



# Standard Test Method for Estimation of Solubility of Gases in Petroleum and Other Organic Liquids<sup>1</sup>

This standard is issued under the fixed designation D 3827; 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 covers a procedure for estimating the equilibrium solubility of several common gases in petroleum and synthetic lubricants, fuels, and solvents, at temperatures between 0 and 488 K.

1.2 This test method is limited to systems in which polarity and hydrogen bonding are not strong enough to cause serious deviations from regularity. Specifically excluded are such gases as HCl, NH<sub>3</sub>, and SO<sub>2</sub>, and hydroxy liquids such as alcohols, glycols, and water. Estimating the solubility of CO<sub>2</sub> in nonhydrocarbons is also specifically excluded.

1.3 Highly aromatic oils such as diphenoxy phenylene ethers violate the stated accuracy above 363 K, at which point the estimate for nitrogen solubility is 43 % higher than the observation.

1.4 Lubricants are given preference in this test method to the extent that certain empirical factors were adjusted to the lubricant data. Estimates for distillate fuels are made from the lubricant estimates by a further set of empirical factors, and are less accurate. Estimates for halogenated solvents are made as if they were hydrocarbons, and are the least accurate of the three.

1.5 The values stated in SI units are to be regarded as the standard. The values in parentheses are for information only.

1.6 *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. Referenced Documents

### 2.1 ASTM Standards:

- D 1218 Test Method for Refractive Index and Refractive Dispersion of Hydrocarbon Liquids<sup>2</sup>
- D 1250 Guide for Petroleum Measurement Tables<sup>2</sup>
- D 1298 Test Method for Density, Relative Density (Specific

TABLE 1 Solubility Parameters of Gaseous Solutes

Gas	$M_2$	$\delta_2$ at 298 K	Fuel Factor
He	4	3.35	1.27
Ne	20	3.87	1.37
H <sub>2</sub>	2	5.52	1.27
N <sub>2</sub>	28	6.04	1.70
Air	29	6.67	1.44
CO	28	7.47	1.37
O <sub>2</sub>	32	7.75	1.28
Ar	40	7.71	1.37
CH <sub>4</sub>	16	9.10	1.42
Kr	84	10.34	1.37
CO <sub>2</sub>	44	14.81	1.14

Gravity) or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method<sup>2</sup>

D 2502 Test Method for Estimation of Molecular Weight (Relative Molecular Mass) of Petroleum Oils from Viscosity Measurements<sup>2</sup>

D 2503 Test Method for Molecular Weight (Relative Molecular Mass) of Hydrocarbons by Thermoelectric Measurement of Vapor Pressure<sup>2</sup>

## 3. Terminology

### 3.1 Definitions:

3.1.1 *Bunsen coefficient*—the solubility of a gas, expressed as the gas volume reduced to 273 K (32°F) and 0.10 MPa (1 atm), dissolved by one volume of liquid at the specified temperature and 0.10 MPa.

3.1.2 *Ostwald coefficient*—the solubility of a gas, expressed as the volume of gas dissolved per volume of liquid when both are in equilibrium at the specified partial pressure of gas and at the specified temperature.

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

3.2.1 *distillate fuel*—a petroleum product having a molecular weight below 300 g/mol.

3.2.2 *halogenated solvent*—a partially or fully halogenated hydrocarbon having a molar volume below 300 mL/mol.

3.2.3 *solubility parameter*—the square root of the internal energy change (heat absorbed minus work done) of vaporization per unit volume of liquid, at 298 K.

3.2.3.1 *Discussion*—For gases in Table 1, the liquid is hypothetical and the values were calculated from actual solubility data.

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.11 on Engineering Sciences of High Performance Fluids and Solids.

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<sup>2</sup> *Annual Book of ASTM Standards*, Vol 05.01.

**TABLE 2 Constants for Synthetic Nonhydrocarbons**

Compound	$\delta_1$	$M_1$	$\rho$	$dp/dT$
Di-2-ethylhexyl adipate	18.05	370	0.928	0.00075
Di-2-ethylhexyl sebacate	17.94	427	0.916	0.00073
Trimethylpropane pelargonate	18.48	459	0.962	0.00070
Pentaerythritol caprylate	18.95	540	1.002	0.00065
Di-2-ethylhexyl phthalate	18.97	390	0.986	0.00075
Diphenoxy diphenylene ether	23.24	440	1.178	0.00079
Diphenoxy triphenylene ether	23.67	520	1.205	0.00076
Polychlorotrifluoroethylene	15.47	600	1.925	0.00166
Polychlorotrifluoroethylene	15.55	700	1.942	0.00154
Polychlorotrifluoroethylene	15.71	1 000	1.998	0.00152
Dimethyl silicone	15.14	10 000	0.969	0.00093
Methyl phenyl silicone	18.41	5 000	1.063	0.00080
Perfluoropolyglycol	14.30	1 000	1.914	0.00180
Tri-2-ethylhexyl phosphate	18.27	467	0.923	0.00090
Tricresyl phosphate	18.82	368	1.158	0.00090

### 3.3 Symbols:

$B$	= Bunsen coefficient at the specified condition,
$\rho$	= density of liquid at 288 K (60°F), g/mL,
$\rho_i$	= density of liquid at specified temperature, g/mL,
$G$	= solubility in mg/k,
$H$	= Henry's law constant, MPa,
$M_1$	= molecular weight of liquid, g/mol,
$M_2$	= molecular weight of gas, g/mol,
$n_D$	= refractive index of liquid, sodium $D$ -line at 298 K,
$p$	= partial pressure of gas, MPa,
$p_v$	= vapor pressure of liquid, MPa,
$T$	= specified temperature, K,
$L$	= Ostwald coefficient at $T$ ,
$X$	= mole fraction of gas in equilibrium solution,
$\delta_1$	= solubility parameter of liquid, (MPa) <sup>1/2</sup> ,
$\delta_2$	= equivalent solubility parameter of gas, (MPa) <sup>1/2</sup> , and
$\phi_i$	= volume fraction of component $i$ in a mixture of liquids.

## 4. Summary of Test Method

4.1 The solubility of gases in petroleum and other organic liquids may be calculated from solubility parameters of the liquid and gas.<sup>3</sup> The parameters are given for several classes of systems and their use illustrated. Alternative methods for estimation of solubility parameters are described.

## 5. Significance and Use

5.1 Knowledge of gas solubility is of extreme importance in the lubrication of gas compressors. It is believed to be a substantial factor in boundary lubrication, where the sudden release of dissolved gas may cause cavitation erosion, or even collapse of the fluid film. In hydraulic and seal oils, gas dissolved at high pressure can cause excessive foaming on release of the pressure. In aviation oils and fuels, the difference in pressure between take-off and cruise altitude can cause foaming in storage vessels and interrupt flow to pumps.

## 6. Procedure

6.1 Obtain the value of  $\delta_1$  for the liquid by the appropriate one of the following options:

6.1.1 If the liquid is a nonhydrocarbon, obtain  $\delta_1$  from **Table 2**. If it is not listed there, and the structure is known, calculate  $\delta_1$  by the method of Fedors.<sup>4</sup>

6.1.2 If the liquid is refined petroleum or a synthetic hydrocarbon, determine  $\rho$  by Test Method **D 1218** or equivalent. If  $\rho$  is 0.885 g/mL or less, calculate  $\delta_1$  as follows:

$$\delta_1 = 12.03\rho + 7.36 \quad (1)$$

6.1.3 If the liquid is refined petroleum or a synthetic hydrocarbon with  $\rho = 0.886$  g/mL or more, or a nonhydrocarbon of unknown structure, determine  $n_D$  by Test Method **D 1218**, and calculate as follows:

$$\delta_1 = 8.63n_D^2 + 0.96 \quad (2)$$

NOTE 1—Values of  $\delta_1$  from **Table 2** or  $\rho$  are accurate to  $\pm 0.2$  unit, but those from  $n_D$  may be in error by as much as  $\pm 1.0$  unit.

6.1.4 For mixtures of liquids with solubility parameters  $\delta_a, \delta_b, \dots, \delta_i$  in volume fractions  $\phi_a, \phi_b, \dots, \phi_i$ , calculate  $\delta_1$  as follows:

$$\delta_1 = \phi_a\delta_a + \phi_b\delta_b + \dots + \phi_i\delta_i \quad (3)$$

6.2 Obtain the value of  $\delta_2$  from **Table 1**.

6.3 Calculate the Ostwald coefficient for a lubricant as follows:

$$L = \exp[(0.0395(\delta_1 - \delta_2)^2 - 2.66)(1 - 273/T) - 0.303\delta_1 - 0.0241(17.60 - \delta_2)^2 + 5.731] \quad (4)$$

6.4 Calculate the Ostwald coefficient for a distillate fuel or halogenated solvent as in **6.3**, then multiply by the fuel factor from **Table 1**.

6.5 Calculate the Bunsen coefficient as follows:

$$B = 2697(p - p_v)L/T \quad (5)$$

NOTE 2—For most lubricants,  $p_v$  is less than 10 % of  $p$  and can be neglected. For fuels, solvents or oils contaminated with solvents and fuels, or at very high temperatures,  $p_v$  is important.

6.6 For mixtures of gases, calculate the individual Ostwald coefficients as in **6.3**, calculate a Bunsen coefficient for each and add them together.

6.7 For hydrocarbon oils, obtain  $\rho_i$  as follows:

$$\rho_i = \rho(1 - 0.000595(T - 288.2)/\rho^{1.21}) \quad (6)$$

<sup>3</sup> Beerbower, A., "Estimating the Solubility of Gases in Petroleum and Synthetic Lubricants," ASLE Trans, Vol 23, 1980, p. 335.

<sup>4</sup> Fedors, R. F., "A Method for Estimating Both the Solubility Parameters and Molar Volumes of Liquids," *Polymer Engineering and Science*, Vol 14, 1974, p. 147.