



Standard Test Method for Determination of Isothermal Secant and Tangent Bulk Modulus¹

This standard is issued under the fixed designation D 6793; 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 (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of isothermal secant and tangent bulk modulus of liquids which are stable and compatible with stainless steel under the conditions of test.

1.2 This test method is designed to be used over the temperature range from -40 to 200°C and from ambient to 68.95 Mpa (10 000 psig).

NOTE 1—Because of the design of the test apparatus, the upper limit of pressure which can be attained is limited by the bulk modulus of the test fluid. Pressures as high as 68.95 Mpa will not be attained for fluids of relatively low bulk modulus at the test temperature.

1.3 This test method assumes that the user is proficient in the assembly and use of medium pressure (m/p) threaded and coned fittings which are intended for use at pressures up to 137.9 Mpa (20 000 psig).

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 and health practices and determine the applicability of regulatory limitations prior to use.*

NOTE 2—Because hydraulic pressure in the test system is produced by purely mechanical means, the test method is not subject to the hazards associated with systems which are pressurized pneumatically. Even small leaks will result in immediate drop in pressure to ambient without production of a high pressure liquid stream or mist.

2. Referenced Documents

2.1 ASTM Standards:

D 235 Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)²

D 4057 Practice for Manual Sampling of Petroleum and Petroleum Products³

D 4177 Practice for Automatic Sampling of Petroleum and Petroleum Products³

E 300 Practice for Sampling Industrial Chemicals⁴

¹ 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.

Current edition approved April 10, 2002. Published August 2002.

² *Annual Book of ASTM Standards*, Vol 06.04.

³ *Annual Book of ASTM Standards*, Vol 05.02.

⁴ *Annual Book of ASTM Standards*, Vol 15.05.

3. Terminology

3.1 Definitions:

3.1.1 *isothermal secant bulk modulus*—the product of original fluid volume and the slope of the secant drawn from the origin to any specified point on the plot of pressure versus volume change divided by volume at constant temperature.

3.1.2 *isothermal tangent bulk modulus*—the product of fluid volume at any specified pressure and the partial derivative of fluid pressure with respect to volume at constant temperature.

4. Summary of Test Method

4.1 Determination of Isothermal Secant Bulk Modulus:

4.1.1 A piston in the form of a medium pressure valve is forced into a chamber which is liquid-filled. The pressure created by the insertion of the piston is measured.

4.2 A system constant $V/\Delta V$ is determined by use of a standard of known bulk modulus as follows:

$$\left(\frac{V}{\Delta V}\right) = \frac{\bar{B}_i}{P} = \frac{\bar{B}_i}{(P_n - P_o)} \quad (1)$$

where:

\bar{B}_i = isothermal secant bulk modulus,

P_o = pressure at the origin before insertion of the piston, and

P_n = pressure of the system at insertion of piston to Position n .

NOTE 3— $V/\Delta V$ is thus a constant determined by system volume and piston displacement only. It is independent of temperature and when known, can be used to determine isothermal secant bulk modulus from pressure data obtained for various degrees of piston insertion.

4.3 Isothermal tangent bulk modulus and sample density, if desired, may be determined from isothermal secant bulk modulus data determined as a function of pressure by use of the calculations in Section 12.

5. Significance and Use

5.1 Isothermal secant bulk modulus (static bulk modulus) is a property that measures the compressibility of a liquid. The greater the value, the less the compressibility of the liquid.

5.2 Isothermal secant bulk modulus is employed in the

design of high performance hydraulic fluid and braking systems. High bulk modulus is desirable in that the response time of a system is faster when applied pressure more directly effects the action of the system rather than in the compression of the working liquid.

5.3 If isothermal secant bulk modulus is known as a function of pressure, the data may be used to calculate isothermal tangent bulk modulus and density as a function of pressure. The data may not, however, be used to determine isentropic (dynamic) bulk modulus. That property is usually determined from velocity of sound measurements and differs from isothermal bulk modulus by the ratio of $C_p/C_v = \gamma$ (the ratio of heat capacity at constant pressure to that at constant volume for the test specimen).

6. Apparatus

6.1 The apparatus for the determination of isothermal secant bulk modulus is shown schematically in Fig. 1. An oven capable of maintaining temperature within $\pm 0.1^\circ\text{C}$ at the desired test temperature is required. All fittings are of the coned and threaded m/p type for use at working pressures up to 137.9 Mpa (20 000 psig). Pressure is created in the system by use of the pressure valve (see 3 in Fig. 1) by which a piston (valve stem) is inserted into the liquid-filled system by turning 1,2,3...n turns as determined by a scale affixed to the valve stem to ensure repeatability of turns from the starting point. Pressure transducers, thermocouples and system fixtures should be such as to have minimal contribution to system volume so that the system volume is such as to allow a maximum pressure increase for any given degree of insertion of the pressure valve stem.

7. Reagents and Materials

7.1 *Cleaning Solvent*—Mineral spirits conforming to Specification D 235, Type I.

7.2 *Other Solvents*—Some test specimens may not be soluble in mineral spirits. A suitable solvent for such materials will be needed to clean the apparatus after their use. The solvent must be compatible with stainless steel and the elastomeric components of the valves in the test apparatus.

8. Sampling

8.1 Obtain a representative sample of the test specimen in accordance with the requirements of Practice D 4057, D 4177, or E 300.

9. Preparation of Apparatus

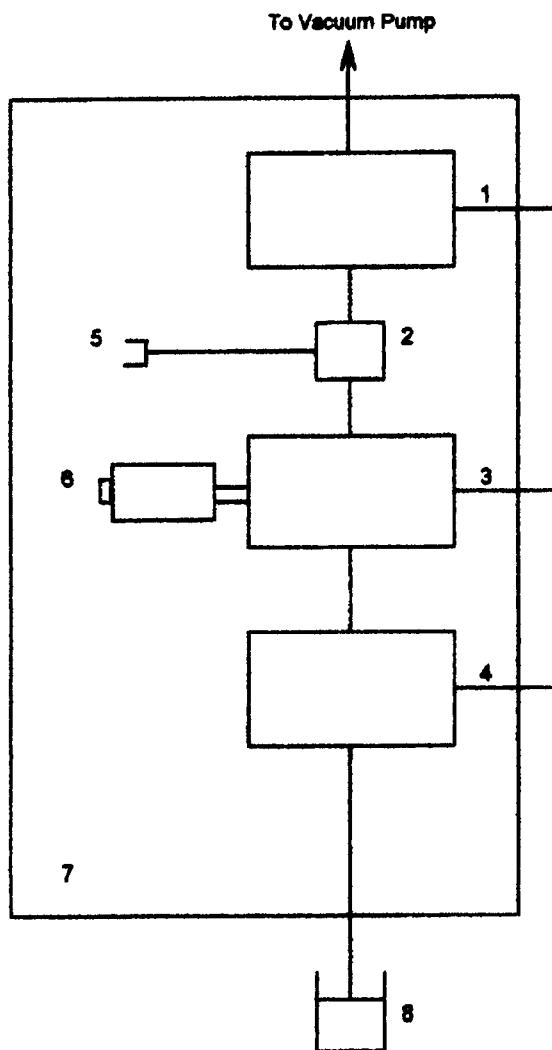
9.1 Introduce a portion of mineral spirits into the sample container (Fig. 1, Item 8).

9.2 Open Valves 1 and 4 and slowly draw the mineral spirits through the system by gentle application of vacuum.

NOTE 4—Always use a trap between the test apparatus and the vacuum source to prevent introduction of the liquid solvent or the test specimen into the vacuum system.

9.3 Replace the sample container with an empty vessel and allow excess solvent to drain from the test system. Repeat 9.1-9.3.

9.4 Remove the vessel containing excess solvent and with Valves 1 and 4 open allow the vacuum pump to draw air



- 1 = Top valve
- 2 = A Tee
- 3 = Pressure valve
- 4 = Bottom valve
- 5 = Thermocouple
- 6 = Pressure transducer
- 7 = Oven
- 8 = Sample container

NOTE—All fittings are m/p coned and threaded type for use at working pressure up to 20 000 psig.

FIG. 1 Apparatus for Determination of Secant Bulk Modulus

through the test system to evaporate the residual solvent. Start at ambient temperature and raise the oven temperature to 100°C while drawing air through the system.

9.5 When the oven temperature reaches 100°C , close Valve 4 and allow the vacuum pump to release the pressure in the test system to complete removal of solvent residues by evaporation.

10. Calibration

10.1 With the cleaned system at ambient temperature introduce the calibrating fluid (usually water) into container 8.

10.2 Open Valves 1 and 4 and draw sufficient fluid into the test cell to ensure that it is liquid-filled. Close Valve 4.

10.3 Adjust the oven to the preselected test temperature with Valve 1 still open and Pressure Valve 3 set at the 0 turn or full open position.

10.4 Apply vacuum to the system to remove any residual air bubbles. Close Valve 1 and record the system pressure with pressure transducer 6.

10.5 Turn Pressure Valve 1 full turn and record the pressure. Repeat for turns 2 through n (usually $n = 7$) and record the system pressure after each full turn.

10.6 Calculate $V/\Delta V$ for each pressure valve position as described in 4.2, Eq 1. An example is shown in Appendix X1.

10.7 Drain the calibration fluid from the test cell. If water was used for calibration, remove all residual traces as described in 9.4 and 9.5. If an organic standard was used, clean the cell in accordance with 9.1-9.5.

11. Procedure

11.1 Introduce the test specimen into the test cell as described in 10.1-10.4. Record the pressure reading at turn 0 of Pressure Valve 3.

11.2 Turn Pressure Valve 1 a full turn and record the pressure. Repeat for turns 2 through n (usually $n = 7$) and record the system pressure after each full turn.

11.3 Calculate the isothermal secant bulk modulus of the test specimen as described in Section 12. An example is shown in Appendix X2.

12. Calculations⁵

12.1 *Isothermal Secant Bulk Modulus*—Calculate according to the following equation:

$$\bar{B}_i = \frac{V}{\Delta V} (P_n - P_o) \quad (2)$$

where:

- \bar{B}_i = isothermal secant bulk modulus, psi,
- $\frac{V}{\Delta V}$ = ratio of volume to volume change as determined by Eq 1,
- P_n = pressure of the system at insertion of Position n , psi, and
- P_o = pressure at origin, psi.

12.2 *Isothermal Tangent Bulk Modulus*—Calculate according to the following equation:

$$B_i = \frac{\bar{B}_i (\bar{B}_i - P)}{\bar{B}_i^o} \quad (3)$$

where:

- B_i = isothermal tangent bulk modulus, psi, and
- \bar{B}_i^o = isothermal secant bulk modulus at 0 psig as determined by linear extrapolation, psi.

12.3 *Density from Secant Bulk Modulus*—Calculate according to the following equation:

$$d = \frac{d_o}{1 - P/\bar{B}_i} \quad (4)$$

where:

- d_o = density at 0 Pa (ambient), kg/m^3 , and
- d = density at P , kg/m^3 .

13. Report

13.1 Report the isothermal secant bulk modulus at the test temperature and whatever pressure is desired within range of pressures observed in 11.2 and 11.3. Since isothermal secant bulk modulus is a linear function of pressure with the range from ambient to 68.95 Mpa (10 000 psig) extrapolation may be employed to obtain values at pressures above and below those which can be obtained directly (depending upon the actual isothermal secant bulk modulus of the test specimen).

13.2 If determination of isothermal tangent bulk modulus is required, convert the isothermal secant bulk modulus data obtained as above as described in 12.2.

13.3 If determination of density as a function of pressure is required, calculate density at non-ambient pressures provided the density of the test specimen at ambient pressure is known from the isothermal secant bulk modulus as described in 12.3.

14. Precision and Bias

14.1 Because of the complex nature of the procedure for the determination of isothermal secant and tangent bulk modulus, and because of the expensive equipment required in the initial set-up of the procedure, there is not a sufficient number of volunteers to permit a cooperative laboratory program for determination of the precision and bias of this test method. If the necessary volunteers can be obtained, a program will be undertaken at a later date.

15. Keywords

15.1 density; dynamic bulk modulus; isentropic bulk modulus; isothermal bulk modulus; isothermal secant bulk modulus; isothermal tangent bulk modulus; pressure; static bulk modulus

⁵ Supporting data on the derivation of equations have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR: D02-1523.

APPENDIXES
(Nonmandatory Information)
X1. ISOTHERMAL BULK MODULUS CALIBRATION

X1.1 *Calibration Fluid*—Water.

Pressure, psig
7349
14697

Bulk Modulus
354299
382654

X1.2 *Calibration Temperature*—40°C.

X1.4 *Calibration*—See Table X1.1.

X1.3 *Data from International Critical Tables*:⁶
⁶ International Critical Tables, Vol 3, McGraw Hill Co. Inc., New York, NY.

TABLE X1.1 Calibration for Isothermal Bulk Modulus

NOTE 1—Because the volume constant is a unit-less quantity consisting of a volume divided by a volume difference, it is independent of temperature.

Turn No.	(1) <i>P</i> , psi	(2) <i>P_n</i> - <i>P_o</i>	(3) <i>B_s</i> , psi	(4) <i>V</i> /Δ <i>V</i>
0	36			
1	1318	1282	330 888	258.10300
2	2681	2654	336 147	127.08770
3	4084	4048	341 561	84.37772
4	5531	5495	347 145	63.17470
5	7022	6986	352 899	50.51517
6	8549	8513	358 791	42.14625
7	10 129	10 093	364 888	36.15258

- (1) = Pressure readings at the 0 and *n*th turn of the valve.
- (2) = Pressure difference between the *n*th turn and the 0 turn.
- (3) = Secant bulk modulus of the calibration fluid at the observed pressure as obtained by linear interpolation and/or extrapolation.
- (4) = Volume constant of the system equal to:

$$\left(\frac{V}{\Delta V} \right) = \frac{B_i}{(P_n - P_o)}$$

X2. DETERMINATION OF ISOTHERMAL SECANT BULK MODULUS

X2.1 Once the volume constant, $(V/\Delta V)$, has been determined for the test system, the data may be used with data obtained with the test specimen to determine its isothermal secant bulk modulus as follows:

$$\bar{B}_i = (P_n - P_o) (V/\Delta V) \quad (X2.1)$$

X2.2 *Test Specimen*—Unknown hydraulic fluid.

X2.3 *Test Temperature*—40°C.

X2.4 *Calibration Fluid*—Water at 40°C.

TABLE X2.1 Calibration for Isothermal Secant Bulk Modulus

Turn No.	(1) P_i , psi	(2) $P_n - P_o$	(3) $V/\Delta V$	(4) B_i , psi
0	36			
1	825	789	258.10300	203 644
2	1661	1625	127.08770	206 518
3	2545	2509	84.37772	211 704
4	3473	3437	63.17470	217 132
5	4448	4412	50.51517	222 873
6	5470	5434	42.14625	229 023
7	6539	6503	36.15258	235 101

- (1) = Pressure readings at the 0 and n^{th} turn of the valve.
- (2) = $P_n - P_o$ = pressure difference between the n^{th} turn and the 0 turn.
- (3) = Volume constant as determined by calibration with a fluid of known isothermal secant bulk modulus.
- (4) = Isothermal secant bulk modulus as determined from Eq X2.1.

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