



## Standard Test Method for Vapor Pressure<sup>1</sup>

This standard is issued under the fixed designation E 1194; 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.

<sup>ε1</sup> NOTE—Section 13 was added editorially in April 1993.

### 1. Scope

1.1 This test method describes procedures for measuring the vapor pressure of pure liquid or solid compounds. Since no single technique is available to measure vapor pressures from  $1 \times 10^{-11}$  to 100 kPa (approximately  $10^{-10}$  to 760 torr), two procedures are presented. An isoteniscope (standard) procedure for measuring vapor pressures of liquids from  $1 \times 10^{-1}$  to 100 kPa (approximately 1 to 760 torr) is available in Test Method D 2879. A gas-saturation procedure for measuring vapor pressures from  $1 \times 10^{-11}$  to 1 kPa (approximately  $10^{-10}$  to 10 torr) is presented in this test method. Both procedures are subjects of U.S. Environmental Protection Agency Test Guidelines.

1.2 These two methods were selected to provide data at normal environmental temperatures (10 to 60°C). At least three temperature values should be studied to allow definition of a vapor pressure-temperature correlation. Values determined should be based on temperature selections such that a measurement is made at 25°C (as recommended by IUPAC) (1),<sup>2</sup> a value can be interpolated for 25°C, or a value can be reliably extrapolated for 25°C. Extrapolation to 25°C should be avoided if the temperature range tested includes a value at which a phase change occurs. Extrapolation to 25°C over a range larger than 10°C should also be avoided. The test methods were selected because of their extended range, simplicity, and general applicability (2). Examples of results produced by the gas-saturation procedure during an interlaboratory evaluation are given in Table 1. These data have been taken from Reference (3).

1.3 *This standard does not purport to address all of the safety problems, 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:

D 2879 Test Method for Vapor Pressure-Temperature Rela-

**TABLE 1 Gas-Saturation Procedure Results Obtained During an Interlaboratory Evaluation**

Test Compound	Temperature, °C	Mean Vapor Pressures, kPa	Standard Deviation Estimate, $S_r^A$	Square Root, $S_r^B$	Precision Estimate, $S_r^C$
Naphthalene	25	$1.3 \times 10^{-2}$	0.31	0.39	0.50
	35	$3.5 \times 10^{-2}$	0.55	1.23	1.35
Benzaldehyde	25	$1.8 \times 10^{-1}$	0.31	1.24	1.28
	35	$2.8 \times 10^{-1}$	0.33	1.12	1.17
Aniline	25	$7.9 \times 10^{-2}$	1.9	3.8	4.3
	35	$1.5 \times 10^{-1}$	0.25	0.28	0.38
2-Nitrophenol	25	$1.2 \times 10^{-2}$	0.33	0.41	0.53
	35	$3.2 \times 10^{-2}$	0.53	1.57	1.66
Benzoic Acid	25	$1.5 \times 10^{-4}$	0.32	1.69	1.72
	35	$5.7 \times 10^{-4}$	2.3	5.2	5.7
Phenanthrene	25	$1.6 \times 10^{-5}$	0.36	0.46	0.58
	35	$4.7 \times 10^{-5}$	2.41	2.39	2.42
2,4-Dinitrotoluene	25	$7.1 \times 10^{-5}$	1.9	6.3	6.6
	35	$2.3 \times 10^{-4}$	1.0	3.2	3.4
Anthracene	25	$6.0 \times 10^{-6}$	3.7	13.8	14.3
	35	$1.1 \times 10^{-5}$	0.23	2.29	2.30
Dibutylphthalate	25	$6.8 \times 10^{-6}$	4.4	8.8	9.8
	35	$2.0 \times 10^{-5}$	0.49	2.28	2.33
p,p'-DDT	25	$1.7 \times 10^{-7}$	0.55	1.66	1.75
	35	$5.7 \times 10^{-7}$	11.1	4.7	12.1

<sup>A</sup>  $S_r$  is the estimated standard deviation within laboratories, that is, an average of the repeatability found in the separate laboratories.

<sup>B</sup>  $S_L$  is the square root of the component of variance between laboratories.

<sup>C</sup>  $S_R$  is the between-laboratory estimate of precision.

tionship and Initial Decomposition Temperature of Liquids by Isoteniscope<sup>3</sup>

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of Test Methods<sup>4</sup>

2.2 U.S. Environmental Protection Agency Test Guidelines: Toxic Substances Control Act Test Guidelines; Final Rules, Vapor Pressure<sup>5</sup>

### 3. Terminology Definition

3.1 *vapor pressure*—the pressure of the vapor of a substance in equilibrium with the pure liquid or solid of the same substance at a given temperature (4).

### 4. Summary of Isoteniscope Method

4.1 The isoteniscope method is a relatively simple technique

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee E-47 on Biological Effects and Environmental Fate and is the direct responsibility of Subcommittee E 47.06 on Environmental Fate of Chemical Substances.

Current edition approved Sept. 25, 1987. Published November 1987.

<sup>2</sup> The boldface numbers in parentheses refer to the list of references at the end of this test method.

<sup>3</sup> *Annual Book of ASTM Standards*, Vol 05.02.

<sup>4</sup> *Annual Book of ASTM Standards*, Vol 14.02.

<sup>5</sup> *Federal Register*, Vol 50, No. 188, 1985, pp. 39270–39273.

to use for vapor pressures of liquids above 0.133 kPa. The procedure is fully described in Test Method D 2879.

4.2 Dissolved and entrained gases are removed from the sample in the isoteniscope by heating the sample at reduced pressure. The vapor pressure of the sample at selected temperatures is determined by balancing the pressure due to the vapor of the specimen against a known pressure of an inert gas. The vapor pressure of the test compound is determined in sets of at least three points at each selected temperature. Without opening the test system, additional vapor pressure measurements are made, as necessary, to ensure that no additional degassing is needed, as described in the test method by changing the system temperature to the new temperature.

## 5. Summary of Gas-Saturation Method

5.1 Pressures less than 1.33 kPa may be measured using the gas-saturation procedure (4).

5.2 In this test method, an inert carrier gas (for example N<sub>2</sub>) is passed through a sufficient amount of compound to maintain saturation for the duration of the test. The compound may be coated onto an inert support (for example glass beads) or it may be in a liquid or solid granular form. The compound is removed from the gas stream using a suitable agent (sorber or cold trap). The amount of the test sample collected is then measured using gas chromatography or any other sensitive and specific technique capable of low-level detection.

## 6. Significance and Use

6.1 Vapor pressure values can be used to predict volatilization rates (5). Vapor pressures, along with vapor-liquid partition coefficients (Henry's Law constant) are used to predict volatilization rates from liquids such as water. These values are thus particularly important for the prediction of the transport of a chemical in the environment (6).

## 7. Reagents and Materials

7.1 The purity of the substance being tested shall be determined and documented as part of the effort to define the vapor pressure. If available, all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society.<sup>6</sup>

7.2 Every reasonable effort should be made to purify the chemical to be tested. For the isoteniscope method, the vapor pressure reported is actually the sum of partial pressure resulting from the chemical being studied and its contaminants. There is no way of defining the partial pressure of all constituents. If this test method is used, the vapor pressure should be reported as a vapor pressure for the contaminated material and not as the pure component vapor pressure.

7.3 For the gas-saturation method, the results can be reported in terms of the partial pressure for each component of the mixture that is identified and quantified through the trapping procedure. However, unless the pure component

vapor pressures and the vapor/liquid activity coefficients of the contaminants are known, the results cannot be interpreted any more clearly. If the activity coefficient of the major constituent is defined as one ( $\gamma = 1$ ) its partial pressure and analytical purity data can be converted to a pure component vapor pressure.

## 8. Procedures

8.1 *Isoteniscope Procedure*—Refer to Test Method D 2879.

8.2 *Gas-Saturation Procedure:*

8.2.1 The test sample can be (1) coated onto clean silica sand, glass beads, or other suitable inert support from solution; (2) in solid granular form; or (3) a liquid. If using a coated-support procedure, the thickness of the coating must be sufficient to ensure that surface energy effects will not impact vaporization. Following volatilization the surface must remain completely coated with the test compound.

8.2.2 Coat the support prior to column loading, to ensure the support is properly coated. Use sufficient quantity of material on the support to maintain gas saturation for the duration of the test.

8.2.3 Put the support into a suitable saturator column. The dimensions of the column and gas velocity through the column should allow complete saturation of the carrier gas and negligible back diffusion.

8.2.4 Connect the front and back-up traps to the column discharge line downstream from the saturator column. Use the back-up trap to check for breakthrough of the compound from the front trap. For example systems, see Figs. 1-4.

8.2.5 Surround the saturator column and traps by a thermostated chamber controlled at the test temperature within  $\pm 0.05^\circ\text{C}$  or better.

8.2.6 If any test material is detected in the second trap, breakthrough has occurred and the measured vapor pressure may be too low. To eliminate breakthrough, take one or both of the following steps:

8.2.6.1 Increase trapping efficiency by using more efficient traps, such as a larger higher capacity or a different type of trap.

8.2.6.2 Decrease the quantity of material trapped by decreasing the flow rate of carrier gas or reduce the sampling period.

8.2.7 After temperature equilibration, the carrier gas passes through the specimen and the sorber (or cold) traps and exits from the thermostated chamber. The thermostatically-controlled chamber should utilize liquid baths. Liquid (water or oil) baths are suggested because of the difficulty in controlling temperatures in accordance with the tight specifications required (7) using air baths. Variations in the ambient temperature in facilities designed for hazardous chemical work make this a critical need.

8.2.8 Measure the flow rate of the effluent carrier gas at the adiabatic saturation temperature with a bubble meter or at ambient temperature for other, nonhumidifying devices considered suitable. Check the flow rate frequently during the procedure to ensure that the total volume of carrier gas is accurately measured. Use the flow rate to calculate the total volume (at room temperature) of gas that has passed through the specimen and sorber or trap.  $(\text{volume}/\text{time}) \times (\text{time}) = \text{volume}$ .

8.2.9 Measure the pressure at the outlet of the saturator.

<sup>6</sup> "Reagent Chemicals, American Chemical Society Specifications," Am. Chemical Soc., Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see "Reagent Chemicals and Standards," by Joseph Rosin, D. Van Nostrand Co., Inc., New York, NY, and the "United States Pharmacopeia."

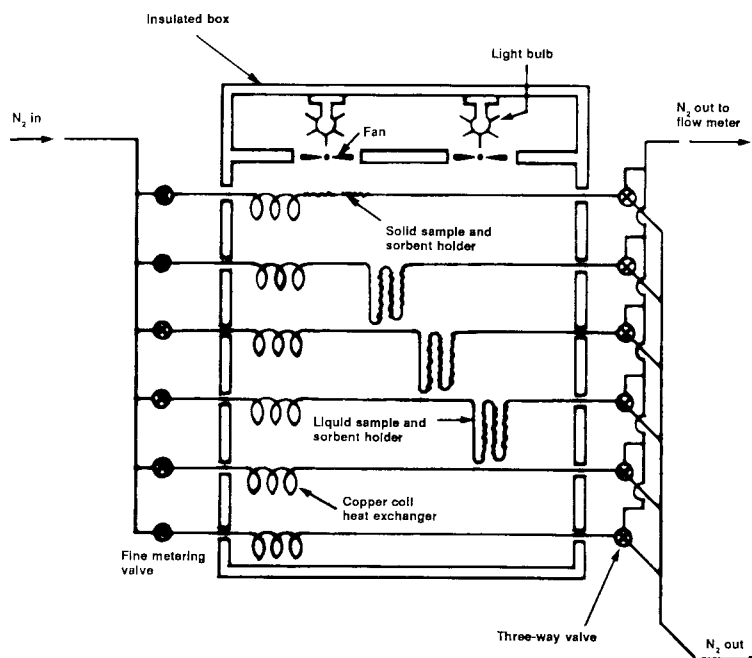


FIG. 1 Schematic Diagram of Vapor Saturation Apparatus

Determination of the saturator operating pressure is critical because it will always be above ambient pressure due to a pressure drop through the system. Measure either by including a pressure gage between the saturator and traps or by determining the pressure drop across the particular trapping system used in a separate experiment for each flow rate.

8.2.10 Calculate the test specimen vapor pressure (which is its partial pressure in the gas stream) from the total gas volume (corrected to the volume at the temperature at the saturator) and the mass of specimen vaporized.

8.2.11 Record the ambient pressure frequently during the test to ensure an accurate saturator pressure value. Laboratories are seldom at normal atmospheric pressure of 760 torr and this fact is often overlooked.

8.2.12 Determine the time required for collecting the quantity of test specimen necessary for analysis in preliminary runs or by estimates based on experience. Before calculating the vapor pressure at a given temperature, carry out preliminary runs to determine the flow rate that will completely saturate the carrier gas with sample vapor. To check, determine whether another flow rate at the same system temperature gives a different calculated vapor pressure.

8.2.13 Measure the desorption efficiency for every combination of sample, sorbent, and solvent used. To determine the desorption efficiency, inject a known mass of sample onto a sorbent. Then desorb and analyze it for the recovered mass.

8.2.14 For each combination of sample, sorbent and solvent used, make triplicate determinations at each of three concentrations. Desorption efficiency may vary with the concentration of the actual sample and it is important to measure the efficiency at or near the concentration of the sample under gas saturation test procedure conditions. It is usually necessary to interpolate between two measured efficiencies.

8.2.15 If the test specimen vapor pressure is very low, check and make sure significant amounts of the test specimen are not

lost on the surface of the apparatus. This is checked by a material compatibility test prior to loading the sorbent into the traps or saturation column. If the tested chemical has a significant affinity for the traps or saturation column material of construction, select and test an alternative material of construction.

8.2.16 When testing elevated temperature conditions, it is necessary that the system is operating at a uniform temperature. Contaminant condensation on cold spots will give low vapor pressure values.

8.2.17 The choice of the analytical method, trap, and desorption solvent depends upon the nature of the test specimen and the temperature conditions of interest.

8.2.18 Advantages of this test method when used with an analysis specific for the compound of interest are:

8.2.18.1 Minor impurities are not likely to interfere with either the test protocol or the accuracy of the vapor pressure results.

8.2.18.2 Pressures of two or more compounds may be obtained simultaneously, providing the compounds do not have significant vapor/liquid activity interaction.

## 9. Alternative Procedures

9.1 Although the procedures stated in Section 8 are preferred for vapor pressure measurement at ambient temperatures, many laboratories have employed other successful methods. If an alternative is chosen, determine the vapor pressure in triplicate at each of three temperatures and report the average value at each temperature. As stated in 1.2, determine a value at 25°C by direct measurement, interpolation, or reliable extrapolation.

## 10. Calculation

10.1 For the gas-saturation procedure, compute the vapor pressure based on the volume of gas passing through the

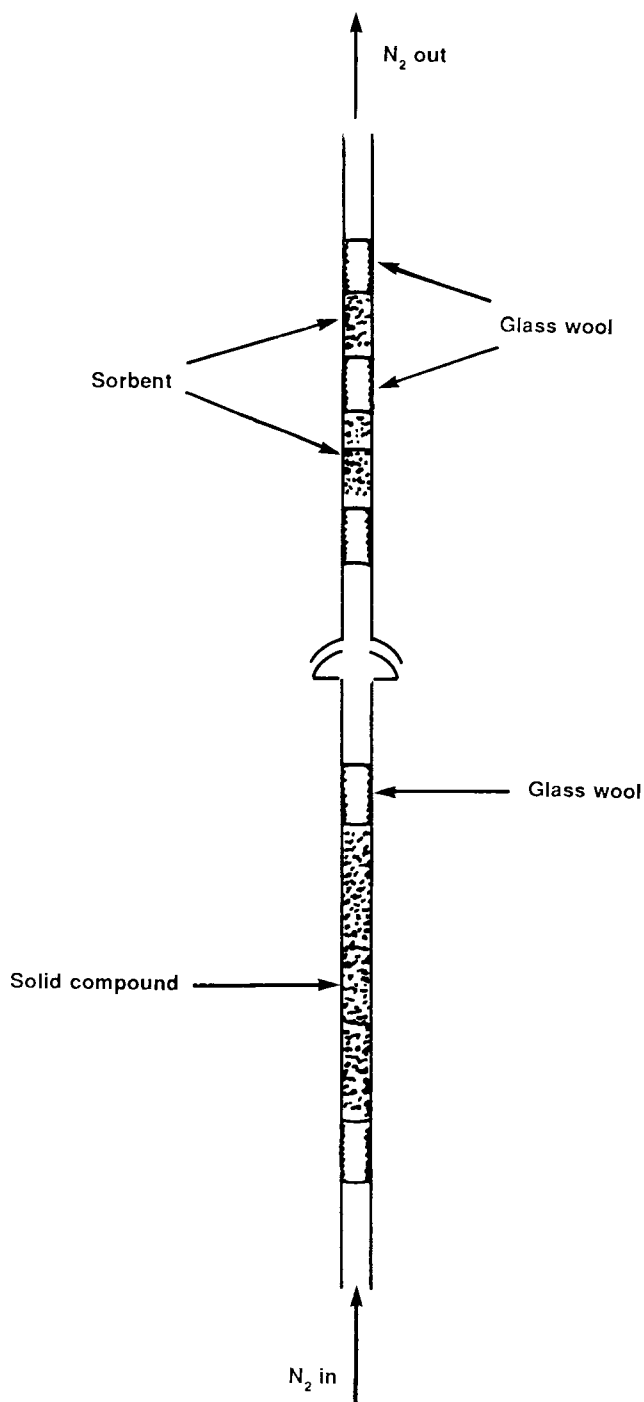


FIG. 2 Solid Compound Sampling System

saturator and traps and the quantity of chemical removed from the saturated gas stream. The calculations involve a series of equations that convert wet gas flow and mass of organic to the vapor pressure of the chemical in the dry gas at the saturator column outlet. The equations (7) used for the calculations are as follows:

$$Q_w = q(\Delta T) \quad (1)$$

$$Q_D = Q_w(P_T - P_{H_2O})/P_T \quad (2)$$

$$m_{gas} = Q_D/22414((273.15 + t_{exh})/(273.15)(760)/(P_T - P_{H_2O})) \quad (3)$$

$$m_{org} = W_{org}/M \quad (4)$$

$$y = m_{org}/m_{gas} \quad (5)$$

$$P = y(P_T - P_{H_2O} + \Delta P) \quad (6)$$

where:

- $T$  = elapsed time, min,
- $q$  = wet gas flow rate, L/min,
- $Q_w$  = wet gas flow, L,
- $Q_D$  = dry gas flow, L,
- $W_{org}$  = weight of trapped test chemical, g,
- $m_{org}$  = test chemical, mol,
- $m_{gas}$  = carrier gas, mol
- $P_T$  = total ambient pressure, torr,
- $P_{H_2O}$  = saturation water vapor pressure at adiabatic saturation temperature, torr
- $\Delta P$  = pressure drop through the system, torr,
- $P$  = vapor pressure, torr,
- $M$  = molecular weight of test chemical, g/mol,
- $t_{exh}$  = exhaust gas temperature, °C, and
- $y$  = fraction of test chemical in carrier gas, mol.

10.1.1 Report pressure in kilopascals (kPa). To convert or compare with other units, 1 torr = 0.13334 kPa and 1 atm = 101.3 kPa.

## 11. Report

11.1 Report the following information:

11.1.1 The test method used, along with any modification.

11.1.2 A complete description of all analytical methods used to analyze the test material and all analytical results.

11.1.3 For the isoteniscope procedure, the plot of  $\log P$  versus the reciprocal of the temperature in K, developed during the degassing step and showing linearity in the region of environmental concern and any other required test temperatures (See Appendix X1).

11.1.4 For the gas-saturation procedure, calculations of vapor pressure at three or more gas flow rates at each test temperature showing no dependence on flow rate.

11.1.4.1 Describe the sorbents and solvents employed and the desorption efficiency calculation.

11.1.5 Vapor pressure reported in kilopascals (kPa) at the experimental temperatures. It is suggested that at least three replicate samples be used at each temperature and the mean values obtained.

11.1.6 Average calculated vapor pressure at each temperature including the calculated standard deviation and the number of data points.

11.1.7 A description of any difficulties experienced or any other pertinent information such as possible interferences.

## 12. Precision and Bias

12.1 An interlaboratory evaluation was conducted at eight laboratories using the gas-saturation procedure and ten chemicals (8). The evaluation results are summarized in Table 1. Table 1 follows the format given in Practice E 691.

## 13. Keywords

13.1 gas saturation procedure; isoteniscope procedure; vapor pressure; vapor pressure temperature correlation

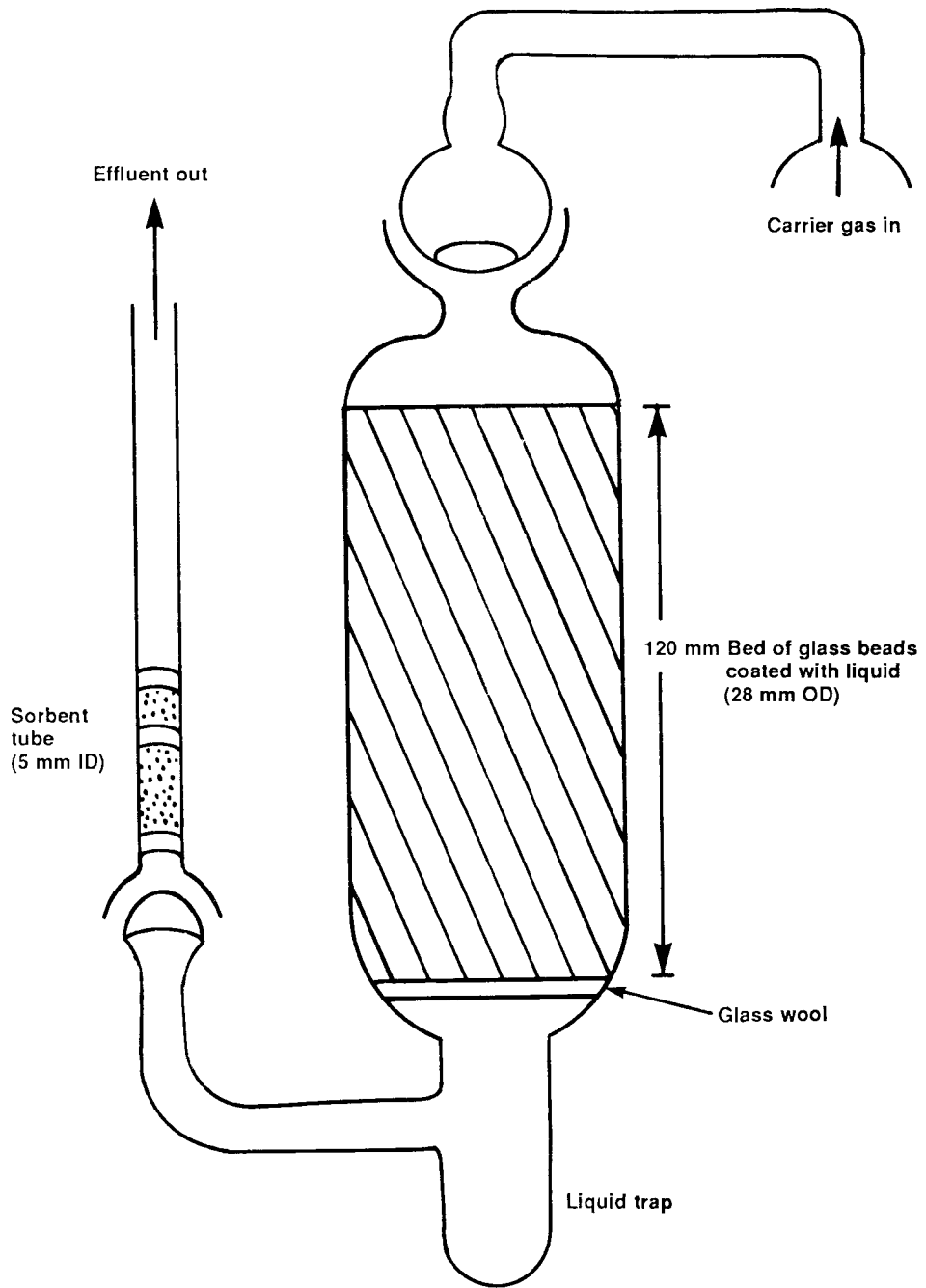


FIG. 3 Liquid Compound Sampling System

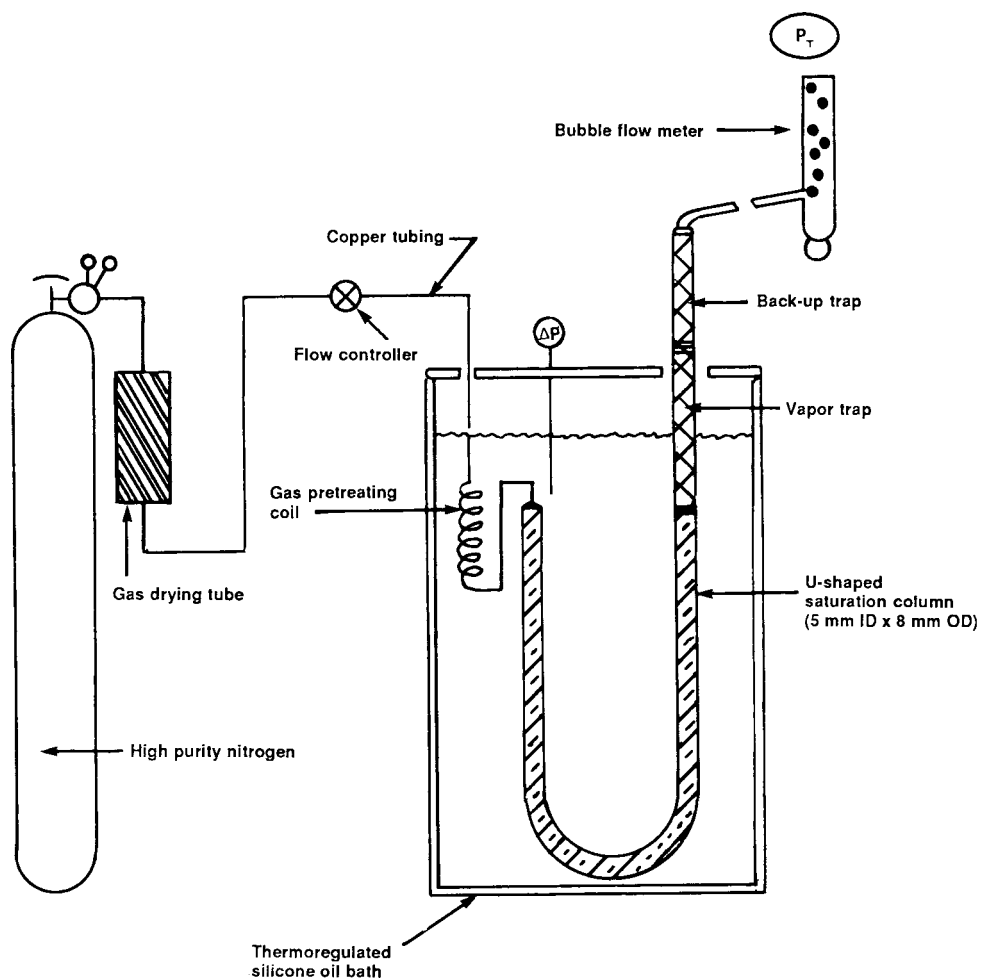


FIG. 4 The Flow Diagram of the Vapor Collection System

## APPENDIX

(Nonmandatory Information)

### X1. HEAT OF VOLATILIZATION

X1.1 Heat of volatilization may be obtained from a plot of log of vapor pressure versus the reciprocal of the temperature in K. The heat of volatilization is the heat of sublimation for a solid and heat of vaporization for a liquid. The change in vapor pressure with temperature is related to the molar heat of volatilization,  $H_{vol}$ , by the Clapeyron expression (4):

$$dP/dT = H_{vol}/T(\Delta V) \quad (X1.1)$$

where:  
 $\Delta V$  is the increase in volume when one mole of compound is vaporized.

At a sufficiently low temperature, when the vapor pressure is less than 10 to 20 kPa, the vapor may be assumed to obey the perfect gas law. Under these conditions, the above equation reduces to:

$$-d \ln P/d(1/T) = \Delta H_{vol}/R \quad (X1.2)$$

where:  
 =

$\Delta H_{vap}$  or  $\Delta H_{sub}$  may now be determined directly from the slope of the above plot.

## REFERENCES

- (1) International Union of Pure and Applied Chemistry (IUPAC), Commission on Thermodynamics and Thermochemistry, "A Guide to Procedures for the Publication of Thermodynamic Data," *Pure and Applied Chemistry*, Vol 29, 1972, pp. 387.
- (2) Thompson, G. W. and Douslin, D. R., "Determination of Pressure Volume," *Physical Methods of Chemistry*, Wiley Interscience, Vol 1, Part V, 1971.
- (3) Roublik, T., et al., *The Vapor Pressure of Pure Substances*, Elsevier Scientific Publishing Co., Amsterdam, 1973.
- (4) Spencer, W. F., et al., "Vapor Pressure and Relative Volatility of Ethyl and Methyl Parathion," *Journal of Agricultural and Food Chemistry*, Vol 27, 1978, p. 273.
- (5) Liss, P. S. and Slater, P. G., "Flux of Gases Across the Air-Sea Interface," *Nature*, Vol 247, 1974, p. 181.
- (6) Smith, J. H., et al., "Environmental Pathways of Selected Chemicals in Freshwater Systems," U.S. Environmental Protection Agency, Athens, Ga., Part 1, *EPA-600/7-77-113*, 1977.
- (7) Schroy, J. M., Hileman, F. D., and Cheng, S. C., "Physical Chemical Properties of 2,3,7,8-Tetrachloro-p-Dioxin," *Eighth Symposium on Aquatic Toxicology and Hazard Assessment, ASTM STP 891*. ASTM, 1985, pp. 409-421.
- (8) Zeilinski, W. L., Jr., et al., "Interlaboratory Evaluation of Vapor Pressure Test Standard Based on Gas Saturation Technique," National Bureau of Standards report to U.S. Environmental Protection Agency under EPA/NBS Interagency Agreement No. *EPA-80-D-X0958*, Task No. 6, 1983.

*The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.*

*This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 100 Barr Harbor Drive, West Conshohocken, PA 19428.*

*This standard is copyrighted by ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or [service@astm.org](mailto:service@astm.org) (e-mail); or through the ASTM website (<http://www.astm.org>).*