"Density of Liquids and Solids"
(Buoyancy Methods, using hydrometer, hydrostatic balance and immersed ball method - Pycnometer Method - Oscillating Density Meter Method - Air Comparison Pycnometer Method)

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1. INTRODUCTORY INFORMATION

• Guidance information

– Melting point/melting range
– Boiling point/boiling range

• Qualifying statement

The methods for determining density discussed in this Test Guideline are applicable to pure and commercial grade solids and liquids. Table 1 compares the various methods.

The hydrostatic balance method and the pycnometer method are applicable for both solids and liquids. The air comparison pycnometer method is only applicable for solids.

The hydrometer method, the immersed ball method and the oscillating density meter methods are applicable for liquids only.

• Coefficient of variation

Coefficients of variation appeared to be dependent on the chemicals tested. They are calculated from the mean values given by the participants of the OECD Laboratory Intercomparison Testing, Part I, 1979 and their range is from 0.001 to 0.020, without referring to different methods applicable.

• Additional comments

These methods are capable of greater precision than is likely to be required for environmental assessment.

• Standard documents

The majority of the methods described is based on both international and national standards. The appropriate ISO standards and some of the national standards are listed in the Annex.

The oscillating density meter method and the air comparison pycnometer method are described on the basis of the manufacturers' instructions (2,3).

2. METHOD

A. INTRODUCTION, PURPOSE, SCOPE, RELEVANCE, APPLICATION AND LIMITS OF TEST

The density of a substance is environmentally relevant because it is helpful in estimating the distribution of the substance within and between water, soil and air.

For gaseous materials, density is of value in determining the tendency to settle or to disperse when discharged at high concentrations into the atmosphere. The density of gaseous substances can be calculated from molecular weight using the gas law.

For insoluble liquids and solids density will be a determining factor in the settling of the substance.

The methods for determining density dealt with in this Test Guideline are applicable to liquids and solids. Table 1 compares the various methods.

- Definitions and units

The density ρ of a substance is the quotient of the mass m and its volume V:

$$\rho = \frac{m}{V}$$

SI unit is kg/m^3.

- Reference substances

The reference substances need not be employed in all cases when investigating a new substance. They are provided primarily so that calibration of the method may be performed from time to time and to offer the chance to compare the results when another method is applied. The values presented below are note necessarily representative of the results which can be obtained with this test method as they have been derived from an earlier version of the Test Guideline.

I.U.P.A.C. recommendations for reference substances are as follows in Table 2.

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Table 1: APPLICABILITY OF METHODS

Method of measurement	Density		Maximum possible dynamic viscosity	Standardisation
	solid	liquid		
Hydrometer		X	< 5 Pa s	ISO 387 - 1977 ISO R 649 - 1968
Hydrostatic balance a. solids b. liquids	X	 X	 < 5 Pa s	ISO/R 1185 - 1970(A) ISO/R 91 - 1970 and R 758 - 1968
Immersed ball method		X	< 20 Pa s	
Pycnometer a. solids b. liquids	X	 X	 < 500 Pa s	ISO/R 3507 - 1976 ISO/R 1183 - 1970(B) ISO/R 758 - 1968
Oscillating density meter		X	< 5 Pa s	—
Air comparison pycnometer	X		—	—

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Table 2: REFERENCE SUBSTANCES, I.U.P.A.C. RECOMMENDATIONS (1).

Purity mole fraction %	Chemical name (identification n°)	Certified value and accuracy*	Source	Remarks
		4. DENSITY (Confidence level 99%)		
99.95	Cyclohexane	(0.77854 ± 0.000005)g . cm^{-3} (20°C)	G	Temperature flotation method and pycnometric method. Density for these materials is given also at 10, 30, 40, 50 and 60°C.
Unknown	Kerosene (a)	(0.81016 ± 0.000005)g . cm^{-3} (20°C)	G	
Unknown	Kerosene (b)	(0.86188 ± 0.000005)g . cm^{-3} (20°C)	G	
97.5	Methylcyclohexane	(0.77037 ± 0.000005)g . cm^{-3} (20°C)	G	
99.9	Toluene	(0.86668 ± 0.000005)g . cm^{-3} (20°C)	G	
99.5	2,2,4 - Trimethyl-pentane	(0.69194 ± 0.000005)g . cm^{-3} (20°C)	G	Also certified for heat of combustion and refractive index and at 25 and 30°C.
99.993	2,2,4 - Trimethyl-pentane (217 b)	(0.69183 ± 0.000002)g . cm^{-3} (20°C)	I	
99.72	n-Hexane	659.38 ± 0.07 kg . m^{-3} (20°C)	G	
Unknown	n-Heptane	683.79 ± 0.03 kg . m^{-3} (20°C)	G	
99.75	Isooctane	691.96 ± 0.07 kg . m^{-3} (20°C)	G	
99.40	n-Octane	702.57 ± 0.03 kg . m^{-3} (20°C)	G	Certified also at 25, 30, 35, 40, 45 and 50°C.
97.20	n-Nonane	717.68 ± 0.06 kg . m^{-3} (20°C)	G	
99.80	Methylcyclohexane	769.58 ± 0.07 kg . m^{-3} (20°C)	G	
99.98	Cyclohexane	773.58 ± 0.06 kg . m^{-3} (20°C)	G	
99.74	Toluene	866.77 ± 0.04 kg . m^{-3} (20°C)	G	

* Units are given as reported by issuing laboratory.

G Division of Physico-Chemical Metrology, National Board for Quality Control and Measures, 2 Flectroralna Street, Warsaw, Poland.

I Office of Standard Reference Materials, U.S. Department of Commerce, National Bureau of Standards, Washington D.C. 20234, U.S.A.

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Those substances tested in the OECD-Laboratory Intercomparison, Part I, are listed below.

Table 3: SUBSTANCES TESTED IN OECD LABORATORY INTERCOMPARISON TESTING PROGRAMME

Density mean values and range values of the substances tested in OECD Laboratory Intercomparison testing, Part I, 1979. Values given in g/cm^3 at 20°C.

substance	density ρ g/cm^3 (mean)	density ρ g/cm^3 (range)	N° of laboratories
Di (2-ethyl hexyl-phthalate)	0.9843	0.9837 to 0.9850	14
Hexachlorobenzene	2.075	2.065 to 2.087	4
Toluene	0.8661	0.8633 to 0.8676	14
Trichloroethylene	1.466	1.464 to 1.475	12

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- Principle of the test methods

Buoyancy methods: (a) Hydrometer (for liquid substances)

For quick and sufficiently accurate determinations of density, floating hydrometers may be used which allow the density of a liquid to be deducted from the depth of immersion by reading of a graduated scale.

Buoyancy method: (b) Hydrostatic balance (for liquid and solid substances)

The difference between the weight of a test sample measured in air and in water can be employed to determine its density. For solids a bulk density is obtained for the discrete sample employed. For the determination of density of liquids a body of known volume V is weighed first in air and then in the liquid.

Buoyancy method: (c) Immersed ball method (for liquid substances) (2)

In this method, the density of a liquid is determined from the difference between the results of weighing the liquid before and after immersing a ball of known volume in the test liquid.

Pycnometer methods

For solids or liquids, pycnometers of various shapes and with known volumes may be employed. The density is calculated from the difference in weight between the full and empty pycnometer and its known volume.

Oscillating density meter (3, 4, 5)

The density of a liquid can be measured by an oscillating density meter. A mechanical oscillator constructed in the form of a U-tube is vibrated at a specific frequency that depends on the mass of the oscillator.

Introducing a sample changes the resonance frequency of the oscillator. The apparatus must be calibrated by two substances with known densities. These substances should preferably be chosen such that their densities span the range to be measured.

Air comparison pycnometer (for solids) (7, 8)

The density of a solid in any form can be measured at room temperature with the gas comparison pycnometer. The volume of a substance is measured in air or in an inert gas in a cylinder of variable calibrated volume. For the calculation of density one mass measurement is taken after concluding the volume measurement.

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- Quality criteria

Possibility for standardisation: yes, see Table 1, above

Possibility for automation: yes

- Test conditions

The test should preferably be carried out at 20°C.

B. DESCRIPTION OF THE TEST PROCEDURES

The procedures for some of these test methods have been established in various international and national standards publications. Refer to those standards for details on preparations, test conditions, and conduct of the tests (see Annex for list). At least two measurements should be made for any temperature chosen.

3. DATA AND REPORTING

- Treatment of results

The density should be reported in SI units together with the temperature of the determination, the physical state of the measured substance and the method employed. Any deviations from an international or national standard method must be described in detail.

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4. LITERATURE

1 I.U.P.A.C., Recommended Reference Materials for Realization of Physico-Chemical Properties In: *Pure and Applied Chemistry*, Vol. 48, p. 508, Pergamon Press, 1976.

2. H. Wagenbreth, "Die Tauchkugel zur Bestimmung der Dichte von Flüssigkeiten", Technisches Messen tm, *11*, 427-430 (1979).

3. H. Leopold, "Die digitale Messung von Flüssigkeiten", Elektronik *19*, 297-302 (1970).

4. D. Baumgarten, "Füllmengenkontrolle bei vorgepackten Erzeugnissen - Verfahren zur Dichtebestimmung bei flüssigen Produkten und ihre praktische Anwendung", Die Pharmazeutische Industrie *37*, 717-726 (1975).

5. J. Riemann, "Der Einsatz der digitalen Dichtemessung in Brauereilaboratorium", Brauwissenschaft *9*, 253-255 (1976).

6. F.W. Meier-Grolman, H. Dietrich, "Der offene und geschlossene Porenraum im Zementmörtel und der Einflusschemischer und mineralischer Zusätze", Zement-Kalk-Gips *4*, 165-174 (1969).

7. DIN 55990, Part 3, Prüfung von Anstrichstoffen und ähnlichen Beschichtungsstoffen; Pulverlack; Bestimmung der Dichte.

8. DIN 53243, Anstrichstoffe; Chlorhaltige Polymere; Prüfung (April 1968).

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5. ANNEX

LIST OF STANDARD METHODS

- Buoyancy methods

Hydrometer

DIN 12790 Hydrometer; general instructions
ISO 387-1977

DIN 12791 Part 1: Density hydrometers; construction, adjustment and use
Part 2: Density hydrometers; standardised sizes, designation

ISO/R 649-1968

DIN 12793 Laboratory glassware: range find hydrometers

Hydrostatic balance

For solid substances

ISO R 1183-1970, Method A	Methods for determining the density and relative density of plastics excluding cellular plastics
ASTM-D-792	Specific gravity and density of plastics by displacement
DIN 53479	Testing of plastics and elastomers; determination of density

For liquid substances

ISO/R 91-1970

DIN 51757	Testing of mineral oils and related materials; determination of density
ISO 758-1976	Liquid chemical products for industrial use; determination of density at 20°C

ASTM D 941-55, ASTM D 1298-67 and ASTM D 1481-62

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ASTM D 1298	Density, specific gravity or API gravity of crude petroleum and liquid petroleum products by hydrometer method.
BS 4714	Title: the same as ASTM D 1298

Immersion ball

See: PTB-W-8, 1977

- Pycnometer methods

For liquid substances

ISO 3507-1976	Pycnometers
ISO/R 758-1968	Liquid chemical products; determination of density at 20°C
DIN 12797	Gay-Lussac pycnometer (for non-volatile liquids which are not too viscous)
DIN 12798	Lipkin pycnometer (for liquids with a kinematic viscosity of less than $100.16^{-6}m^2s^{-1}$ at 15°C)
DIN 12800	Sprengel pycnometer (for liquids as DIN 12798)
DIN 12801	Reischauer pycnometer (for liquids with a kinematic viscosity of less than $100.10^{-6}m^2s^{-1}$ at 20°C, applicable in particular to hydrocarbons and aqueous solutions as well as to liquids with higher vapour pressure, approximately 1 bar at 90°C.
DIN 12806	Hubbard pycnometer (for viscous liquids of all types which do not have too high a vapour pressure, in particular also for paints, varnishes and bitumen).
DN 12807	Bingham pycnometer (for liquids, as in DIN 12801)
DN 12808	Jaulmes pycnometer (in particular for ethanol-water mixture)

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DN 12809	Pycnometer with ground-in thermometer and capillary side tube (for liquids which are not too viscous)
DIN 53217	Testing of paints, varnishes and similar products; determination of density by pycnometer
DIN 51757	Point 7; Testing of mineral oils and related materials; determination of density
ASTM D 297	Section 15; Rubber Products-Chemical Analysis
ASTM D 2111	Method C; Halogenated organic compounds
BS 4699	Method for Determination of Specific Gravity and Density of Petroleum Products (Graduated Bicapillary Pycnometer Method)
BS 5093	Method for Determination of Relative Density and Density of Petroleum Products by the Capillary-Stoppered Pycnometer Method
ISO 2811-1974	Paints and varnishes; determination of density

For solid substances

ISO/R 1183	Method B: Methods for Determining the Density and Relative Density of Plastics excluding Cellular Plastics.
DIN 19683	Determination of the Density of Soils
DIN 787/10.2	General methods of test for pigments and extenders - Part 10: determination of density (pycnometer method)
ISO 787/23-1979	General methods of test for pigments and extenders - Part 23: determination of density (using a centrifuge to remove entrained air)

(See Introduction to Physical Chemistry Test Guidelines for addresses of agencies supplying Standards).

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