



Standard Test Method for Determining Vapor Pressure by Thermal Analysis¹

This standard is issued under the fixed designation E 1782; 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 describes a procedure for the determination of the vapor pressure of pure liquids or melts from boiling point measurements made using differential thermal analysis (DTA) or differential scanning calorimetry (DSC) instrumentation operated at different applied pressures.

1.2 This test method may be used for the temperature range 273 to 773 K (0 to 500 °C) and for pressures between 5 kPa to 2 MPa. These ranges may differ depending upon the instrumentation used and the thermal stability of materials tested. Because a range of applied pressures is required by this test method, the analyst is best served by use of instrumentation referred to as high pressure differential thermal instrumentation (HPDSC or HPDTA).

1.3

1.4 There is no ISO standard equivalent to this test method.

1.5 *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:*²

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E 473 Terminology Relating to Thermal Analysis and Rheology

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

E 967 Test Method for Temperature Calibration of Differential Scanning Calorimeters and Differential Thermal Analyzers

E 1142 Terminology Relating to Thermophysical Properties

E 2071 Practice for Calculating Heat of Vaporization or

Sublimation from Vapor Pressure Data

SI 10 Standard for Use of the International System of Units (SI) The Modern Metric System

3. Terminology

3.1 *Definitions:*

3.1.1 The following terms are applicable to this test method and can be found in either Terminology **E 473** or Terminology **E 1142**: *boiling pressure, boiling temperature, differential scanning calorimetry (DSC), differential thermal analysis (DTA), vapor pressure, vaporization point, vaporization temperature.*

3.2 Symbols:

3.2.1 A, B, C—Antoine vapor pressure equation (**1**)³ constants ($\log_{10}$, kPa, K):

Antoine vapor pressure equation: $\log_{10} P = A - B/(T + C)$

where:

P = vapor pressure, kPa, and

T = temperature, K.

4. Summary of Test Method

4.1 A specimen in an appropriate container is heated at a constant rate within a DTA or DSC instrument operated under an applied constant vacuum/pressure between 5 kPa and 2 MPa until a boiling endotherm is recorded. Boiling is observed at the temperature where the specimen partial pressure equals the pressure applied to the test chamber. The pressure is recorded during observance of the boiling endotherm and the boiling temperature is recorded as the extrapolated onset temperature. This measurement is repeated using new specimens for each of five or more different pressures covering the pressure range of interest. The pressure-temperature data are fitted as $\log_{10} P$ and $1/T$ (K^{-1}) to the Antoine vapor pressure equation (see **Fig. 1**). Vapor pressure values required for specific reports are then computed from the derived equation.

4.2 The capability of the assembled system after calibration should be periodically checked by using this method on pure water as a reference substance and comparing the derived vapor pressure data with the NBS/NRC steam tables attached as **Appendix X1**.

¹ This test method is under the jurisdiction of ASTM Committee E37 on Thermal Measurements and is the direct responsibility of Subcommittee E37.01 on Thermal Test Methods and Practices.

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² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

³ The boldface numbers given in parentheses refer to a list of references at the end of the text.

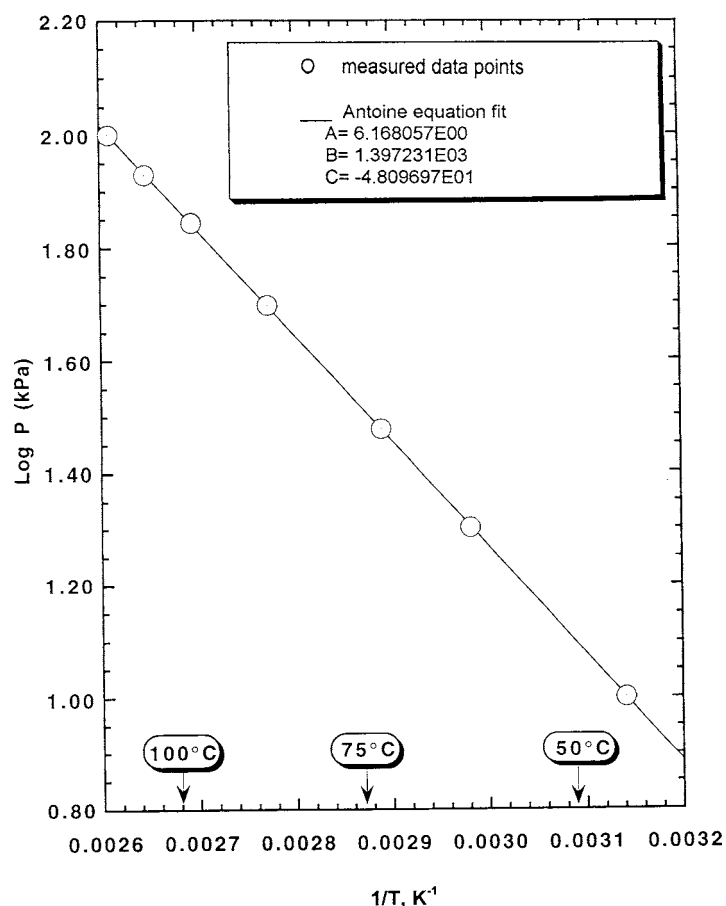


FIG. 1 Vapor Pressure Curve with Experimental Data and Antoine Equation Fit

5. Significance and Use

5.1 Vapor pressure is a fundamental thermophysical property of a liquid. Vapor pressure data are useful in process design and control, in establishing environmental regulations for safe handling and transport, for estimation of volatile organic content (VOC), and in deriving hazard assessments. Vapor pressure and boiling temperature data are required for Material Safety Data Sheets (MSDS). The enthalpy of vaporization may also be estimated from the slope of the vapor pressure curve (See Practice E 2071).

6. Interferences

6.1 This test method is limited to materials that exhibit a singular sharp boiling endotherm under the conditions outlined in this test method.

6.2 Oxidation, pyrolysis, or polymerization of condensed organic materials retained at temperatures above their ambient boiling point may be encountered at the elevated pressures of this method. This will be observed as an exotherm or a significantly broadened endotherm, or both, and shall not be considered a valid pressure-temperature datum point. Use of an

inert gas for elevated pressures or for back-filling after evacuation of the sample chamber is recommended to minimize the risk of oxidation.

6.3 Partial blockage of the pinhole in the DSC containers could occasionally be encountered. This may be observed as noise spikes on the boiling endotherm and shall not be considered a valid pressure-temperature datum point.

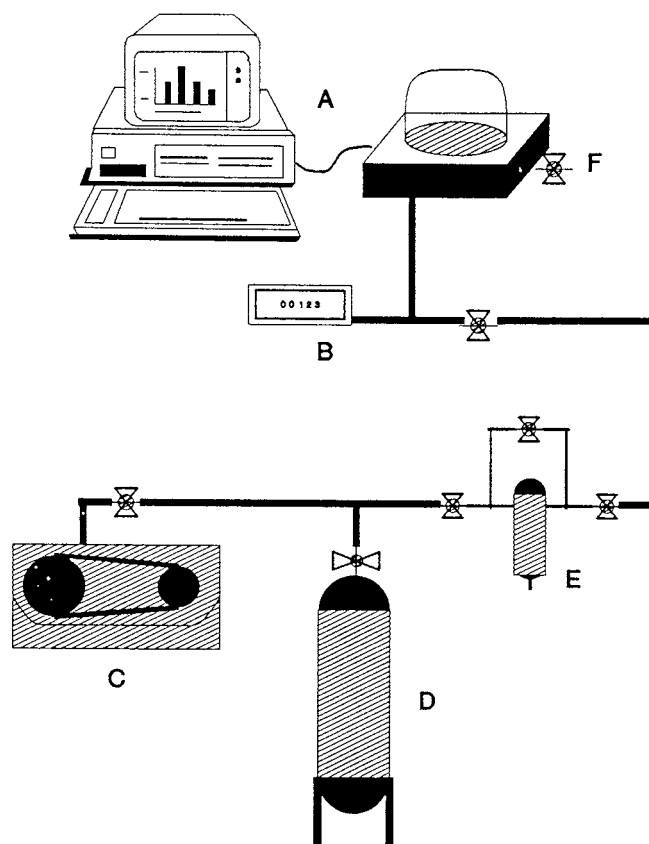
7. Apparatus

7.1 The essential equipment required to provide the minimum instrument capability of this test method includes (see Fig. 2):

7.1.1 *Differential Scanning Calorimeter (DSC) or Differential Thermal Analyzer (DTA)*, consisting of:

7.1.1.1 *DSC/DTA Test Chamber*, composed of a furnace(s) to provide uniform controlled heating of a specimen and reference at a constant rate within the 273 to 773 K temperature range of this test method; a temperature sensor to provide an indication of the specimen/furnace temperature to ± 1 K; a differential sensor to detect a difference (temperature or heat flow) between the specimen and reference equivalent to 5 mW; and a means of sustaining an inert gas or vacuum test chamber environment at pressures above and below ambient.

7.1.1.2 *Temperature Controller*, capable of executing a specific temperature program by operating the furnace(s)



NOTE—"A," DSC/DTA instrument; "B," pressure transducer; "C," pressure/vacuum source; "D," pressure stabilizer; "E," pressure regulator; and "F," relief valve.

FIG. 2 Schematic of Apparatus

between selected temperature limits to ± 1 K at a rate of temperature change of 5 K/min constant within ± 1 %.

7.1.1.3 *Recording Device*, to provide a means of acquiring, storing and displaying measured or calculated signals or both. The minimum output signals are heat flow, temperature and time.

7.1.2 *Pressure/Vacuum System*, consisting of:

7.1.2.1 *A pressure vessel*, or similar means of sealing the test chamber at any applied absolute pressure within the 5 kPa to 2 MPa range of this test method.

7.1.2.2 *Source of Pressurized Gas*, or vacuum capable of sustaining a regulated inert gas pressure to the test chamber of between 5 kPa and 2 MPa.

7.1.2.3 *Pressure Transducer(s)*, to measure the pressure in the test chamber to within 1 % including any temperature dependence of the transducer(s) over the range of 5 kPa to 2 MPa.

NOTE 1—Distance (or dead volume) between the pressure transducer and the specimen in the test chamber should be minimized to ensure accurate recording of the pressure at the time of boiling.

7.1.2.4 *Pressure Regulator*, or similar device to adjust the applied pressure in the test chamber to ± 2 % of the desired value.

7.1.2.5 *Ballast*, or similar means to maintain the applied pressure in the test chamber constant to ± 1 %.

7.1.2.6 *Valves*, to control delivery of the inert gas/vacuum to the test chamber or to isolate components of the pressure/vacuum system, or both. Valves shall be rated in excess of the 2 MPa upper pressure limit of this test method.

7.1.3 *Containers*, (pans, capillary tubes, etc.) that are inert to the specimen and reference materials and which are of suitable structural shape and integrity to contain the specimen and reference in accordance with the following specific requirements:

7.1.3.1 It is imperative that the containers used in this test method be capable of retaining the specimen in a manner that minimizes sample loss through vaporization prior to boiling and that promotes the development of vapor-liquid equilibrium at boiling. When both conditions are met a sharp endotherm with little or no baseline curvature at the onset will be observed.

NOTE 2—Studies by ASTM task group E37.01.05 and others (2, 3) have determined glass cylindrical containers of 2 to 4 mm inside diameter by 25 mm long are suitable for thermocouple inserted style DTA instruments; and a hermetic sealable pan (approximately 40 μ L vol) with a single pinhole in the center of the lid of ≤ 125 μ m diameter is suitable for DSC instruments. For purposes of this test method, pinhole diameters of 50 to 75 μ m are recommended. These pinhole dimensions for DSC containers were established specifically for use with heating rates of nominally 5 K/min. Use of heating rates other than 5 K/min are not recommended for this test method. Higher rates may result in some self-pressurization of the specimen and lesser rates will extend measurement times and will tend to promote preboiling vaporization.

7.2 Auxiliary equipment considered useful in conducting this test method include:

7.2.1 A coolant system that can be coupled directly with the controller to the furnace to hasten its recovery from elevated temperatures or to sustain a subambient temperature to within ± 1 K of a lower limit temperature.

7.2.2 A balance to weigh specimens or specimen containers, or both, to ± 0.1 mg.

7.2.3 A syringe or micropipet to deliver liquid specimens of 1 to 5 μ L ± 10 %.

7.2.4 Pressure relief valve to prevent accidental overpressurization in the pressure system. A rating of 10 % in excess of the upper use pressure is suggested provided it does not exceed the maximum working pressure rating of any individual component in the system.

8. Precautions

8.1 Safety Precautions:

8.1.1 Pressures in addition to ambient are employed in this test method. Ensure that the pressure/vacuum system is certified for operation at the extremes of pressure encountered with this test method. Incorporation of a pressure relief device is recommended.

8.1.2 Adequate provisions shall be available for retention and disposal of any spilled mercury if mercury-containing pressure devices are employed.

9. Sampling

9.1 Typical specimen sizes used for individual pressure measurements are 1 to 5 mg of solid or 1 to 5 μ L of liquid. Similar size specimens should be used for each individual measurement of a given sample.

9.2 Samples are assumed to be tested as received. Report any special sampling or pretreatment used with this test method.

10. Calibration

10.1 Perform calibration according to Practice E 967, using the heating rate and specimen containers intended for this test method. Accomplish temperature calibration at ambient pressure.

NOTE 3—The effect of pressure on the melting temperature of pure materials used to calibrate the temperature axis has been shown to be < 0.01 K at the maximum pressure of this method (4). The effects of vacuum on the heat transfer characteristics and subsequent thermal lag of various differential thermal instruments (DSC and DTA) have not been established. From general experiences these effects should not alter the temperature axis calibration by more than 1 K at the minimum pressure of this test method.

10.2 Calibrate the pressure transducer according to the recommendations of the manufacturer or similar appropriate procedure.

11. Procedure

11.1 Place the specimen and inert reference in suitable containers (see 7.1.3) into the test chamber.

NOTE 4—If hermetic sealable DSC pans with pinholed lids are used, make sure there is no sample material on the outer surfaces of the container and that a good hermetic seal is accomplished. Either will result in preboiling vaporization that at least partially negates the function of the pinhole. Be certain, also, that the pinhole is free of dirt or debris.

11.2 Seal the test chamber and apply the desired pressure.

NOTE 5—It is recommended to flush residual oxygen from the test chamber by either purging for several minutes with inert gas or by

evacuation and back-filling with inert gas.

11.3 Allow the pressure to stabilize and equilibrate the test chamber at a start temperature which shall be at least 30 K below the expected boiling temperature to ensure stable temperature control and baseline.

11.4 Heat the specimen and reference at a constant rate of 5 K/min, recording the DSC/DTA curve until the vaporization is complete.

11.5 Record the absolute pressure in the test chamber at the time the boiling endotherm is observed.

NOTE 6—Most pressure gauges report pressure relative to ambient pressure. In such cases, the measured pressure shall be added to or subtracted from atmospheric pressure measured by a barometer to obtain absolute pressure.

11.6 Restore the test chamber to ambient conditions upon completion of the heating curve.

11.7 Repeat 11.1-11.6 with a new specimen at each of four or more additional pressures throughout the pressure range capability of the equipment.

NOTE 7—A minimum of five measurements at different pressures are required for this test method. Additional measurements should improve the fit of the Antoine vapor pressure equation and reduce the uncertainty of the Antoine constants used to calculate the vapor pressure curve.

12. Calculation

12.1 Determine and tabulate each boiling temperature (as T_o or T_e in Fig. 3) along with its corresponding observed pressure, P .

NOTE 8—Traditionally, the extrapolated onset temperature (T_o) of an endotherm recorded by DSC is used as the transition temperature; the peak maximum temperature (T_e) is used for thermocouple inserted DTA configurations. The convention employed during temperature calibration shall be used for these calculations.

12.2 If necessary, correct the observed pressures and temperatures by the amount determined from the calibrations. Plot the logarithms of pressure ($\log_{10}P$) versus the reciprocal of the absolute temperature ($1/T$, K^{-1}). Examine this plot for any abrupt deviation from linearity as evidence of instability.

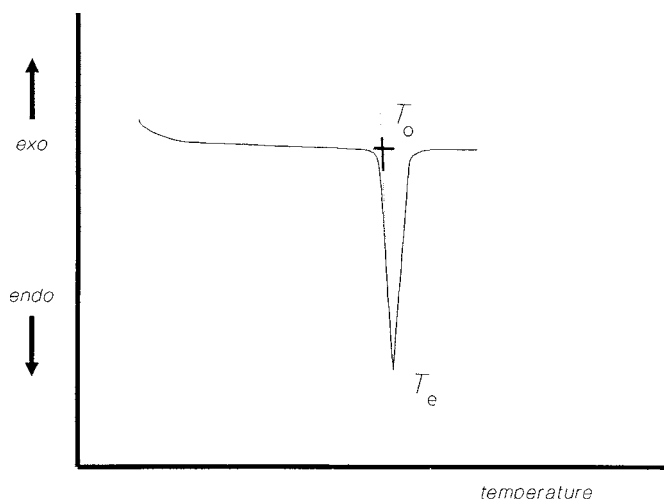


FIG. 3 Boiling Endotherm from DSC/DTA Instrumentation with: extrapolated Onset, T_o and Peak Maximum, T_e

NOTE 9—Deviations from linearity (curvature) due to expected decreases in enthalpy of vaporization with temperature (Antoine equation “C” constant negative) should not be confused with the abrupt deviation due to decomposition or polymerization. Curvature of normal data is barely perceptible.

12.3 Calculate the Antoine vapor pressure equation constants: A , B , and C retaining all available decimals using a nonlinear least-squares regression program to fit the Antoine equation, $\log_{10} P = A - B/(T + C)$ to the corrected pressure-temperature data points. Data for which any of the fitted Antoine equation constants fall outside of ranges given in Note 10 shall be rejected.

NOTE 10—This test method uses the SI units of Kelvin for temperature instead of the traditional use of Celsius. The only effect of this change is to make the “C” constant of the Antoine equation a negative value. Antoine equation constants (for $\log_{10}$, kPa, and K units) typically fall in these ranges:⁴ A , 4.9 to 7.8; B , 750 to 3000; and C , -235 to -3. If a nonlinear least-squares regression program is not available, a multilinear least-squares regression program may be used for Antoine equation fitting by making these variable transformations:⁵ $a = A$; $b = A * C - B$; and $c = -C$. The fitting equation, now linear in the parameters, is:

$$t * \log_{10} P = a * t + b + c * \log_{10} P$$

12.4 Using the Antoine equation with constants determined in 12.3, compute a table of pressure-temperature data pairs encompassing the range of conditions tested including the boiling point temperatures for pressures of 1000, 101.32 (760 torr), and 10 kPa and the vapor pressure at 293.15 K (20 °C).

13. Report

13.1 Report the following information:

13.1.1 Sample identity, purity (if known or determined, as well as how it was determined), and source,

13.1.2 A table of the corrected pressure-temperature data points,

13.1.3 The Antoine vapor pressure equation constants A , B , and C rounded to the nearest 0.000001,

13.1.4 A table of the computed pressure-temperature data including the boiling point temperatures at 1000, 101.32 (760 torr), and 10 kPa rounded to the nearest 0.1 K, and the vapor pressure at 293.15 K (20 °C) rounded to the nearest 0.1 kPa.

13.1.5 A graphic presentation of the vapor pressure curve including the regression fit to the Antoine vapor pressure equation, and

13.1.6 Any abrupt deviation from linearity in the vapor pressure curve and the temperature of its occurrence.

13.1.7 The specific dated version of this test method used.

14. Precision and Bias

14.1 *Interlaboratory Study (ILS)*—An interlaboratory study for measurement of vapor pressure by this test method was conducted in 1995. Two materials were studied: *n*-heptane and distilled water. Each of six laboratories measured vapor pressure data for *n*-heptane; each of six laboratories measured vapor pressure data for distilled water. Practice E 691 was followed for the ILS design and for the analysis of the data.

⁴ These ranges were determined by examination of Antoine equation literature and databanks, for example, see Refs (1) and (5).

⁵ This procedure was described in Ref (6).

14.2 Test Results—The precision information given below is for duplicate determinations of vapor pressure data calculated from the derived Antoine equations as described in 12.3.

14.3 Precision—The terms repeatability and reproducibility given below are used as specified in Practice E 177. Standard deviations among study results may be calculated by dividing the third and fourth table columns by 2.8.

14.3.1 Precision for *n*-Heptane:

	ILS Average	Repeat- ability	Repro- duc- ibility	NIST Data
Boiling point (K) at 1000 kPa	467.7	11.3	19.1	474.3
Normal Boiling point (K) at 101.325 kPa	371.2	2.0	3.5	371.6
Boiling point (K) at 10.0 kPa	308.3	3.2	3.6	308.5
Vapor pressure (kPa) at 293.15 K	4.9	0.9	1.0	4.7

14.3.2 Precision for Distilled Water:

	ILS Average	Repeat- ability	Repro- duc- ibility	NIST Data
Boiling point (K) at 1000 kPa	450.9	3.5	10.0	453.1
Normal Boiling point (K) at 101.325 kPa	373.6	1.0	2.9	373.2

Boiling point (K)	320.4	4.9	5.1	319.0
at 10.0 kPa				
Vapor pressure (kPa)	2.1	1.2	1.2	2.3
at 93.15 K				

14.4 Bias:

14.4.1 Bias for *n*-Heptane—The values listed in the NIST column in 14.3.1 can be used as accepted reference values as defined in Practice E 177. The deviation of the study results from the NIST Data is less than the reproducibility bounds.

14.4.2 Bias for Distilled Water—The values listed in the NIST column in 14.3.2 can be used as acceptable reference values as defined in Practice E 177. The deviation of the study results from the NIST Data is less than the reproducibility bounds.

15. Keywords

15.1 Antoine equation; boiling pressure; boiling temperature; differential scanning calorimetry (DSC); differential thermal analysis (DTA); vapor pressure

APPENDIX

(Nonmandatory Information)

X1. VAPOR PRESSURE OF WATER 5 kPa TO 2 MPa

TABLE X1.1 Vapor Pressure and Temperature

Pressure, MPa	Temperature, K	Pressure, MPa	Temperature, K	Pressure, MPa	Temperature, K
0.005	306.03	0.465	422.30	0.925	449.71
0.015	327.13	0.475	423.09	0.935	450.17
0.025	338.13	0.485	423.87	0.945	450.62
0.035	345.85	0.495	424.64	0.955	451.08
0.045	351.89	0.505	425.39	0.965	451.52
0.055	356.88	0.515	426.13	0.975	451.97
0.065	361.17	0.525	426.86	0.985	452.41
0.075	364.93	0.535	427.58	0.995	452.85
0.085	368.30	0.545	428.29	1.005	453.28
0.095	371.35	0.555	428.99	1.015	453.71
0.105	374.15	0.565	429.68	1.025	454.14
0.115	376.74	0.575	430.36	1.035	454.57
0.125	379.14	0.585	431.03	1.045	454.99
0.135	381.40	0.595	431.69	1.055	455.41
0.145	383.51	0.605	432.34	1.065	455.82
0.155	385.52	0.615	432.98	1.075	456.23
0.165	387.41	0.625	433.61	1.085	456.64
0.175	389.22	0.635	434.24	1.095	457.05
0.185	390.94	0.645	434.86	1.105	457.45
0.195	392.59	0.655	435.47	1.115	457.85
0.205	394.17	0.665	436.08	1.125	458.25
0.215	395.69	0.675	436.67	1.135	458.64
0.225	397.16	0.685	437.26	1.145	459.04
0.235	398.57	0.695	437.84	1.155	459.43
0.245	399.93	0.705	438.42	1.165	459.81
0.255	401.25	0.715	438.99	1.175	460.20
0.265	402.52	0.725	439.55	1.185	460.58
0.275	403.76	0.735	440.11	1.195	460.96

TABLE X1.1 Continued

Pressure, MPa	Temperature, K	Pressure, MPa	Temperature, K	Pressure, MPa	Temperature, K
0.285	404.96	0.745	440.66	1.205	461.33
0.295	406.13	0.755	441.21	1.215	461.71
0.305	407.27	0.765	441.75	1.225	462.08
0.315	408.38	0.775	442.28	1.235	462.45
0.325	409.46	0.785	442.81	1.245	462.82
0.335	410.51	0.795	443.33	1.255	463.18
0.345	411.54	0.805	443.85	1.265	463.54
0.355	412.54	0.815	444.37	1.275	463.90
0.365	413.52	0.825	444.87	1.285	464.26
0.375	414.48	0.835	445.38	1.295	464.62
0.385	415.42	0.845	445.88	1.305	464.97
0.395	416.34	0.855	446.37	1.315	465.32
0.405	417.24	0.865	446.86	1.325	465.67
0.415	418.12	0.875	447.34	1.335	466.02
0.425	418.99	0.885	447.83	1.345	466.36
0.435	419.84	0.895	448.30	1.355	466.71
0.445	420.68	0.905	448.77	1.365	467.05
0.455	421.50	0.915	449.24	1.375	467.39
1.385	467.73	1.845	481.52		
1.395	468.06	1.855	481.79		
1.405	468.40	1.865	482.06		
1.415	468.73	1.875	482.33		
1.425	469.06	1.885	482.59		
1.435	469.39	1.895	482.86		
1.445	469.71	1.905	483.12		
1.455	470.04	1.915	483.38		
1.465	470.36	1.925	483.64		
1.475	470.68	1.935	483.90		
1.485	471.00	1.945	484.16		
1.495	471.32	1.955	484.42		
1.505	471.63	1.965	484.68		

TABLE X1.1 *Continued*

Pressure, MPa	Temperature, K	Pressure, MPa	Temperature, K	Pressure, MPa	Temperature, K
1.515	471.95	1.975	484.93		
1.525	472.26	1.985	485.19		
1.535	472.57	1.995	485.44		
1.545	472.88	...	...		
1.555	473.19	...	...		
1.565	473.50	...	...		
1.575	473.80	...	...		
1.585	474.11	...	...		
1.595	474.41	...	...		
1.605	474.71	...	...		
1.615	475.01	...	...		
1.625	475.31	...	...		
1.635	475.60	...	...		
1.645	475.90	...	...		
1.655	476.19	...	...		
1.665	476.48	...	...		
1.675	476.78	...	...		
1.685	477.06	...	...		

TABLE X1.1 *Continued*

Pressure, MPa	Temperature, K	Pressure, MPa	Temperature, K	Pressure, MPa	Temperature, K
1.695	477.35	...	...		
1.705	477.64	...	...		
1.715	477.93	...	...		
1.725	478.21	...	...		
1.735	478.49	...	...		
1.745	478.77	...	...		
1.755	479.05	...	...		
1.765	479.33	...	...		
1.775	479.61	...	...		
1.785	479.89	...	...		
1.795	480.16	...	...		
1.805	480.44	...	...		
1.815	480.71	...	...		
1.825	480.98	...	...		
1.835	481.25	...	...		

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