P_{ad} \times \left( \frac{100 - M_{ar}}{100 - M_{ad}} \right)$	...	$P_d = P_{ad} \times \left( \frac{100}{100 - M_{ad}} \right)$	$P_{daf} = P_{ad} \times \left( \frac{100}{100 - M_{ad} - A_{ad}} \right)$
$H$ (hydrogen)	no corrections (see standard method)	$H_{ar} = \left[ (H_{ad} - 0.1119 M_{ad}) \times \left( \frac{100 - M_{ar}}{100 - M_{ad}} \right) + 0.1119 M_{ar} \right]$	$H_{ar} = (H_{ad} - 0.1119 M_{ad}) \times \left( \frac{100 - M_{ar}}{100 - M_{ad}} \right)$	$H_d = (H_{ad} - 0.1119 M_{ad}) \times \left( \frac{100}{100 - M_{ad}} \right)$	$H_{daf} = (H_{ad} - 0.1119 M_{ad}) \times \left( \frac{100}{100 - M_{ad} - A_{ad}} \right)$
$O$ (oxygen)	$O_{ad} = 100 - (A_{ad} + C_{ad} + H_{ad} + N_{ad} + S_{ad} + Cl_{ad})$	$O_{ar} = \left[ (O_{ad} - 0.8881 M_{ad}) \times \left( \frac{100 - M_{ar}}{100 - M_{ad}} \right) + 0.8881 M_{ar} \right]$	$O_{ar} = (O_{ad} - 0.8881 M_{ad}) \times \left( \frac{100 - M_{ar}}{100 - M_{ad}} \right)$	$O_d = (O_{ad} - 0.8881 M_{ad}) \times \left( \frac{100}{100 - M_{ad}} \right)$ or $O_d = 100 - (A_d + C_d + H_d + N_d + S_d + Cl_d)$	$O_{daf} = (O_{ad} - 0.8881 M_{ad}) \times \left( \frac{100}{100 - M_{ad} - A_{ad}} \right)$

**TABLE 3 Standard Reporting Form Analyses Data of RDF**

	As-Determined	As-Received		Dry Basis	Dry, Ash-Free Basis
		$H_{ar}$ and $O_{ar}$ include $H$ and $O$ in sample $M_{ar}$	$H_{ar}$ and $O_{ar}$ do not include $H$ and $O$ in sample $M_{ar}$		
Air dry loss, %	18.69	...	...	...	...
Residual moisture ( $M_{ad}$ ), %	2.15	...	...	...	...
Total moisture ( $M_{ar}$ ), %	...	20.44	20.44	...	...
Ash, %	20.68	16.82	16.82	21.14	...
Volatile matter, %	62.29	50.65	50.65	63.66	80.73
Fixed carbon, %	14.88	12.09	12.09	15.20	19.27
Total, proximate	100.00	100.00	100.00	100.00	100.00
Total, moisture, %	...	...	20.44	...	...
Ash, %	20.68	16.82	16.82	21.14	...
Carbon, %	39.66	32.25	32.25	40.53	51.40
Hydrogen, %	5.12	6.25	3.97	4.99	6.32
Nitrogen, %0.60	0.60	0.49	0.49	0.61	0.78
Chlorine, %	0.30	0.24	0.24	0.31	0.39
Sulfur, %0.15	0.15	0.12	0.12	0.15	0.19
Oxygen, %	33.49	43.83	25.68	32.28	40.93
Total, ultimate	100.00	100.00	100.00	100.00	100.00
Gross heating value, Btu/lb	6868	5584	5584	7019	8900
Chloride, water soluble, %	0.19	0.15	0.15	0.19	0.25

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