ASTM INTERNATIONAL

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

1. Scope

1.1 This test method covers the estimation of the equilibrium solubility of several common gases encountered in the aerospace industry in hydrocarbon liquids. These include petroleum fractions with densities in the range from 0.63 to 0.90 at 288 K (59°F). The solubilities can be estimated over the temperature range 228 K (−50°F) to 423 K (302°F).

1.2 This test method is based on the Clausius-Clapeyron equation, Henry's law, and the perfect gas law, with empirically assigned constants for the variation with density and for each gas.

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

1.4 *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.*

1.5 *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]

D1298 Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method

3. Terminology

3.1 *Definitions:*

3.1.1 *Bunsen coefficient*—the solubility of a gas expressed as the volume, reduced to 273 K (32°F) and 101.3 kPa (1 atm), dissolved by 1 volume of liquid at the specified temperature and 101.3 kPa.

3.1.2 *Henry's law*—the principle that the ratio of partial pressure to mole fraction of gas in solution is a constant.

3.1.2.1 *Discussion*—In non-ideal systems the fugacity is used to replace the pressure, but the systems within the scope of this test method can be considered ideal within the limits of the accuracy statement.

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

3.2 *Symbols:*

d = density of the liquid at 288 K (59°F), kg/L,
T = specified temperature, K,
L_o = Ostwald coefficient at 273 K for a liquid of $d = 0.85$,
L = Ostwald coefficient at T for a liquid of $d = 0.85$,
L_c = Ostwald coefficient at T for a liquid of the specified density,
p = pressure of the gas, or mixed gases, MPa,
p_v = vapor pressure of the liquid at the specified temperature, MPa,
$p_1, p_2 \ldots p_i$ = partial pressures of the gases in a mixture, MPa,
G = solubility, mg/kg,
B = Bunsen coefficient at the specified d, p, and T,
X = mole fraction of gas in equilibrium solution,
L_m, B_m = coefficients for mixture of gases,
M = molecular weight of the gas, g/mol,
M_l = molecular weight of the liquid, g/mol,
H = Henry's law constant, MPa, and
C = molarity, kg mol/m^3.

4. Summary of Test Method

4.1 Correlations have been established by the National Aeronautics and Space Administration (formerly National

Advisory Committee on Aeronautics) in NACA Technical Note 3276 (1956)[3] Their work was extended to include most of the data published since that time, and extrapolated by semi-empirical methods into regions where no data are available.

4.2 The only data required are the density of liquid at 288 K (59°F) and the nature of the gas. These are used in the equations, with the specific constant for the gas from Table 1, or with Fig. 1, to estimate the Ostwald coefficient.

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 out of the storage vessels and interrupt flow to the pumps.

6. Procedure

6.1 Determine d by Test Method D1298 if it is not otherwise available.

6.2 Determine L for the desired gas at T from Fig. 1, if it is shown.

6.3 Determine L_o from Table 1 for gases not shown in Fig. 1.

6.4 Calculate L for such gases by the equation:

$$L = 0.300\exp\left[\left(0.639(700 - T)/T\right)\ln 3.333L_o\right] \qquad (1)$$

6.4.1 (Eq 1) is based on the assumption that all gases have $L = 0.3$ at 700 K (800°F). All the constants are empirical. The equation shall not be applied to such gases as methane or

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[3] Available from National Aeronautics and Space Administration, Washington, DC.

TABLE 1 Ostwald Coefficients at 0°C for Petroleum Liquids with d = 0.85

Gas	Ostwald Coefficient, L_o	Validated[A] Temperature Range,° C
Helium	0.012	20–150
Neon	0.018	15–40
Hydrogen	0.040	0–200
Nitrogen	0.069	0–200
Air	0.098	0–100
Carbon monoxide	0.12	25–200
Oxygen	0.16	25–100
Argon	0.18	15–40
Methane	use Fig. 1[B]	0–150
Krypton	0.60	15–40
Carbon dioxide	1.45[B]	25–215
Ammonia	1.7[B]	25–200
Xenon	3.3	15–40
Ethylene	use Fig. 1[B]	22–200
Hydrogen sulfide	5.0[B]	25–200

[A] Indicated by solid lines in Fig. 1.
[B] Do not use this method for these gases in highly aromatic liquids.

ethylene. When there is a difference, the result from Fig. 1 is to be preferred over that from Table 1.

6.5 The Ostwald coefficient L applies only to liquids of $d = 0.85$. To correct to other densities, use the following equation:

$$L_c = 7.70L(0.980 - d) \qquad (2)$$

NOTE 1—The constant 0.980 is based on the intermolecular volume of hydrocarbons as measured by compressibility and contraction on freezing. It is also the best empirical fit of the data. The use of this equation for very dense liquids is inadvisable, as the Ostwald coefficient becomes negative above $d = 0.980$. The constant 7.70 is also predictable from molecular theory, but the value used was determined empirically.

6.6 Calculate the Bunsen coefficient using the following equation:

$$B = 2697(p - p_v)L/T \qquad (3)$$

NOTE 2—Fig. 2 shows the relations of the various solubility expressions to one another in chart form.

6.7 Calculate the solubility, which is expressed sometimes as parts per million by weight, using the following equation:

$$G = \left(\frac{BM_g}{0.0224}\right)\left\{d\left[1 - 0.000595\left(\frac{T - 288.6}{d^{1.21}}\right)\right]\right\}^{-1} \qquad (4)$$

where:

0.0224 = molar volume at 273 K and 101.3 kPa in litres per mole, and 0.000595 and 1.21 = empirical constants for correcting d to specified T.

6.8 Calculate the solubility as the mol fraction by using the following equation:

$$X = 10^{-6} G \times M_l/M_g \qquad (5)$$

(neglecting the moles of gas in the divisor)

6.9 Calculate the Henry's law constant as follows:

$$H = (p - p_v)/X \qquad (6)$$

6.10 Calculate the solubility coefficient for a mixture of gases as follows:

6.10.1 Calculate the individual Ostwald coefficients as described in 6.2 or 6.4, and combine them using the following equation:

$$L_m = (L_{c1} \times p_1 + L_{c2} \times p_2 \ldots L_{ci} \times p_i)/p \qquad (7)$$

6.10.2 Calculate the Bunsen coefficient using the following equation:

$$B_m = 273pL_m/T \qquad (8)$$

7. Precision and Bias[4]

7.1 *Precision*—The repeatability of prediction for various gases is shown in Table 2, expressed as the 95 % confidence interval. Only in one case out of 20 will the percent difference between the predicted value and an accepted experimental value exceed that shown, within the temperature range indicated in Table 1.

7.2 *Bias*—The L_o values were selected to give a bias of less than 2 % for each gas.

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[4] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1129.
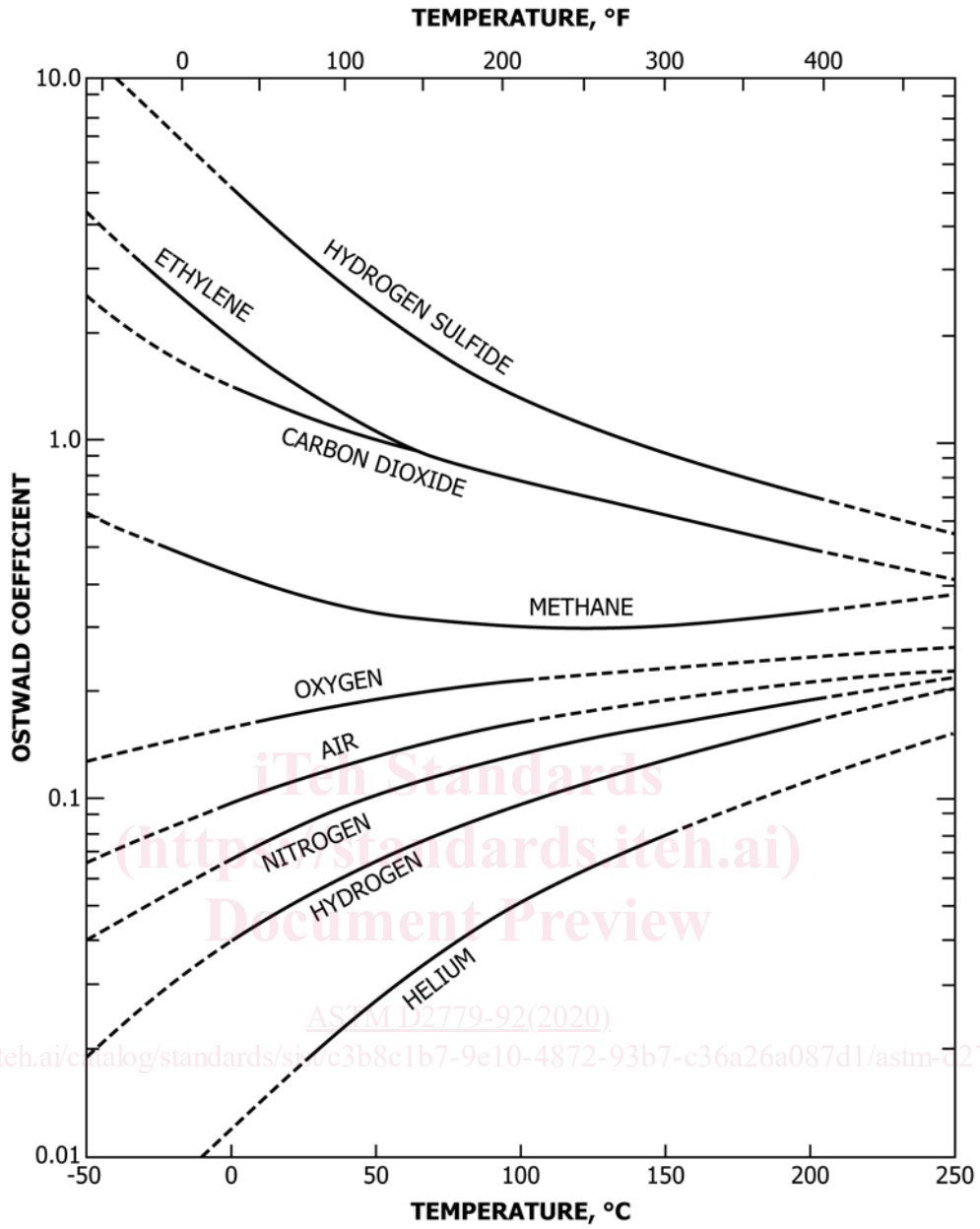
FIG. 1 Solubility of Gases in Petroleum Liquids with *d* = 0.85

8. Keywords

8.1 gases; petroleum liquids; solubility