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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Practice for Calculating Formulation Physical Constants of Paints and Coatings[1]

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1. Scope

1.1 This practice describes procedures for calculating weight solids, volume solids, solvent content, and density of liquid paints and coatings based on formulation data (not from analytical determinations). These calculations may be related to either as-supplied (unreduced) or as-applied (reduced) coating materials, including multicomponent types.

1.2 These values may not be acceptable for regulatory purposes.

1.3 Calculated values for these physical constants are used in the coatings industry for developing lower volatile organic compound (VOC) paints, making comparisons, etc.

1.4 The calculations described in this practice are based on the following assumptions: (1) Solids (nonvolatile) content and density of the individual ingredients (raw materials or intermediates, or both) have been established by appropriate analytical methods (see Test Methods D 153, D 1475, D 2369, D 4758, and Guide D 2832), and (2) The blended formulation behaves as an *ideal* solution with no volume change on mixing (see 6.2).

1.5 In calculations involving the liquids in a formulation, those volatile liquids that are incorporated primarily for vehicle solvency and control of the application characteristics should be classified as *solvents*. This would include solvents normally used to adjust viscosity for application and appearance of the coating. Liquids that are expected to be retained in the dried film to affect the final performance properties should be classified as part of the coating solids.

NOTE 1—For regulatory VOC purposes, use EPA Reference Method 24and ASTM standards listed, or state regulatory requirements (see EPA 450/3-88-018 and Federal Register 40 CFR 51.100).

1.6 Volatile by-products of cross-linking reactions (cure volatiles) are not considered in these calculations since the object of this practice is to define paint physical constants based on formulation information.

1.7 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

[1] This practice is under the jurisdiction of ASTM Committee D-1 on Paint and Related Coatings, Materials, and Applications and is the direct responsibility of Subcommittee D01.24 on Physical Properties of Liquid Paints and Paint Materials.

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2. Referenced Documents

2.1 *ASTM Standards:*

D 153 Test Methods for Specific Gravity of Pigments[2]

D 1475 Test Method For Density of Liquid Coatings, Inks, and Related Products[3]

D 2369 Test Methods for Volatile Content of Coatings[3]

D 2832 Guide for Determining Volatile and Nonvolatile Content of Paint and Related Coatings[3]

D 3960 Practice for Determining Volatile Organic Compound (VOC) Content of Paints and Related Coatings[3]

D 4758 Test Method for Nonvolatile Content of Latexes[2]

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications[4]

2.2 *U. S. Environmental Protection Agency Standards:*

EPA 450/3-88-018, U.S. Environmental Protection Agency Protocol for Determining the Daily Volatile Organic Compound Emission Rate of Automobile and Light Duty Truck Topcoat Operations[5]

EPA Federal Reference Method 24 —Determination of Volatile Matter Content, Water Content, Density Volume Solids, and Weight Solids, of Surface Coatings[6]

Federal Register 40 CFR 51·100 (par·s) Def. of VOC and "Exempt Compounds"[6]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *formula density*—(see Test Method D 1475), the mass (weight in vacuum) of a unit volume of material at any given temperature.

3.1.1.1 *Discussion*—In this practice, density is expressed in pounds per U.S. gallon (lb/gal) since this is commonly used in the coatings industry. Where dry materials are concerned, actual density (not bulk density) should be determined analytically or obtained from supplier information. Use Test Methods D 153 where applicable.

[2] *Annual Book of ASTM Standards*, Vol 06.03.

[3] *Annual Book of ASTM Standards*, Vol 06.01.

[4] *Annual Book of ASTM Standards*, Vol 14.02.

[5] Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. Refer to EPA 450/3-88-018 dated December 1988. This protocol makes reference to the paint formulation physical constants for VOC and volume solids content.

[6] Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

3.1.2 *formula percent volume solids content*—the calculated volume of nonvolatile material in a formula divided by the total volume of the paint material, times 100 %.

3.1.3 *formula percent weight solids content*—the calculated weight of nonvolatile material in a formula divided by the total weight of the coating material, times 100 %.

3.1.4 *formula solvent content*—the calculated weight of the solvents in a specific volume of paint (such as pounds of solvent per gallon of paint) based on formulation, which is determined by totalling all solvents present.

3.1.5 *Discussion*—Volatile by-products of cross-linking reactions (cure volatiles) are *not* included in the formula solvent content. See Note 1 and applicable government regulations for definition of the term VOC.

3.1.5.1 *Discussion*—Some government regulations may require that water be excluded when considering formula solvent content.

3.1.6 *formula solvent density*—the calculated density of the combined solvent composition.

3.1.7 *formula VOC content*—calculated amount based upon total formula solvent content, (such as pounds of solvent per gallon of paint) exclusive of water or solvents that are exempted by government regulations. This is a theoretical value.

3.1.7.1 *Discussion*—Solvent and VOC are not equivalent terms. See the EPA current definition of volatile organic compound (VOC) and description of compounds that are exempt. Ammonia and water are exempt by definition as they are not organic compounds.

4. Significance and Use

4.1 Physical constants of paints and coatings are required in all aspects of their formulation, manufacture and use. This practice demonstrates standard methods agreed upon for calculating formulation values for some of these physical constants. The calculations are the same for either metric or inch/pound units.

4.2 These formula values may not be used to replace measured values required by government regulations unless specifically stated in the governing documents.

5. Calculations

5.1 Calculated values should be rounded to the appropriate number of significant digits in accordance with Practice E 29 at 7.

5.2 *Formula Density (weight per unit volume)*:

5.2.1 The formula density (D_f) can be calculated from the total weight (W_f) and total volume (V_f) of the formulation. The formulation volume can be calculated from the weight and density of each ingredient as given by the following equation:

$$D_f = \frac{W_f}{V_f} = \frac{W_1 + W_2 + \ldots W_n}{W_1/D_1 + W_2/D_2 + \ldots W_n/D_n} = \frac{\Sigma W_i}{\Sigma W_i/D_i} \quad (1)$$

where:

n = number of items in the formulation,
D_f = formula density, lb/gal (g/L),
W_f = total weight of formula, lb (g),
V_f = total volume of formula, gal (L),
W_i = weight of ingredient, lb (g), and
D_i = density of ingredient.

5.2.1.1 An example would be as follows:

Ingredient	Weight W, (lb)	Density D, (lb/gal)	Volume V, (gal)
1	81.50	7.74	10.530
2	6.10	7.90	0.772
3	0.40	8.72	0.046
4	12.00	7.65	1.569
Formula	100.00	D_f	12.917

Therefore, formula density, $D_f = \frac{100}{12.917} = 7.74$ lb/gal.

5.2.2 The density of any one of the ingredients in a product can be calculated as long as the density of the paint formulation and the other ingredients in that formulation are known ($D = W/V$), as in the following example:

Ingredient	Weight W, (lb)	Density D, (lb/gal)	Volume V, (gal)
Polymer solids	50.00	D_{ps}	V_{ps}
Solvent A	25.00	6.95	3.60
Solvent B	25.00	7.18	3.48
Formula	100.00	7.50	V_f

where:

V_f = volume of total formula, gal $= \frac{100.00}{7.50} = 13.3$ gal,
V_{ps} = volume of polymer solids, gal = 13.33 − (3.60 + 3.48) = 6.25 gal, and
D_{ps} = density of polymer solids, lb/gal $= \frac{50.00}{6.25} = 8.00$ lb/gal.

5.3 *Formula Solvent (Volatile) Density*:

5.3.1 The density of the solvent (volatile) portion can be calculated using the following equation:

$$D_s = \frac{V_1D_1 + V_2D_2 + V_3D_3 + \ldots V_nD_n}{V_1 + V_2 + V_3 + \ldots V_n} = \frac{\Sigma V_iD_i}{\Sigma V_i} \quad (2)$$

where:

D_s = density of solid formula, lb/gal (g/L),
V_i = volume of solvent, gal (L),
D_i = density of solvent, lb/gal (g/L), and
n = number of items in the formulation.

5.4 *Formula Weight Percent Solids (Nonvolatile)*:

5.4.1 Calculate percent of solids by weight as follows:

$$S_w = \frac{\text{weight of solids}}{\text{total weight of coating}} \times 100 \quad (3)$$

where S_w = weight percent of solids (nonvolatile), %.

5.5 *Formula Volume Percent Solids (Nonvolatile)*:

5.5.1 Calculate percent of solids by volume using *either* of the following equations depending on available information:

$$S_v = \frac{\text{volume of solids}}{\text{total volume of paint}} \times 100 \quad (4)$$

where S_v = volume percent of solids (nonvolatile), %.

or,

5.5.1.1 Generally the volume solids content is calculated by subtracting the volume of all solvent from the total volume since the volume of the solvent portion is usually more readily available than the volume of solid materials

$$S_v = \frac{\text{total volume of paint} - \text{volume of solvents}}{\text{total volume of paint}} \times 100 \quad (5)$$

where S_v = total volume percent of paint minus volume of solids.

5.5.2 When the volume solids of each ingredient in a formulation is known, the volume solids of the formulation can be calculated.

5.5.2.1 The volume (V_i) of each ingredient is calculated from the formula weight (W_i) of each ingredient divided by its density (D_i).

$$V_i = W_i/D_i \quad (6)$$

5.5.2.2 Total volume of the formula is determined by the sum of the volumes of the individual ingredients

$$V_f = \Sigma V_i \quad (7)$$

5.5.2.3 Formula volume solids (S_{vf}) is calculated in the following manner. The volume of each ingredient (V_i) is multiplied by the volume percent solids of that ingredient (S_{vi}) and the sum of these volume solids is divided by the total volume of the formula to give formula volume solids. This is shown symbolically as follows:

$$S_{vf} = \frac{\Sigma(S_{vi} \times V_i)}{V_f} \quad (8)$$

5.5.2.4 An example would be as follows:

Ingredient	Weight W, (lb)	Density D, (lb/gal)	Total Volume	Volume Solids, %	Volume of Solids
1	7.35	8.00	0.92	31.0	0.29
2	22.41	7.96	2.82	21.5	0.61
3	52.85	8.24	6.41	23.8	1.53
4	5.98	7.16	0.84	0.0	...
5	6.13	9.27	0.66	100.00	0.66
6	0.28	7.17	0.04	0.0	...
7	5.00	8.14	0.61	33.6	0.20
	100.00		12.30		3.29

$$V_s, \% = \frac{\text{volume of solids, gal}}{\text{total volume, gal}} \times 100 \quad (9)$$

$$= \frac{3.29}{12.30} \times 100 = 26.7\ \%$$

5.6 *Formula Total Solvent Content and VOC Content (see section 3.6)*:

5.6.1 If all of the solvent in the formulation is considered to be VOC for regulatory purposes, the VOC content may be expressed as pounds of VOC per gallon (grams per litre) of paint material, calculated as follows:

VOC (lb/gal),

$$= \frac{(100 - \text{weight \% solids}) \times \text{density of coating}}{100} \quad (10)$$

5.6.2 If water is present in the paint material formulation, it must be subtracted from the total volatile portion in determining the formulation VOC content.

VOC (lbs/gal) (less water)

$$= \frac{\text{weight of volatiles} - \text{weight of water}}{\text{volume of paint} - \text{volume of water}} \quad (11)$$

or,

$$= \frac{(100 - \text{weight percent of solids} - \text{weight percent of water})\ \text{formula density}}{100 - \dfrac{(\text{weight percent of water})\ \text{formula density}}{\text{water density}}} \quad (12)$$

where density equals pounds/gallon (grams per litre).

NOTE 2—Deduction for other exempt non-VOC volatile ingredients as defined in local ordinances may be treated in a manner similar to water as just illustrated and in Practice D 3960 and Federal Register 40 CFR 51.100.

NOTE 3—Solvent content and VOC content values may be converted from pounds per (U.S.) gallon (lb/gal) to grams per litre (g/L) by multiplying by 119.84.

5.7 *Paints Reduced for Application*:

5.7.1 The calculations and examples shown in 5.2-5.6 are for as-supplied materials intended for use without further reduction. The same calculations can be used for determining the formulation density, percent weight solids content, percent volume solids content, and solvent (VOC) content of materials that have been reduced for application. It is only necessary to know the amount of reduction (volume or weight) and the density of the reducing solvent. The reducing solvent then becomes an additional ingredient in the paint formulation.

5.7.2 Each of the following examples is based on the equation:

$$D = \frac{W}{V} \quad (13)$$

where:
D = density,
W = weight, and
V = volume.

5.7.2.1 *Density of Reduced Material Knowing Percent Reduction by Volume*:

(1) The paint material described in the example in 5.2.1.1 is reduced 20 % by volume with reducing thinner having a density of 7.20 lb/gal as follows:

	Volume, gal	Density, lb/gal	Weight, lb
Unreduced material	1.00	7.74	7.74
Reducing thinner	0.20	7.20	*W*

where (reducing thinner), weight = volume × density,

or

$$W = 0.20 \times 7.20 = 1.44\ \text{lb}. \quad (14)$$

(2) The density of the reduced material is obtained by adding the volume and weight of each component, and dividing the total weight by the total volume:

	Volume, gal	Weight, lb
Unreduced material	1.00	7.74
Reducing thinner	0.20	1.44
	1.20	9.18

where density of reduced paint $= \frac{9.18}{1.20} = 7.65$ lb/gal.

5.7.2.2 *Formula Volume Solids of Reduced Paint Knowing Percent Reduction and Unreduced Volume Solids*:

Using the information from the previous example and assuming an unreduced volume solids of 50 % and a volume reduction of 20 % thinner, the reduced formula volume solids content (S_{vr}) is calculated as follows:

	Volume, gal	Solids, gal
Unreduced material	1.00	0.50
Reducing thinner	0.20	0.00
	1.20	0.50

where formula volume solids, reduced $= \frac{0.50}{1.20} =$ 0.42 gal, or $S_{vr} = 42.0$ %.

6. Precision and Bias

6.1 No statement is made about either the precision or bias of this practice for calculating formulation physical constants since the results are obtained strictly by mathematical calculations and will be related to the accuracy of the data used and conformance to the prescribed calculations.

6.2 A bias toward slightly smaller volumes and higher densities may result from non-ideal solution behavior (see 1.3, (2)).

7. Keywords

7.1 density; formulation; physical constants; solids content; volatile organic compound; (VOC)