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A Volatile Aerosol Sampler and Particle Size Analyzer

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16. Abstract (Limit: 200 words) This report presents a prototype portable vapor/particle sampler (PVPS) which was developed for sampling and quantifying the phase distribution of volatile components in micrometer sized particles and coexisting vapors. The tool is relatively simple and inexpensive and serves as a personal and a field sampling device to measure the phase distribution of volatile organic compound (VOC) components. The sampler is appropriate for industrial sprays (reinforced plastic industry, paint spray booths), indoor sprays (air fresheners, cleaning solvents, insecticides, hair sprays, nail driers), and organic pesticide sprays in farmland or greenhouse environments. The author indicates that the concept of the PVPS can be extended to develop a particle size analyzer for measuring size distribution of the VOC containing particles by using a series of similar sampler units with different cut sizes. The PVPS was tested and calibrated using laboratory generate particles and vapors. Test results showed that some design modifications will improve the performance of the prototype and indicated that additional laboratory and field studies are needed to validate and modify the sampler.

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Significant Findings

A prototype portable vapor/particle sampler (PVPS) has been developed for sampling and quantifying the phase distribution of volatile components in micrometer sized particles and coexisting vapors.

Usefulness of Findings

The PVPS developed in this research project will make contributions to the proper assessment of worker exposure to VOCs:

1) The PVPS is a relatively simple and inexpensive personal and field sampling device for measuring the phase distribution of VOC components. The sampler may be used in many industry or household spray work environments, where the particle sizes are frequently large (> 1 μm). The applications may include: a) industrial spray, such as the reinforced plastic industry and paint spray booths; b) indoor sprays, such as household chemicals (air fresheners, cleaning solvents, insecticides) and products used in beauty salons (hairsprays, nail dryers); and c) organic pesticides sprays on farmland or in greenhouses.

2) The PVPS sampling techniques will provide data needed for proper evaluation of worker exposure to the vapor and particle phases of a VOC and for establishing the dual TLVs of vapors and particles.

3) The concept of the PVPS may be extended to develop a particle size analyzer for measuring size distribution of the VOC-containing particles by using a series of similar sampler units with different cut sizes.

Abstract

The airborne particle and vapor phases of a volatile organic chemical (VOC) often coexist in the real workplace environment. Assessment of worker exposure to a VOC requires measuring not only the total airborne concentration but also the phase distribution because the deposition efficiency of the material in the respiratory tract will depend on the form in which it is inhaled. Particle aerodynamic size distribution is also basic information that is needed for a realistic assessment of the inhalation risk to workers. However, air samplers presently in use are not adequate for efficient separation of the VOC vapor and particles, and there are currently no simple field sampling methods to measure the size distribution of particles that contain VOCs.

A prototype portable vapor/particle sampler (PVPS) has been developed for sampling and quantifying the phase distribution of volatile components in micrometer-sized airborne particles and coexisting gas phase according to differential inertia. The sampler may be used in many industry or household spray work environments, where the particle sizes are frequently large. The mass quantities of materials collected by the sampler can be determined by standard analytical procedures. The particle collection efficiency of the PVPS was measured with monodisperse particles in the aerodynamic diameter range of 0.03 – 10 µm. The vapor collection efficiency was measured with toluene, xylene and styrene in a test chamber equipped with a vapor generating device. The sample inlet flowrate is designed to be 1.8 LPM, which can be conveniently and reliably provided by lightweight, commercial personal sampling pumps.

The test results showed that some design modifications would improve the performance of the prototype sampler. These modifications and further testing are beyond the scope of the current work.

The concept of the PVPS may be extended to develop a particle size analyzer for measuring size distribution of the VOC-containing particles by using a series of similar sampler units with different cut sizes.

Background

Volatile organic chemicals (VOCs) are used in many industrial spraying processes. Airborne particle phase and vapor phase of a VOC often coexist in the real workplace environment. Measurements by our laboratory, during the process of a resin spraying operation in the reinforced plastic industry, showed that the styrene in aerosol droplets could contribute up to 30% of the total styrene concentration in the air (Malek et al. 1986). Cohen et al. (1992) further demonstrated that the concentrations of xylene contained in paint droplets during automobile paint spray operation could represent up to 50% of total airborne xylene concentration. Therefore, the actual worker exposure to a VOC is to both vapor phase and particle phase inhalation. Assessment of worker exposure to a VOC requires measuring not only the total airborne concentration but also the phase distribution because the deposition efficiency of the material in the respiratory tract depends on the form in which it is inhaled. The lung dose resulting from equal inhaled concentrations can differ substantially. The American Conference of Governmental Industrial Hygienists (ACGIH) Chemical Substances Threshold Limit Value (TLV) Committee has recognized this issue and suggested establishing dual TLVs for the two phases of a volatile substance (ACGIH 1983, Perez and Soderholm 1991).

For proper evaluation of worker exposure to the vapor and particle phases of a VOC and for establishing the dual TLVs of vapors and particles, personal and portable field sampling devices are needed for determination of the phase distribution of volatile components in industrial spray environment. Due to vapor evaporation from, and absorption by, particle surfaces in the sampling process, air samplers presently in use are not adequate for quantitative phase separation of a VOC component, and there are currently no simple field sampling methods to measure the size distribution of particles that contain VOCs.

Charcoal sorbent tubes (CST) are recommend by National Institute for Occupational Safety and Health (NIOSH) for sampling airborne vapors of volatile hydrocarbons. However, Cohen et al. (1992) found that the air concentrations of xylene sampled by CSTs were higher than those determined by 3M diffusion monitors (DMs) at paint spray operations. This is attributed to the capture not only vapor molecules but also particles by CSTs (Fairchild and Tillery 1977, Evans and Horstamn 1981). Experiments for examining the particle filtration characteristics of CSTs were done previously in this laboratory. Arizona road dust particles were used as test particles. The overall CST filtration efficiencies measured are in the range of 12% to 33%. The experimental results show that the CST filtration efficiency increases with particle size. They ranged from 10% for 0.5 µm particles at 400 ml / min flowrate to about 100% for particles greater than 2 µm. Particle size distribution in automobile paint spray applications were measured by Brosseau et al. (1992) with Marple personal impactors and a 6-stage Mercer impactor. The particles were large and polydisperse; geometric means of paint droplets ranged from 20 to 40 µm and geometric standard deviations of 2 to 3. It is suspected that the majority of paint droplets could be filtered by either the glass wool tip or the charcoal granules of CSTs. The concentration of an organic solvent sampled by a CST represents not only its airborne concentration in the vapor phase but also an indeterminate portion of the particle phase.

Conventional sampling methods use filters for collecting particles and pre-filtered charcoal sorbent tubes (F-CST) may be used for collecting both vapor and particles when they coexist in the environment. However, in view of the collection characteristics of CST's as noted above, F-CSTs together with CSTs cannot provide efficient separation of two phases of a VOC.

Gunderson and Anderson (1987) developed a 2-stage vapor/particle sampler for separating airborne vapor molecules and particles based on their differential diffusion rates. The sampler consists of a sorbent-coated tube preceding a filter. When sample air flows through the tube, vapor molecules diffuse faster than particles to the tube wall to be collected by the sorbent, and particles pass through the tube to be collected by the filter. Vapor collection efficiency by a sorbent-coated tube mainly depends upon the ratio of the residence time in the tube to that required for vapor molecules to diffuse to the tube wall. To achieve a high sorption efficiency, the flow residence time must be longer than the vapor diffusion time. However, for long residence times in the denuder, a vapor pressure gradient will be established due to removal of the vapor by the sorbent-coated wall, and will cause further evaporation from the particles.

Thus proper sampling devices, especially the personal and portable samplers, are needed for accurately measuring the phase distribution and the size distribution of volatile aerosols.

Specific Aims

1) Develop a prototype portable Vapor/Particle Sampler (PVPS) for sampling and quantifying the phase distribution of VOC substances in spray work environments.
2) Evaluate the performance of the PVPS.
3) Develop a prototype Multiple Vapor/Particle Sampler system (MVPS) for measuring size distribution of the particles that contain VOCs.

Procedures

A prototype PVPS was developed for sampling and quantifying the phase distribution of VOC components in particles and coexisting vapors. The design phase included the experimental determination of a) the optimum geometric parameters of the samplers; b) the optimum operating conditions of the samplers; c) the particle sampling efficiency as a function of the particle aerodynamic size; and d) Sampling artifacts, such as the loss of VOC components from the particle portion collected on the filter media.

Performance of the PVPS was evaluated by: a) comparing airborne vapor concentrations measured by the PVPS with those measured by charcoal sorbent tubes and 3M diffusion monitors; and b) comparing total airborne particle concentrations measured by the sampler with those measured by glassfiber filters for non-volatile test aerosols.

A prototype of MVPS system was also designed and fabricated for measuring size distribution of VOC containing particles based on the principles of the PVPS.

Methodology

Sampler Design

The PVPS was designed for rapid separation of the vapor phase and coexisting particle phase of an airborne VOC into two identifiable fractions according to their differential inertia. The quantities of materials collected by the sampler can be determined by standard chemical analytical procedures.

The MVPS consists of a series of vapor/particle samplers with different cut sizes. The design principles of each sampler unit of the MVPS is similar to the PVPS. With proper sampler geometrical design and flow conditions, the airborne particles can be quickly separated into two designed size fractions according to the differential inertia.

Sampler Calibration

The PVPS was tested and calibrated using laboratory-generated particles and vapors (Table 1). A vibrating orifice aerosol generator (VOAG) was employed to produce monodisperse fluorescein-tagged oleic acid particles in the particle size range greater than 1 µm (Figure 1). Monodisperse submicrometer fluorescein particles were obtained from a system that included a Collison nebulizer and an electrostatic classifier (Figure 2). The particle collection efficiency was measured for particle aerodynamic diameters of 0.03 – 10 µm. The vapor collection efficiency was measured with toluene, xylene and styrene in a test chamber equipped with a vapor generating device.

Table 1. PVPS Calibration Methods

Test Particles	Particle Size Range	Experimental Systems	Analytical Method
Monodisperse Fluorescein Tagged Oleic Acid	> 1 µm	VOAG – Climet System	Fluorometry
	< 0.8 µm	Nebulizer – DMA – CPC System	CPC

Performance Evaluation

To verify the sampler performance, measurements of the PVPS were compared with other well-established reference samplers. The intersampler comparison tests were carried out by comparing: a) the PVPS measurements of airborne vapor concentration from charcoal sorbent tubes and 3M diffusion monitors; b) the PVPS measurements of non-volatile monodisperse test particle concentrations from glassfiber filters.

Chemical Analytical Method for Organic Solvents

The samples of organic solvents collected by both the front and back sections of CSTs (as separate portions), glassfiber filters or the 3M diffusion monitors were desorbed with CS_2 and analyzed by gas chromatography according to NIOSH Manual of Analytical Methods (NIOSH 1994). Desorption efficiencies, which vary with the types of collectors and chemicals, were determined by applying a known amount of the chemical to the collectors.

Gas chromatograph (Varian Aerograph models 2700) was used in this study. The instrument is equipped with a flame ionization detector (FID), an electron capture detector and an interfaced integrator (Hewlett Packard Reporting Integrator 3390A). Optimum GC operating conditions, such as column types, carrier gas flowrates, column temperatures, etc., were chosen according to the types of chemicals to be analyzed. Calibration curves were determined for all chemicals of interest.

Results and Discussion

PVPS Design

A schematic design of PVPS is shown in Figure 3. The sampler consists of a sample flow inlet nozzle (1.0 mm), an anisokinetic tube, a 25mm glassfiber filter, and two charcoal sorbent tubes (CSTs). The flow inlet nozzle is aligned at the centerline of the anisokinetic tube and at the center of the filter disc. At the throat of the inlet nozzle, sample inlet flow (Q_0) splits into two flows, Q_p and Q_v, which instantly go in opposite directions. The Q_p flow travels in the same direction as the inlet flow while the Q_v flow turns 180° abruptly. Particles that pose larger inertia deviate from the Q_v streamline and follow the Q_p flow to be collected on the filter. The vapor in the air is divided into two dichotomous flow potions which are collected by two on-line charcoal sorbent tubes, CST1 and CST2, respectively. The CST1 also serves as a filter backup to collect the vapor potion that evaporated from the particles collected on the filter during the sampling process. The constant flowrates are controlled by needle valves and calibrated using a Gilibrator Primary Flow Calibrator

(Gilian Instrument Co., Wayne, New Jersey). The VOCs collected by the glassfiber filter and the two CSTs can each be desorbed by carbon disulfide (CS_2) and analyzed by gas chromatography separately.

Determination of the Airborne Concentrations of a VOC in the Particulate Phase (C_p) and in the Gas Phase(C_v):

The air concentrations of a VOC in the two phases can be determined based on measured values of the masses collected on the filter (M_f) and two charcoal sorbent tubes (M_{CST1} and M_{CST2}), and the sample inlet flowrate (Q_0) and the dichotomous flowrates, Q_p and Q_v, as:

$$C_v = \frac{M_{CST2}}{Q_v \times t} \qquad (1)$$

$$M_p = C_p \times (Q_0 \times t) = (M_f + M_{CST1}) - \left[\frac{Q_p}{Q_v}\right] M_{CST2} \qquad (2)$$

$$C_p = \frac{M_p}{Q_0 \times t} \qquad (3)$$

$$Q_0 = Q_p + Q_v \qquad (4)$$

Sample Inlet Flowrate

The sampler is designed to operate at a sample inlet flowrate of 1.8 LPM, which can be conveniently and reliably provided by lightweight, commercial personal sampling pumps.

The Particle Cut-off size (D_{50})

The particle cut-off size, D_{50}, is mainly determined by the sampling flowrate and the inlet nozzle size. It can be roughly estimated as shown below for select flow rates and nozzle diameters (Marple and Liu, 1974):

$$\sqrt{C}\, D_{50} = \sqrt{\frac{St_{50} 9 \mu W}{\rho_p V_0}} \qquad (5)$$

$$C = 1 + 1.257 \frac{2\lambda}{D_{50}} + 0.40 \frac{2\lambda}{D_{50}} \exp\left(-1.10 \frac{D_{50}}{2\lambda}\right) \qquad (6)$$

where, C is the slip correction coefficient; St_{50} is the Stokes number at 50% collection efficiency; μ is the fluid viscosity; W is the nozzle diameter; ρ_p is the particle density; V_0 is the average air velocity of sample flow in the nozzle throat; and λ is the mean free path of the air molecules.

For the dichotomous flow sampler, the cut-size is also determined by the dichotomous flow ratio ($\alpha = Q_p/Q_v$).

Particle Collection Efficiency

The particle collection efficiencies of the PVPS were measured for particle aerodynamic diameters of 0.03 – 10 µm at a total sampling flowrate of 1.8 LPM and two dichotomous flow ratios: α = 1:1 and 1:8 (Table 2). The calibration curves are shown in Figure 4.

Table 2. The particle Collection Efficiency of the PVPS with 1.0 mm Nozzle at a Total Sampling Flowrate of 1.8 LPM

Aerodynamic Particle Diameter (µm)	Particle Collection Efficiency (%)	
	α = 1:8	α = 1:1
0.1		54
0.2		60
0.3		67
0.4	12	72
0.5	19	77
0.6	25	81
0.7	32	84
0.8	41	86
0.9	50	88
1.0	59	89
≥ 2.0	≥ 93	≥ 95

Particles generated in spray processes are frequently large. According to the data measured in automobile paint spray process by Brosseau et al. (1992), the particles smaller than 2 µm hold less than 2% of the total mass concentration. Therefore, the PVPS can be used properly in the spray work environments.

Vapor Collection Efficiency

The vapor collection efficiency was measured with toluene, xylene and styrene in a chamber equipped with a vapor generating device and analyzed by gas chromatography. Testing of the vapor collection efficiency of the PVPS was focused on the ratio of the vapor fractions collected on the two CST tubes, CST1 and CST2, which should be represented by the ratio of the dichotomous flow rates. The 3M Diffusion Monitor (DM) and Charcoal Sorbent Tube (CST) were also used in the tests as reference samplers. The results are shown in Figure 5. Agreement between these measurements was within 6% (Table 3).

Table 3. Comparison of the Organic Vapor Concentration Data Measured by PVPS and the Reference samplers, 3M Diffusion Monitors and Charcoal Sorbent Tubes.

Sampler A	Sampler B	C_A / C_B (Mean ± S.D.)	Average
PVPS-CST1	PVPS-CST2	1.02 ± 0.02	1.02 ± 0.02
PVPS CST1	CST	0.96 ± 0.01	0.95 ± 0.01
PVPS CST2		0.93 ± 0.02	
PVPS CST1	DM	1.08 ± 0.03	1.06 ± 0.02
PVPS CST2		1.03 ± 0.02	

Comparison with Reference Glassfiber Filters

Intersampler comparison results showed a good agreement between the mass concentration data of monodisperse fluorescein particles measured by the PVPS and the reference filters (37 mm Glassfiber, whatman GF/A) with a correlation of $\frac{C_{PVPS}}{C_{Reference}} = 0.96 \pm 0.06$ (95% confidence interval, n = 13).

Wall loss

The mean wall loss of the sampler is (2.2±0.9)% with a maximum value of 5.2% for a test set of 13 samples (95% confidence interval).

Loss of the VOC Components from the Particulate Portion Collected on the Filter Media

Due to the rapid equilibrium between vapor and particle phase of a VOC, there is no conventional method for separating the particle-bound VOC and its co-existing vapor without disturbing the equilibrium between the two phases of a VOC. The innovative concepts of the PVPS are: 1) to separate particles from the air stream in a relatively short time period (milliseconds time-scale) to minimize disturbing the phase equilibrium; and 2) to pump out most particle-bound VOC components from filter into a backup charcoal sorbent tube, CST1, with an air flow passing the filter (Q_p). However, the particles collected on the filter media may also be exposed to the side stream air. Under normal sampling conditions, the concentrations of the pollutants are relatively stable. The particle-bound VOC will not be scrubbed into the side air stream (Q_v) due to the dynamic equilibrium. In the situation that ambient VOC concentrations change greatly during sampling process, for example, from highly contaminated air to relatively clean air, particle-bound VOCs may release into not only the air stream passing the filter but also the side air stream.

The quantity of the particle-bound VOC loss is difficult to determine since there are no standard volatile aerosol sources. Our laboratory tests were done by placing a small quantity (10 µl) of liquid Styrene onto the glassfiber filter of the PVPS and immediately closing the sampler and starting sampling. The VOCs will evaporate from the filter and escape to the ambient air during the sampler assembling process, and will be sampled back by CST tubes. The quantities of the VOC vapor loss and collection are unknown. An estimate can be made by assuming that value of the total vapor mass (M_v) to be collected is within 1 inch radius spherical volume (compare to the dimension of the PVPS):

$$M_v = \frac{PV}{RT} * M_w \tag{7}$$

where, P is the VOC partial pressure, V is the volume, R is the gas constant, T is the temperature, and M_w is the molecular weight. For Styrene, P = 6.10 mmHg at 25 °C, $V = \frac{4}{3}\pi r^3 = 69\ cm^3$, M_w = 104.16, so the total vapor mass is about 2.35 mg.

As shown in Table 4, the quantity of VOC loss to the side air stream depends on the dichotomous flowrate ratios, α. Therefore, the problem can be overcome by increasing α. However, corresponding to this increase, the measurement error will be increased. Although the above experiment is only an estimation and represents an extreme variation condition of the ambient environment, we have to use the results as our sample design criterion since there is no other standard. For the selection of the dichotomous flow ratio, α, an value of 1:8 is chosen for operating the sampler under the pseudo-equilibrium environmental conditions and an optimum value of 1:1 is selected for operating the PVPS under all circumstances.

*Table 4. Estimation of the Loss of Styrene from the Glassfiber Filter

$\frac{Q_p\ (\text{lpm})}{Q_v\ (\text{lpm})}$	$\left(\frac{M_{CST1}}{M_0}\right)_{exp}$ (%)	$\left(\frac{M_{CST1}}{M_0}\right)_{est}$ (%)	$\frac{\left(\frac{M_{CST1}}{M_0}\right)_{exp}}{\left(\frac{M_{CST1}}{M_0}\right)_{est}}$
$\frac{0.9}{0.9}$	82.8	83.6	0.99
	86.0		1.03
	92.3		1.10
	83.5		1.00
$\frac{0.85}{0.95}$	81.5	84.2	0.97
	80.0		0.95
$\frac{0.80}{1.00}$	80.5	85.1	0.95
	78.5		0.92
$\frac{0.2}{1.6}$	28.3	56.2	0.50
	21.9		0.39
	25.3		0.45

* M_{CST1} and M_{CST2} are the masses collected on the two CSTs, respectively. M_0 is the total styrene mass sampled ($M_0 = M_{CST1} + M_{CST2}$). The subscripts exp and est represents the experimental value and the estimated value, respectively.

Estimation of the Sampling Errors

The expected sampling error when mixed atmospheres are tested has been estimated by propagation of errors in terms of: a) the concentration ratio of the particle portion to the vapor portion of a VOC in air, $\frac{C_p}{C_v}$, and b) the ratio of the dichotomous flowrates of the two fractions. The variances of means of the vapor and particulate phase concentrations of a VOC, $S_r(C_v)$ and $S_r(C_p)$ can be derived from the equations (1) - (4) by using the propagation of error formulas (Taylor 1990):

$$[S_r(C_v)]^2 = \left(\frac{S(C_v)}{C_v}\right)^2 = \left(\frac{S(M_{CST2})}{M_{CST2}}\right)^2 + \left(\frac{S(Q_v)}{Q_v}\right)^2 \qquad (8)$$

$$[S_r(C_p)]^2 = \left(\frac{S(C_p)}{C_p}\right)^2$$

$$= \frac{[S(M_f)]^2 + [S(M_{CST1})]^2}{(M_p)^2} + \left(\frac{S(Q_0)}{Q_0}\right)^2 + \left(\frac{Q_p}{Q_0}\right)^2\left(\frac{C_v}{C_p}\right)^2\left(\left(\frac{S(M_{CST2})}{M_{CST2}}\right)^2 + \left(\frac{S(Q_p)}{Q_p}\right)^2 + \left(\frac{S(Q_v)}{Q_v}\right)^2 \right) \qquad (9)$$

where, M_f, M_{CST1} and M_{CST2} are the measurement values of VOC collected on the filter and two CSTs and M_p is the particle-bound VOC mass. $\frac{SM_f}{M_p}$, $\frac{SM_{CST1}}{M_p}$, and $\frac{SM_{CST2}}{M_{CST2}}$, are the mass measurement errors with a typical value of 2% for VOCs (NIOSH 1994). The variation of sampling flowrates, $\frac{S(Q_0)}{Q_0}$, $\frac{S(Q_p)}{Q_p}$, and $\frac{S(Q_v)}{Q_v}$ are generally within 5%.

As shown in Figure 6 and 7, the sampling errors are increased as Q_p/Q_0 increases and C_p/C_v decreases. However even when the dichotomous flow ratio is increased to 1:1, i.e., $Q_p = Q_v = 0.9$ lpm, for a total sampling flowrate of 1.8 lpm, the estimated sampling errors are: 1) under 10% when the particulate fraction of the total airborne concentration is higher than 40%; 2) 15% when the particulate fraction is in the range of 15–40%; and 3) 20% when the particulate fraction range is 8–15%, and are still in an acceptable range based on the theoretical analyses.

Multiple Vapor/Particle Sampler (MVPS) System

The concept of the PVPS sampler can be extended to produce a particle size analyzer. The prototype of MVPS system has been designed and fabricated, which consists of a series of vapor/particle samplers with different cut sizes including a PVPS ($D_{50} = 1.0$ µm). The principle of the other sample units is similar to the PVPS. With proper geometrical design and flow conditions, the airborne particles can be quickly separated into two designed size fractions according to the differential inertia. The aerodynamic cut-off sizes of the MVPS system are designed to be 1, 2.5, 4 and 10 µm, of which 4 and 10 µm are the ACGIH defined particle cut sizes for respirable and thoracic particulate mass fractions, respectively. Due to budget limitation, only feasible tests were performed for the units other than the PVPS. Further support is needed to complete the performance tests and calibrations of the whole MVPS system.

Conclusion

1) A prototype portable vapor/particle sampler (PVPS) has been developed and characterized for sampling and quantifying the phase distribution of volatile components in micrometer-sized particles and coexisting vapors. It is adequate for use in general industrial spray operations, where the particles are frequently large.

2) The PVPS is a relatively simple and inexpensive personal and field sampling device. It is quite small, about 1 inch in diameter and 3 inches long, and operates with a standard personal sampling pump. The quantities of materials collected by the sampler can be determined by standard chemical analytical procedures.

3) The PVPS was tested and calibrated using laboratory-generated particles and vapors. The particle collection efficiency of the PVPS has been measured for singled phase atmospheres with sample inlet flowrate of 1.8 LPM and dichotomous flowrate ratios of 1:8 and 1:1. The particle cut size of the PVPS is 1.0 μm with a dichotomous flowrate ratios of 1:8.

4) The possible loss of particle-bound VOC components to the side stream air caused by the environmental condition variations can be overcome by increasing the dichotomous flow ratio to 1:1. Although the increase causes an increase in sampling error, it is still in the acceptable error range based on the theoretical analysis.

5) The performance of the PVPS was tested by comparing: a) the total airborne particle concentration measurements of PVPS with those of glassfiber filters; and b) the airborne gas concentration measurements of PVPS with those of charcoal sorbent tubes and diffusion monitors. Agreement between these measurements was within 6%.

6) The application of the PVPS may include: a) industrial spray, such as the reinforced plastic industry and paint spray booths; b) indoor sprays, such as household chemicals (air fresheners, cleaning solvents, insecticides) and products used in beauty salons (hairsprays, nail dryers); and c) organic pesticides sprays on farmland or in greenhouses.

7) The PVPS sampling techniques will provide data needed for proper evaluation of worker exposure to the vapor and particle phases of a VOC and for establishing the dual TLVs of vapors and particles.

8) The concept of the PVPS sampler may be extended to develop a particle size analyzer for measuring size distribution of the VOC-containing particles by using a series of similar sampler units with different cut sizes.

9) The test results showed that some design modifications would improve the performance of the prototype PVPS. Additional laboratory and field studies are needed to validate and modify the sampler. Since there are no volatile aerosol standards, validation of the sampler may be performed by comparing the phase partition data of volatiles as measured by the PVPS and by other sampling

methods. These modifications and further testing are beyond the scope of the current work. We need continued support to develop and test this sampler.

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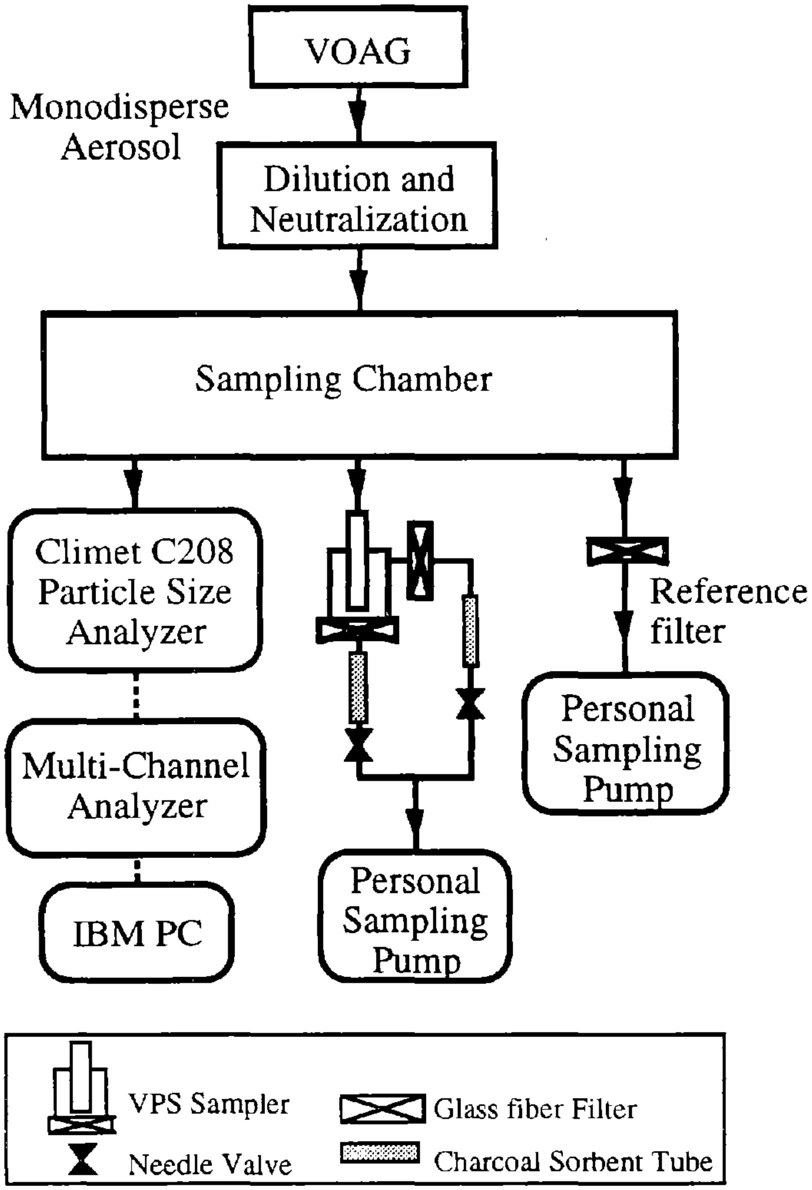


Figure 1. PVPS Calibration System (I).

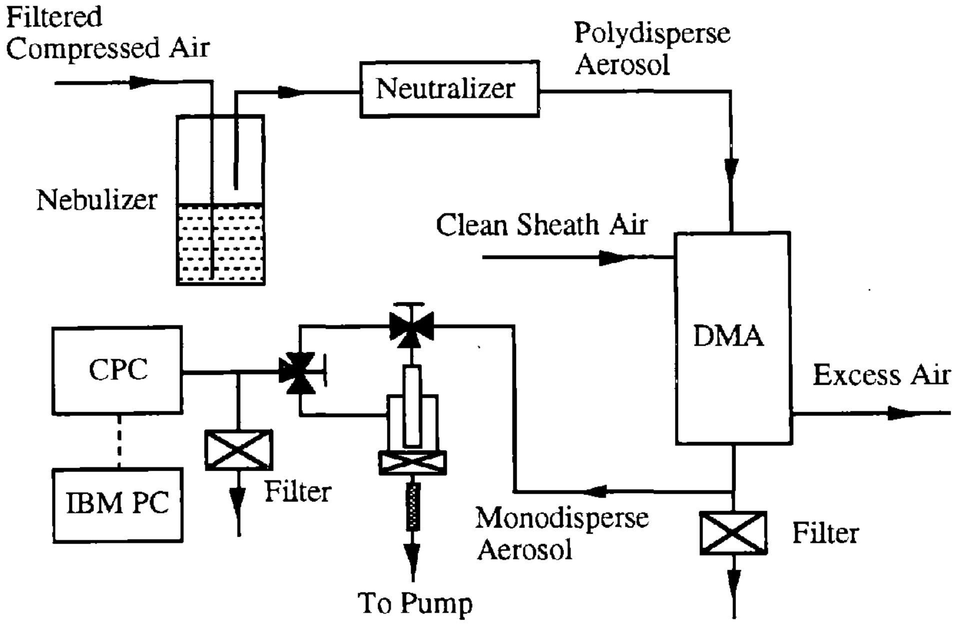
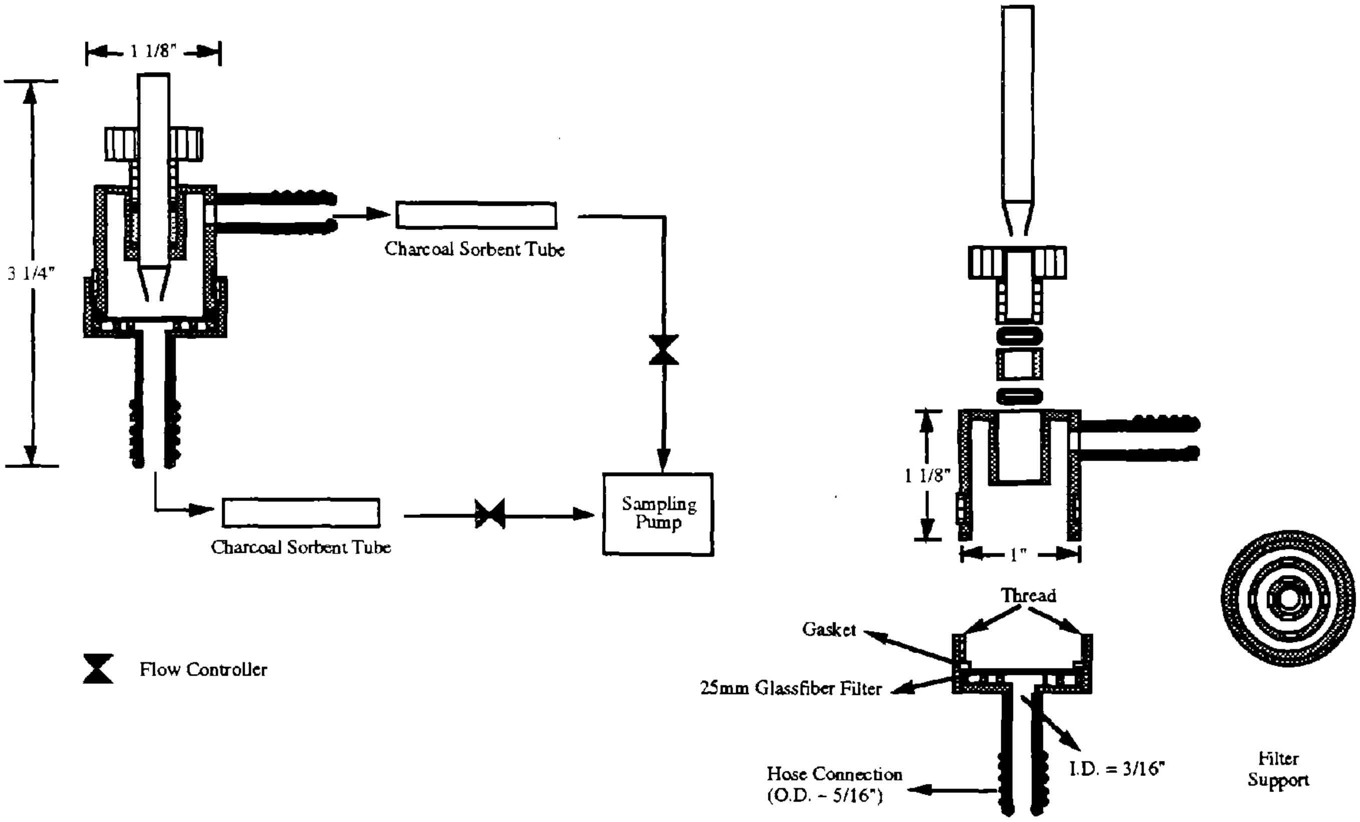


Figure 2. PVPS Calibration System (II).



PVPS
Vapor/Particle Sampler

Figure 3. Schematic diagram of the PVPS.

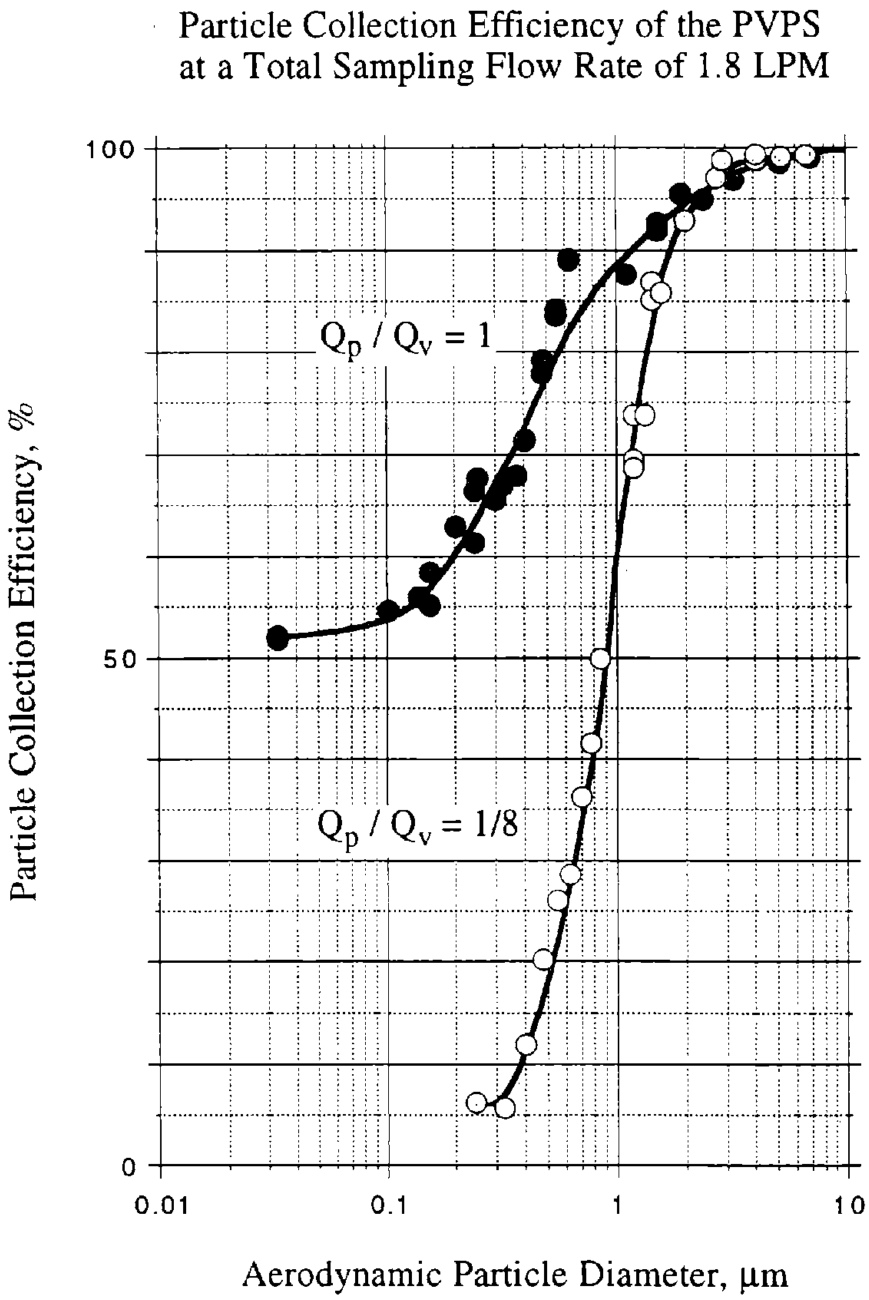


Figure 4. Particle Collection Efficiency of the PVPS.

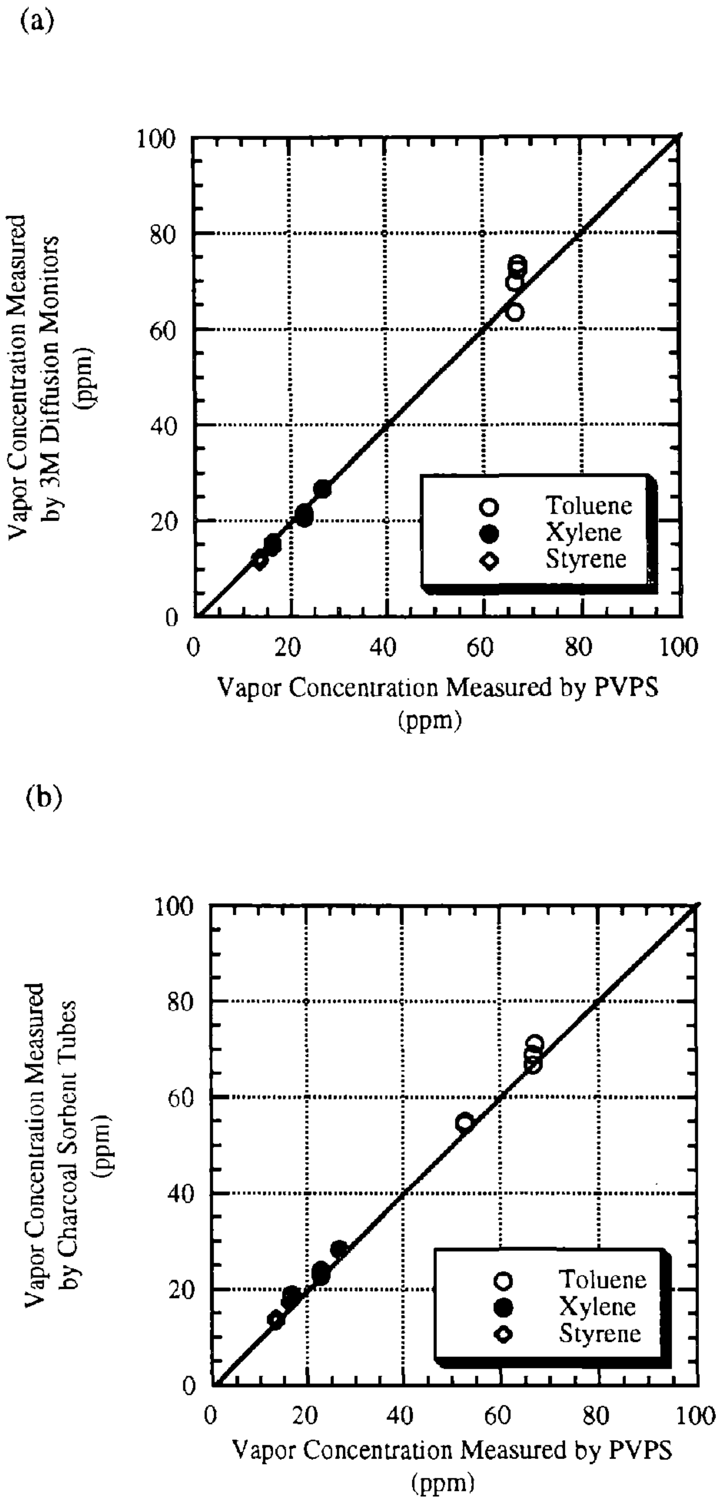


Figure 5. Comparison of Organic Vapor concentration Data Measured by PVPS and the Reference Samplers: (a) 3M Diffusion Monitors (DMs); and (b) Charcoal Sorbent Tubes (CSTs).

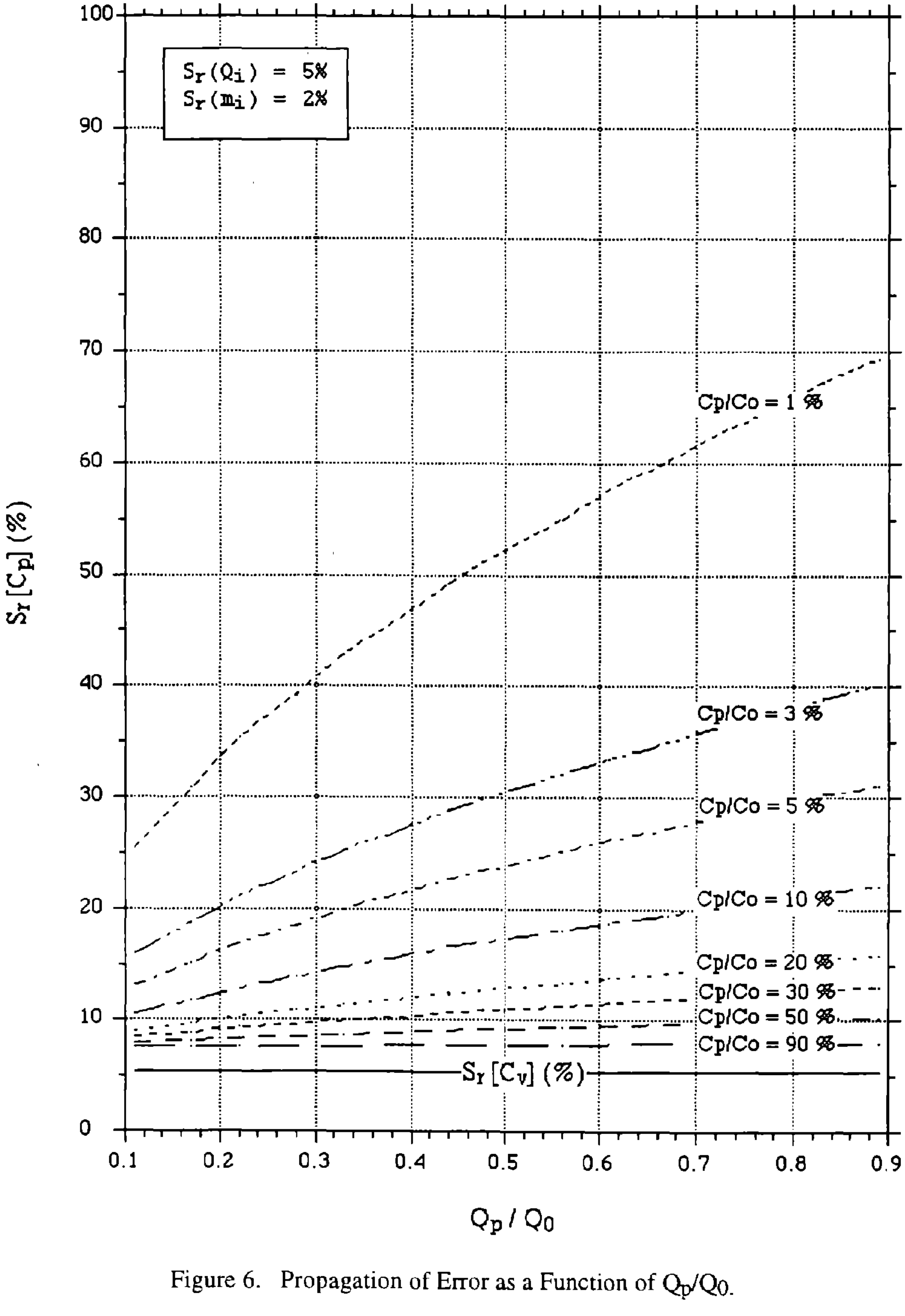


Figure 6. Propagation of Error as a Function of Q_p/Q_0.

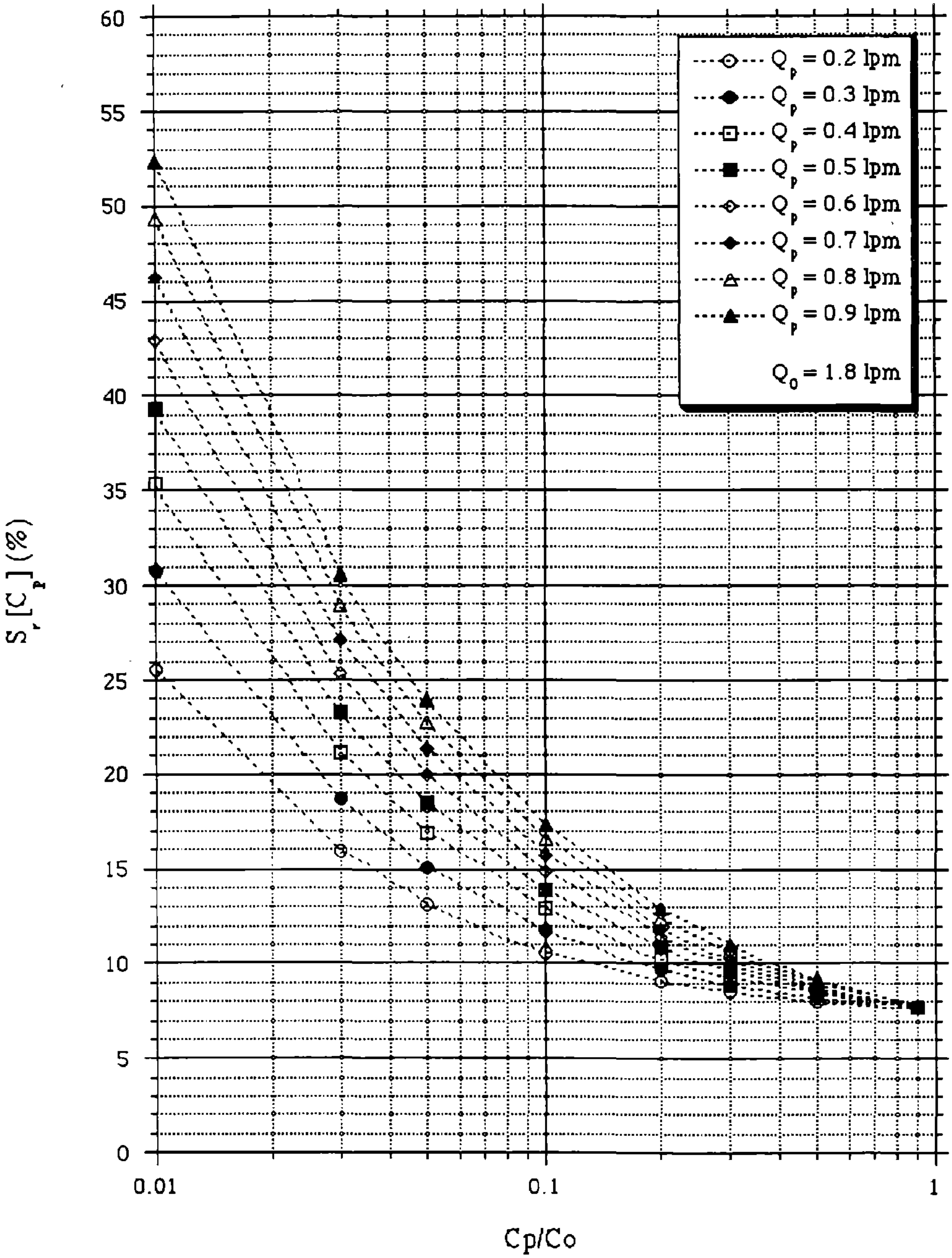


Figure 7. Propagation of Error as a Function of C_p/C_0.

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Planned Publications

Xiong, J.Q., C.P. Fang and B.S. Cohen, A Portable Vapor/Particle Sampler: Design and Calibration, (In preparation).

U.S. Patent Application

Xiong, J.Q., B.S. Cohen, and C.P. Fang, '*Portable Sampler for Volatile Aerosols*', Application Serial No. 08/569,504 (Filed on December 8, 1995).