Designation: D3827 – 92 (Reapproved 2012)

Standard Test Method for
Estimation of Solubility of Gases in Petroleum and Other Organic Liquids[1]

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_3, and SO_2, and hydroxy liquids such as alcohols, glycols, and water. Estimating the solubility of CO_2 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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *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]
D1218 Test Method for Refractive Index and Refractive Dispersion of Hydrocarbon Liquids
D1250 Guide for the Use of the Joint API and ASTM Adjunct for Temperature and Pressure Volume Correction Factors for Generalized Crude Oils, Refined Products, and Lubricating Oils: API MPMS Chapter 11.1
D1298 Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
D2502 Test Method for Estimation of Mean Relative Molecular Mass of Petroleum Oils from Viscosity Measurements
D2503 Test Method for Relative Molecular Mass (Molecular Weight) of Hydrocarbons by Thermoelectric Measurement of Vapor Pressure

3. Terminology

3.1 *Definitions:*

3.1.1 *Bunsen coefficient, n*—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, n*—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, n*—a petroleum product having a molecular weight below 300 g/mol.

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

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

TABLE 1 Solubility Parameters of Gaseous Solutes

Gas	M_2	δ_2 at 298 K	Fuel Factor
He	4	3.35	1.27
Ne	20	3.87	1.37
H_2	2	5.52	1.27
N_2	28	6.04	1.70
Air	29	6.67	1.44
CO	28	7.47	1.37
O_2	32	7.75	1.28
Ar	40	7.71	1.37
CH_4	16	9.10	1.42
Kr	84	10.34	1.37
CO_2	44	14.81	1.14

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

3.3 *Symbols:*

B = Bunsen coefficient at the specified condition,
ρ = density of liquid at 288 K (60°F), g/mL,
ρ_t = 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,
δ_1 = solubility parameter of liquid, $(\text{MPa})_{\frac{1}{2}}$,
δ^2 = equivalent solubility parameter of gas, $(\text{MPa})_{\frac{1}{2}}$, and
φ_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.[3] 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 δ_1 for the liquid by the appropriate one of the following options:

6.1.1 If the liquid is a nonhydrocarbon, obtain δ_1 from Table 2. If it is not listed there, and the structure is known, calculate δ_1 by the method of Fedors.[4]

6.1.2 If the liquid is refined petroleum or a synthetic hydrocarbon, determine ρ by Test Method D1218 or equivalent. If ρ is 0.885 g/mL or less, calculate δ_1 as follows:

$$\delta_1 = 12.03\rho + 7.36 \tag{1}$$

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 D1218, and calculate as follows:

$$\delta_1 = 8.63 n_D{}^2 + 0.96 \tag{2}$$

NOTE 1—Values of δ_1 from Table 2 or ρ are accurate to ±0.2 unit, but those from n_D may be in error by as much as ±1.0 unit.

6.1.4 For mixtures of liquids with solubility parameters δ_a, φ_b ... δ_i in volume fractions φ_{a}, φ_b ... φ_i, calculate δ_1 as follows:

$$\delta_1 = \varphi_a\delta_a + \varphi_b\delta_b \ldots + \varphi_i\delta_i \tag{3}$$

6.2 Obtain the value of δ_2 from Table 1.

6.3 Calculate the Ostwald coefficient for a lubricant as follows:

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

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:

$$B = 2697(p - p_v)L/T \tag{5}$$

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 ρ_t as follows:

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

NOTE 3—The constants 0.000595 and 1.21 are an empirical approximation of the calculations involved in Guide D1250.

6.8 For nonhydrocarbon liquids, obtain ρ_t by one of the following methods, listed in decreasing order of preference:

6.8.1 Determine it directly, using Test Method D1298 or equivalent.

6.8.2 Obtain suitable data from the supplier of the liquids.

6.8.3 Obtain ρ by one of the above, and adjust it as follows, using dd/dT from Table 2:

$$\rho_t = \rho - (T - 288.2)d\rho/dT \tag{7}$$

6.8.4 Obtain both ρ and $d\rho/dT$ from Table 2 and combine as in 6.8.3.

6.9 Obtain M_2 from Table 1, and calculate the solubility in mg/kg:

---

[3] Beerbower, A., "Estimating the Solubility of Gases in Petroleum and Synthetic Lubricants," *ASLE Trans*, Vol 23, 1980, p. 335.

[4] 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.