



Designation: D 5201 – 97

Standard Practice for Calculating Formulation Physical Constants of Paints and Coatings¹

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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 24 and 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.

2. Referenced Documents

2.1 ASTM Standards:

D 153 Test Methods for Specific Gravity of Pigments²

D 1475 Test Method For Density of Liquid Coatings, Inks, and Related Products³

D 2369 Test Methods for Volatile Content of Coatings³

D 2832 Guide for Determining Volatile and Nonvolatile Content of Paint and Related Coatings³

D 3960 Practice for Determining Volatile Organic Compound (VOC) Content of Paints and Related Coatings³

D 4758 Test Method for Nonvolatile Content of Latexes²

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications⁴

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 Operations⁵

EPA Federal Reference Method 24 —Determination of Volatile Matter Content, Water Content, Density Volume Solids, and Weight Solids, of Surface Coatings⁶

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.

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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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.

3.1.4.1 *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.

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

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

3.1.6 *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.

3.1.6.1 *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:

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

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:

$$D_s = \frac{V_1 D_1 + V_2 D_2 + V_3 D_3 + \dots V_n D_n}{V_1 + V_2 + V_3 + \dots V_n} = \frac{\sum V_i D_i}{\sum V_i} \quad (2)$$

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

