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CHARACTERIZATION OF THE SCP 1021 AEROSOL SAMPLER

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13. ABSTRACT *(Maximum 200 words)*

This study characterized the SCP 1021 aerosol sampler (SCP Dynamics, Inc., Minneapolis, MN) at flow rates of 1350 L/min and 1000 L/min. Polydisperse aluminum oxide (Al_2O_3) particles were used as the solid particles, and the analysis was by Coulter counter. Fluorescent oleic acid particles were used as the monodisperse liquid particles, and the analysis was by fluorometry. The results show that (1) the sampling efficiency curves for both solid and liquid particles have a peak at approximately 5 - 6 μm, (2) there are no significant differences between the sampling efficiencies of the 1350 and 1000 L/min air flow rates, (3) there is no difference in sampling efficiency between the liquid and solid particles for particles smaller than 6 μm; however, large (> 6 μm) solid particles bounce when they hit surfaces and are carried by the air to the collection site, resulting in higher sampling efficiency for solid particles, (4) removing the inlet cap and the pre-collector increases the sampling efficiency for particles larger than approximately 4 μm, and (5) washing the final stage stem shows that there is significant particle loss in the stem that takes the aerosol to the liquid impaction/bubbling site.

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PREFACE

The work described in this report was authorized under Project No. 622384/ACB2, Non-Medical CB Defense, and Contract No. DAAD13-98-M-0083. The work was started in January 1999 and completed in July 2001.

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CONTENTS

FIGURES

TABLE

CHARACTERIZATION OF THE SCP1021AEROSOL SAMPLER

1. INTRODUCTION

This study was conducted to characterize the sampler SCP 1021 (SCP Dynamics, Inc., Minneapolis, MN). The performance of an aerosol sampler depends on the sampler's aspiration, transmission, and collection efficiencies. The aspiration efficiency of a sampler gives the efficiency with which particles enter into the sampler inlet; transmission efficiency gives the efficiency with which the particles are transported to the collection point, and the collection efficiency gives the efficiency with which particles are captured and retained by the sampling medium. The performance of a sampler is a product of aspiration, transmission, and collection efficiencies.

To determine the sampling efficiency of sampler, monodisperse fluorescent oleic acid particles were used with fluorometer analysis Kesavan and Doherty (2000a) and polydisperse aluminum oxide particles were used with Coulter analysis (Kesavan and Doherty 2001). Disadvantages of using monodispersed particles are that separate experiments have to be performed for each particle size. On the other hand, using a solid polydisperse aerosol and a Coulter counter analysis method provide a range of particle size information in one test. Particle bounce and re-entrainment are more likely to occur with solid particles when compared with liquid particles.

The objectives of this study were to (1) determine the sampling efficiency of the SCP 1021 sampler at a measured flow rate of 1350 L/min using solid particles, (2) determine the sampling efficiency at the recommended air flow rate of 1000 L/min using both solid and liquid particles, (3) determine the effect of the inlet cap and the pre-collector on sampling efficiency at the air flow rate of 1350 L/min, and (4) determine the amount of aerosol deposited in the stem that takes the concentrated aerosol to the liquid.

2. METHODS

2.1 Sampler

The SCP 1021 aerosol sampler is a high volume sampler. A picture of the sampler is shown in Figure 1. Figure 2 shows the sampler with the door open. The omni-directional cylindrical inlet is approximately 20 cm (8 inch) in diameter and 38 cm (15 inch) high. The rectangular base is 41.9 cm (16 ½ inch) wide, 46.4 cm (18 ¼ inch) long, and 36.8 cm (14 ½ inch) high (box alone). The table lists the operating characteristics of the sampler.

The sampler's recommended air flow rate is 1000 L/min, however, a measured flow rate of 1350 L/min was observed. A voltage controller was used to modify the power to the sampler to lower the actual flow rate of the sampler to the recommended flow rate of 1000 L/min.

The sampler has two virtual impactor concentration stages. A virtual impactor concentrates large particles by accelerating the particles through a nozzle and capturing particles larger than the cut-off point in a receiver port. A small portion of the air flow with the large particles is drawn into the receiver port while most of the air flow is discharged through the system. Virtual impactors are placed in series to concentrate the aerosol.

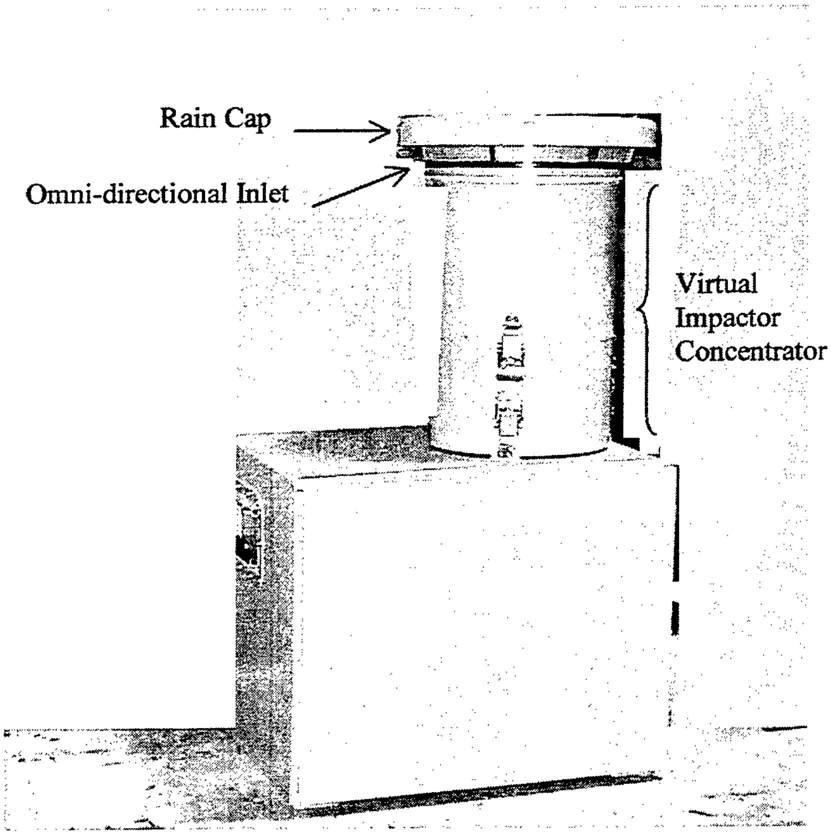

Figure 1. SCP 1021 High Volume Sampler.

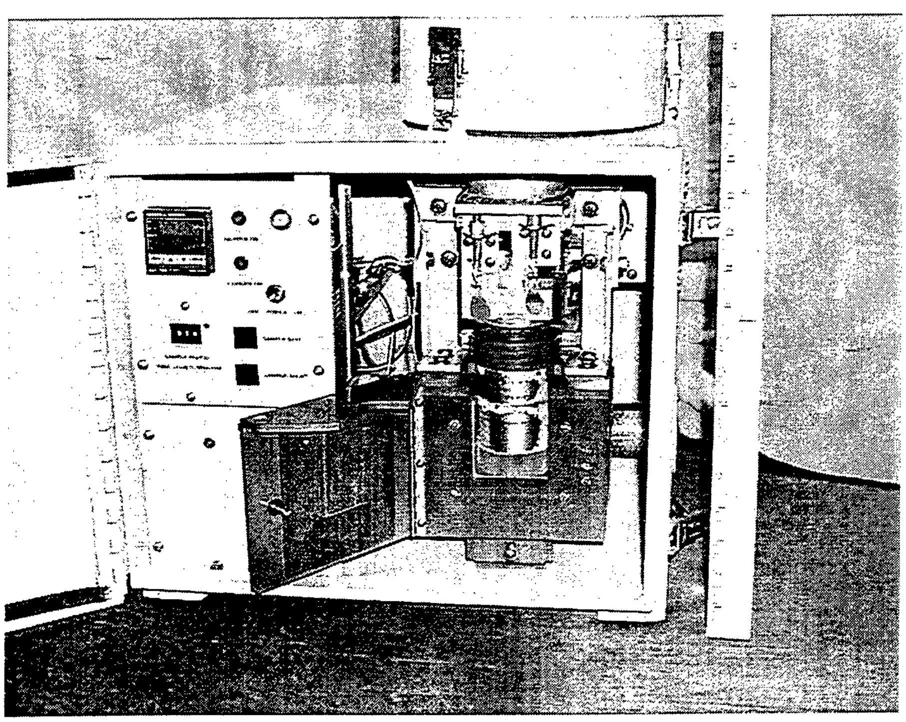
Figure 2. SCP 1021 Sampler with Door Open.

Table. Operating Characteristics of the SCP 1021 Sampler.

Characteristic	
Air sampling rate: measured, L/min recommended, L/min	1350 1000
Concentrated final flow rate through 40 cc of liquid, L/min	20
Overall dimensions, cm (inch) Length, Width, Height,	 46.4 (18 ¼) 41.9 (16 ½) 74.9 (29 ½)
Weight	80 lb 11 oz
Power, Watt Voltage, Volt Current, Amp	495 121.5 5.39

The first stage has multiple acceleration nozzles and receiver ports (Figure 3), and the second stage has a single slot acceleration nozzle and a receiver port (Figures 4a and 4b). The first virtual impactor stage concentrates particles larger than 2.5 μm from an air flow rate of 1000 L/min into an air flow rate of 100 L/min. The second virtual impactor stage further concentrates particles larger than 2.5 μm into a 20 L/min air flow rate. This particle enriched 20 L/min air stream is directed through a long stem to a collection cup containing 40 mL of liquid, which retain the particles by impaction and bubbling action.

Figures 5-7 show three different views of the collection cup. Figures 5 and 6 show, respectively, a side view and a top view. Figure 6 shows the center entrance for the concentrated air and the two outer holes for the air exit. Figure 7 shows the long stem, which transfers the aerosol to the collection liquid. It was noted that the long narrow stem, Figure 7, removes significant amounts of particles from the air stream.

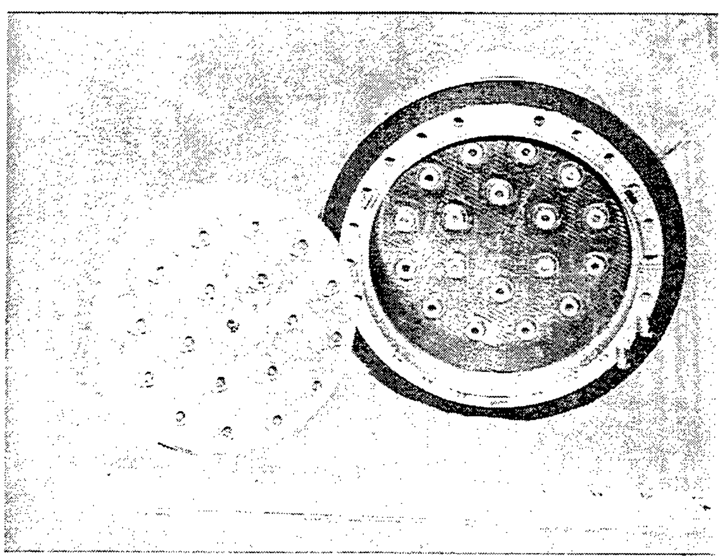

Figure 3: First Concentration Stage of Sampler SCP 1021.

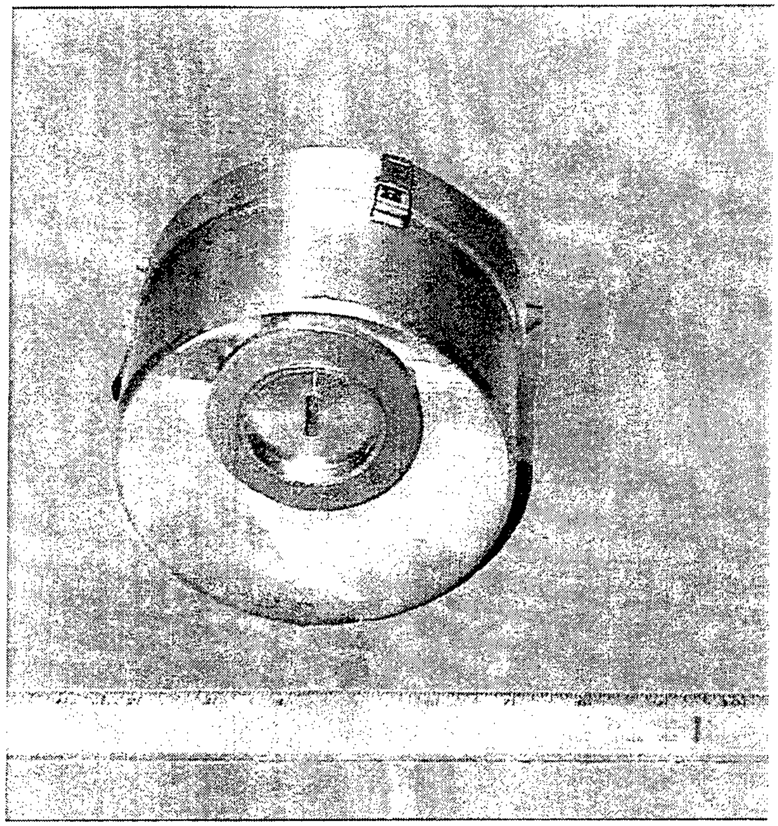

Figure 4a. Second Concentration Stage, Front View.

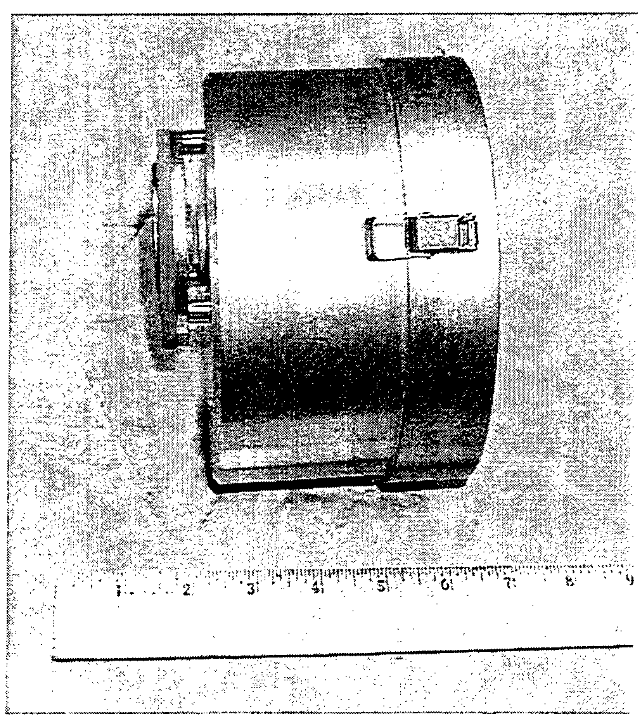

Figure 4b. Second Concentration Stage, Side View.

Power needed (table) and the power actually used by the samplers are important information to determine the use of the sampler in the field. Ideal power, W, to draw air through the sampler is,

$$W = Q\,\Delta P,$$

where Q is the volumetric flow rate, and ΔP is the pressure drop across the system. The expression does not include power losses in either the blower or vacuum pump.

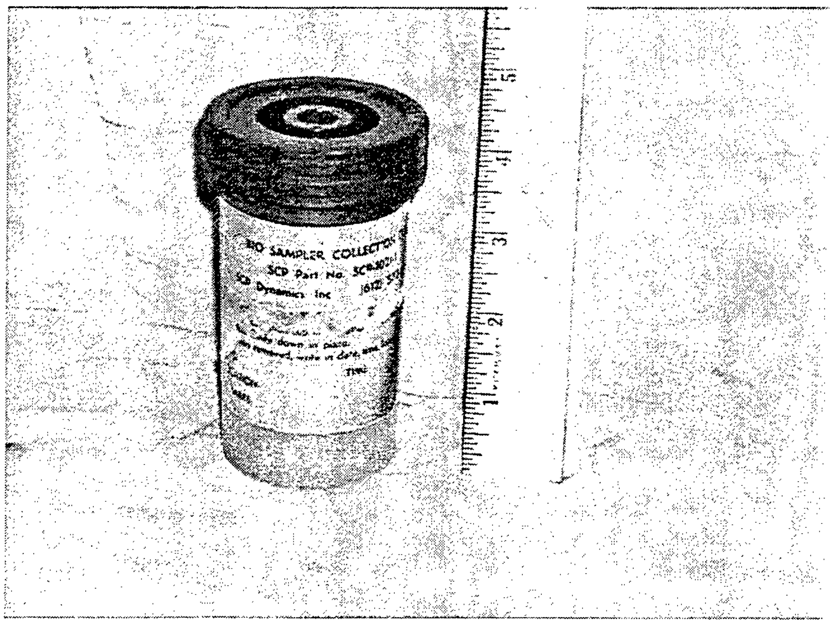

Figure 5. Collection Cup, Side View.

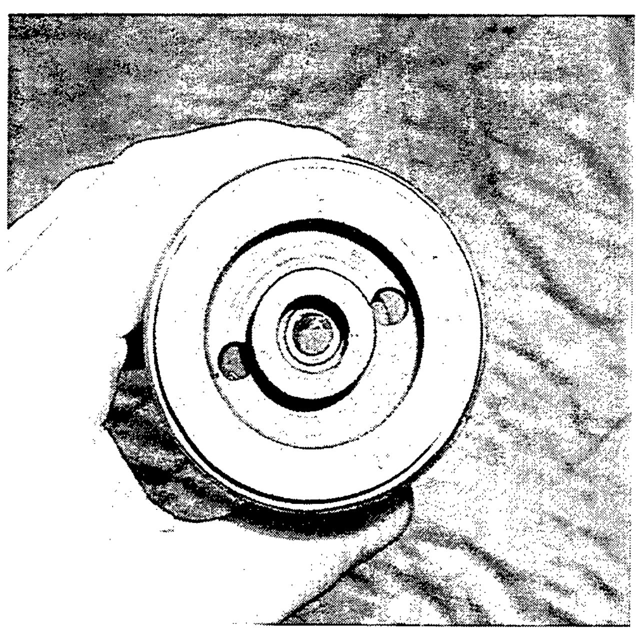

Figure 6. Collection Cup, Top View. The concentrated air enters the cup through the middle and exits through the two outer holes.

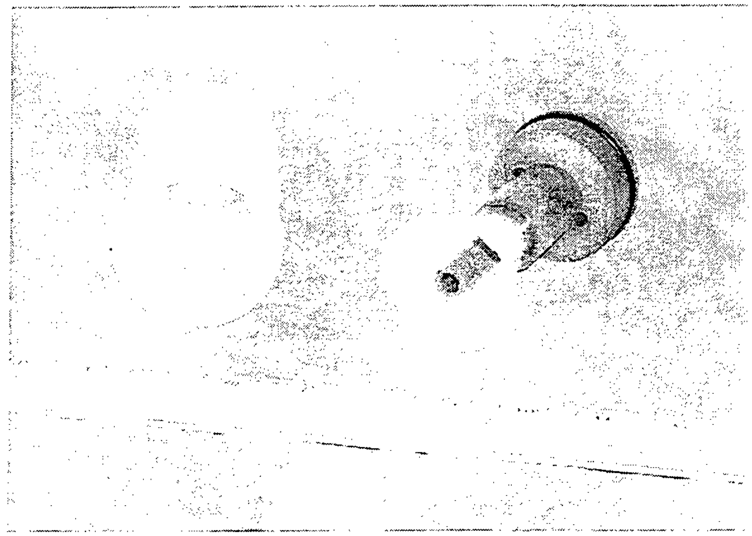

Figure 7. Disassembled Collection Cup. The long stem takes the aerosol to the liquid.

2.2 Chamber.

We conducted the sampler characterization tests in a 70 m^3 chamber (Figure 8). This is a bio-safety level 1 chamber and ultraviolet light sources are installed in the chamber to kill biological material. The temperature and the humidity of the chamber can be set and maintained by a computer. A fan in the chamber mixes the aerosol during the experiment.

Air entering and exiting the chamber are filtered by HEPA filters. Such filters are useful in controlling very low particle concentrations in the chamber. The maximum amount of air flow that can be exhausted from the chamber is approximately 700 cfm using the exhaust pump. This rapidly reduces the aerosol concentration in the chamber. There is also a small re-circulation system that removes air from the chamber, passes it through a HEPA filter, and delivers it back to the chamber. This system is useful when the aerosol concentration in the chamber needs to be reduced by a small amount.

2.3 Al_2O_3 Aerosol with Coulter Analysis Method.

2.3.1 Al_2O_3.

Polydisperse irregularly shaped solid Al_2O_3 particles (Saint-Gobain Industrial Ceramics, Worcester, MA) were used in this study. Two different mass medium diameter polydisperse Al_2O_3 particles were mixed to obtain approximately equal number of particles over the size range of 2 to 12 μm. A density of 4 g/cm^3 was obtained for Al_2O_3 particles using an Autopycnometer (Micromeritics, Norcross, GA) (Kesavan and Doherty, 2000b). A dynamic shape factor correction of 1.22 was used for the Al_2O_3 particles (Vincent, 1989). Both a density and dynamic shape factor corrections were used to convert the volume equivalent diameter measured by the Coulter analyzer into an aerodynamic diameter.

The Al_2O_3 particles were aerosolized by a sonic nozzle (Witham and Gates, 1983). SEM analyses of collected samples showed that the sonic nozzle de-agglomerates the particles into single particles (Figure 9).

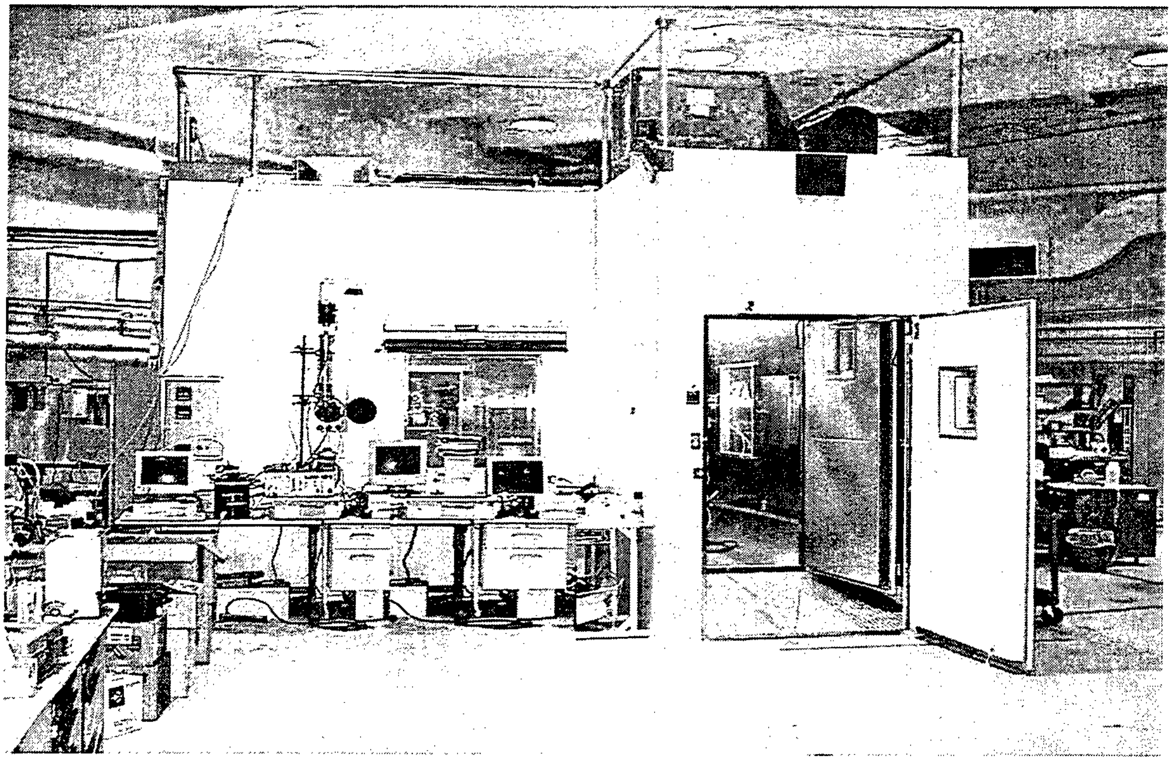

Figure 8. Aerosol Chamber.

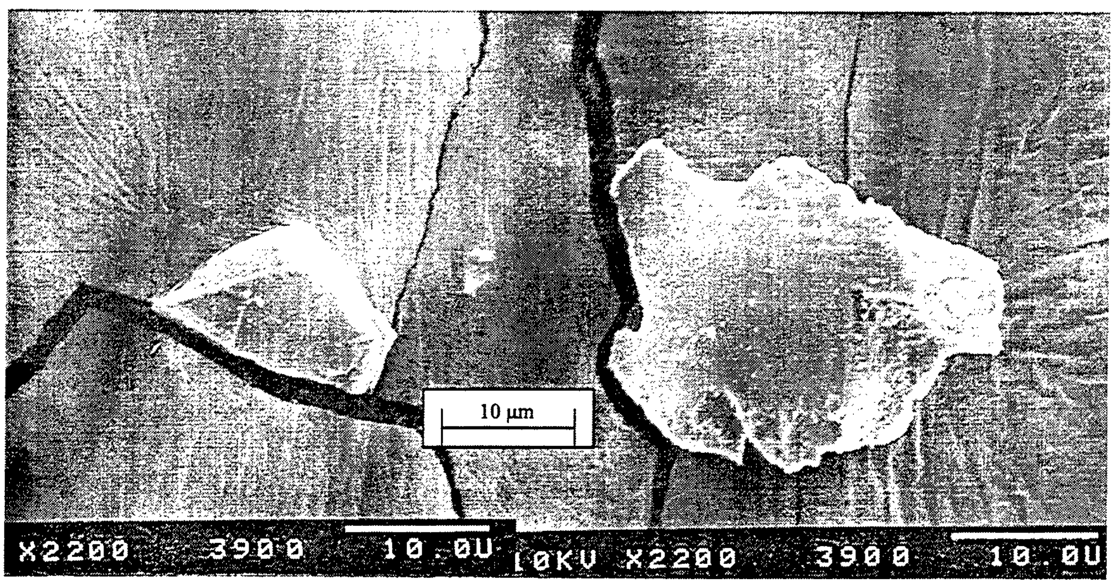

Figure 9. SEM Picture of Typical Al_2O_3 Particles.

2.3.2 Coulter Multisizer™ II Analyzer.

The Coulter Multisizer™ II Analyzer is a multichannel particle size analyzer that is used to measure solid particle size and number. It determines the number and size of particles suspended in a conductive liquid by monitoring the electrical current between two electrodes immersed in the conductive liquid on either side of a small aperture, through which a suspension of the particles is forced to flow. As each particle passes through the aperture, the impedance between the electrodes is changed which produces an electrical pulse of short duration having a magnitude proportional to the particle volume. The series of pulses is electronically scaled, counted, and accumulated in a number of size related channels. The contents of the channels are displayed on an integral visual display in the form of a size distribution curve. The results can be selected to show particle volume, number, or surface area in either differential or cumulative form. The output of the multisizer can be sent to a computer for further analysis. A 50 μm diameter aperture that measures 1 - 30 μm diameter particles was installed in the system during the experiment.

Particles were collected in the electrolyte solution during sampling and the samples were thoroughly mixed to achieve a uniform hydrosol concentration before each Coulter measurement. Each sample was measured three times. The Coulter analyzer was set to count the number of particles in 100 μL aliquots. The approximate time for counting particles in a 100 μL aliquot is 10 seconds. Analyses with counting times greater than 10.5 seconds and less than 9.5 seconds were repeated. In most cases, longer counting time is due to partial or full blockage of the orifice. In addition, total raw count and total coincidence corrected count are displayed so that the operator can decide whether the sample has to be diluted.

Limitations of using a Coulter analyzer are that particles that are measured by the multisizer should not dissolve in the electrolyte solution, the orifice should not become partially or fully clogged during the measurement, the number concentration should be low enough so that there is no coincidence problems, and the density and shape factor of the particles should be known to convert the volumetric size to an aerodynamic size.

2.4 Solid Particle Tests.

The experimental setup of the solid particle tests is shown in Figure 10. Approximately 1.5 g of Al_2O_3 was aerosolized using a sonic nozzle (Witham and Gates, 1983) in a 70 m^3 chamber. The aerosol was not neutralized in this study.

After the end of aerosol generation, the chamber air was mixed using two mixing fans starting 1 minute before sampling to obtain uniform aerosol concentration. Polycarbonate membrane filters were used as reference filters. The air flow rate through the reference filters was measured using an air flow meter (Buck calibrator, A.P. Buck, Inc., Orlando, FL).

A minimum of 7 minutes of sampling time was chosen because it takes some time to stabilize the flow rate of the sampler when turned on, and also takes some time to wind down when shut off. The sampler and the reference filter (Osmonics Inc., Minnitonka, MN) sampled the aerosol for the same amount of time.

Particle removal from the membrane filters were done using the KD shaking method (Kesavanathan and Doherty, 1999) which consists of 50 seconds of vortexing followed by 10 seconds of handshaking repeated for 5 minutes. Particle size and number concentration of the particles in liquid was determined using the Coulter analyzer.

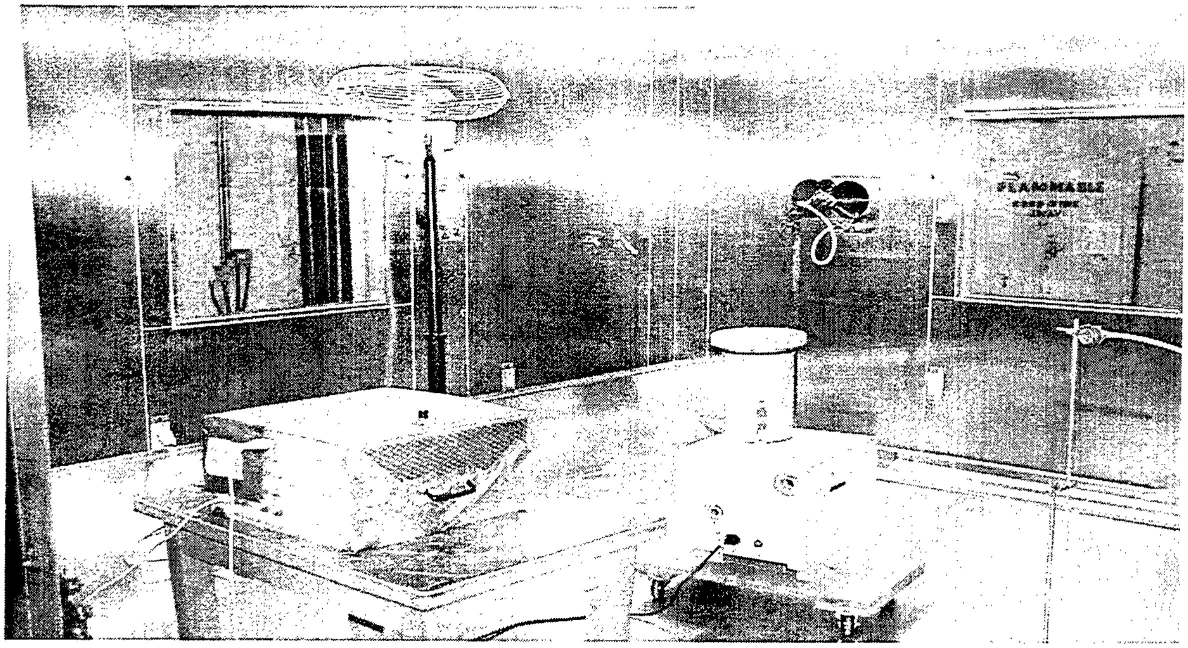

Figure 10. Experimental Setup.

Although particles from earlier tests were undoubtedly present within the SCP sampler on walls and nozzles, they were not shown to be a source of interference between tests. This was demonstrated by blank runs in between tests.

Solid particles collected by the sampler into the liquid and particles removed from the reference filters into the liquid were analyzed using the Coulter analyzer. The Coulter analyzer gives the number and/or mass concentration as a function of a volume equivalent particle diameter that was converted to an aerodynamic diameter using,

$$d_{aer} = d_{vol}\frac{\sqrt{\ }}{S}$$

where, d_{aer} - particle aerodynamic diameter
d_{vol} - volume equivalent diameter
ρ - density
SF - dynamic shape factor.

The sampling efficiency was determined by comparing the number of particles collected in the sampler liquid to the number of particles collected on the reference filter, normalized by the respective flow rates and liquid volumes.

Tests were conducted with and without the rain cap and pre-collector to determine the effect of the rain cap and the precollector on the sampling efficiency at an air flow rate of 1350 L/min. Tests were also conducted with a 1350 L/min air flow rate and a 1000 L/min air flow rate to determine the effect of air flow rate on the sampling efficiency.

2.5 Fluorescein Tagged Oleic Acid Aerosol and Fluorometer Analysis Method.

Monodisperse liquid fluorescent oleic acid aerosol was generated using a vibrating orifice aerosol generator (VOAG) (TSI Inc., St. Paul, MN) and the aerosol was delivered directly into the chamber for 10 minutes. An Aerodynamic Particle Sizer (TSI Inc., St. Paul, MN) measured the particle size during the test, and an impactor sampled the particles onto a glass slide for microscopic evaluation. A microscopic picture of fluorescent oleic acid droplet on a slide is shown in Figure 11.

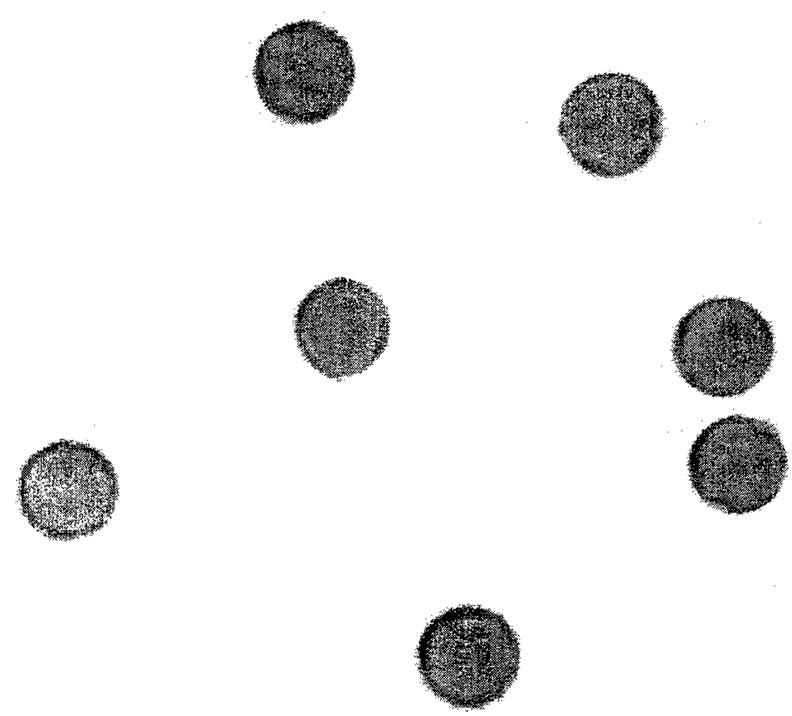

Figure 11. Microscopic Picture of Fluorescent Oleic Acid Droplets. Droplet size is approximately 10 μm.

The measured particle diameter was converted to an aerodynamic particle size using a spread factor (Olan-Figueroa et al., 1982) and the density of fluorescent oleic acid.

Glass fiber filters (Pall Corporation, Ann Arbor, MI) were used in the fluorescein tagged oleic acid tests as the reference filters. The air flow rate of the reference filters were measured using an air flow meter (Buck calibrator, A.P. Buck, Inc., Orlando, FL). The sampler and the reference filters sampled the air for the same amount of time, approximately 10 minutes. Reference filters were removed from the filter holders and were put into the recovery solution to remove the fluorescein from filters for fluorometry. The sampler collected the particles directly into 40 mL of recovery liquid. The liquid was removed, and the fluorescence was measured using a fluorometer (Barnstead/Thermolyne, Dubuque, IA).

The recovery solution has equal amounts of alcohol and water and a pH between 8 and 10, obtained by adding a small amount of NH_4OH (e.g., 500 mL of 2-propanol + 500 mL of water + 0.5625 mL of 14.8 N NH_4OH). This method is described in detail by Kesavan and Doherty (2000a).

The sampling efficiency of each sampler was determined, as earlier, by comparing the sample collected by the sampler to that collected by the reference filter. The air flow rate and the liquid volumes were taken into account in the sampling efficiency calculations.

The stem that carries the aerosol to the liquid was washed after each test to remove deposited particles and the solution was analyzed for fluorescence.

3. RESULTS

Figure 12 shows the sampling efficiency of the SCP 1021 sampler with an air flow rate of 1350 L/min.

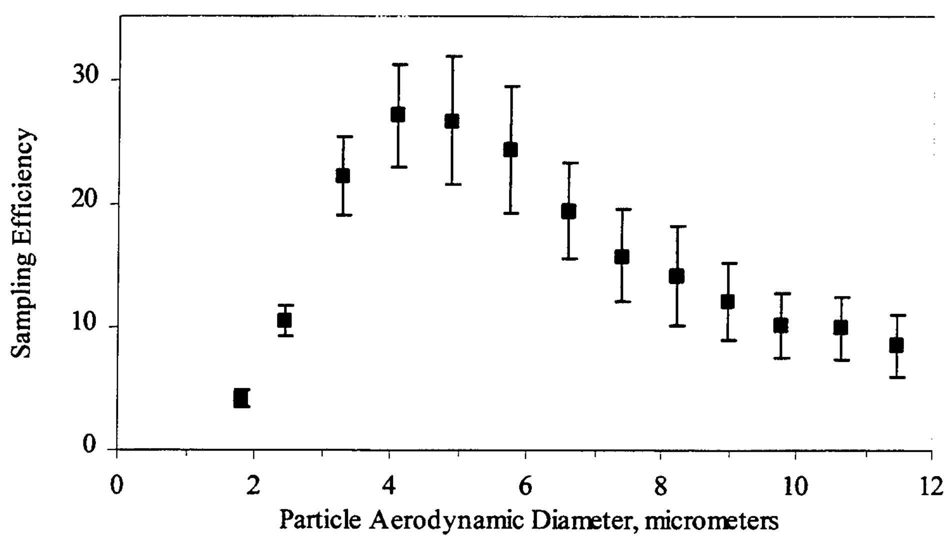

Figure 12. Sampling Efficiency of SCP 1021 Sampler with an Air Flow Rate of 1350 L/min.

Figure 13 shows the sampling efficiency of the SCP 1021 sampler at a flow rate of 1000 L/min using the polydisperse solid Al_2O_3 particles with Coulter analysis and monodisperse fluorescent oil droplets with fluorometric analysis.

The sampling efficiency curves for both Figures 12 and 13 show that the sampling efficiency peaks at approximately 5-6 μm. In general, the sampling efficiency is lower for particles smaller than 6 μm because smaller particles are discharged with the secondary air flow of the virtual impactors. In addition, the sampling efficiency of larger particles is low because of internal losses. This trend is seen for solid as well as for liquid particles at both air flow rates. More specifically, the results of Figure 13 also shows that for particles smaller than 6 μm, there is little difference in sampling efficiency between using solid and liquid particles, however, for larger particles the sampling efficiency is higher for solid particles. This is most likely due to solid particle bounce and re-entrainment into the air flow.

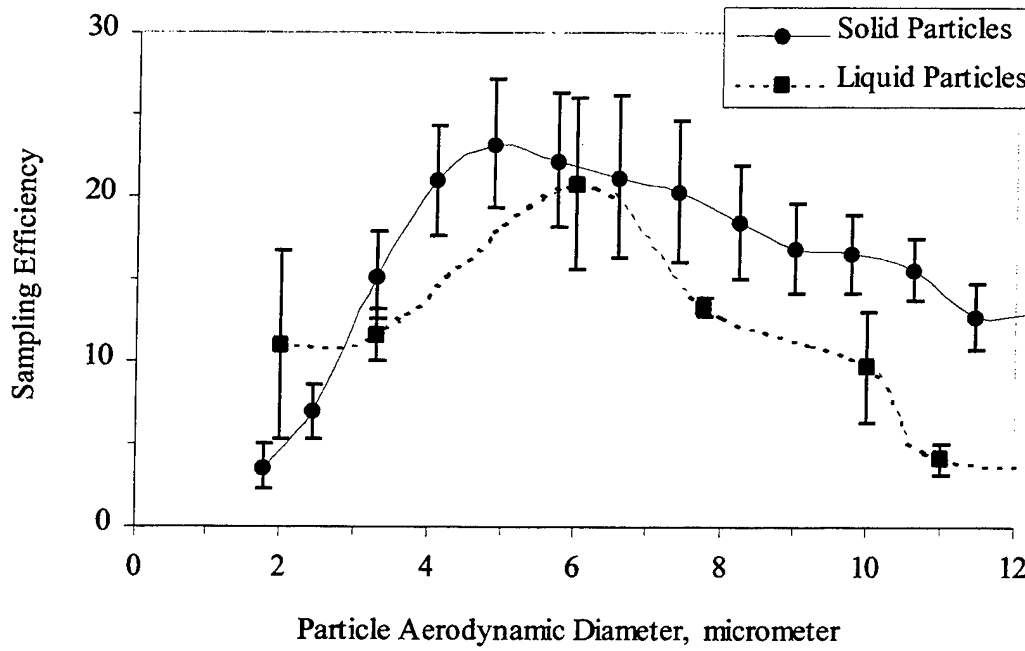

Figure 13. Sampling Efficiency of SCP 1021 Sampler with an Air Flow Rate of 1000 L/min Using Solid and Liquid Particles.

Figure 14 shows the sampling efficiency of the sampler with and without the rain cap and the pre-collector with an air flow rate of 1350 L/min. There is no effect of rain cap and pre-collector in sampling efficiency for particles smaller than 4 μm. For particles larger than 4 μm, there is significantly higher sampling efficiency when the rain cap and the pre-collector were removed.

Figure 15 shows the sampling efficiency with and without particle deposition in the stem added to the sampling efficiency. The results show that for some particle sizes, especially around 6 μm, there is a significant amount of aerosol removed by the stem that carries the concentrated aerosol to the liquid.

The pressure drop before the air blower is 16.5 in (4.125 kPa) and the air flow is 1000 L/min. Therefore, the power needed by the system is 68.75 W; this does not include the losses at the blower. The actual power used by the system is 495 W. Therefore, the blower efficiency is 13.9%.

4. DISCUSSION

A reference sample is required when the sampling efficiency is experimentally determined. A filter sample is taken as a reference sample along with the sampler under testing. Full removal of particles from the filters is required for the analysis. We have conducted tests to validate the method of recovery of solid particles from polycarbonate membrane filters (Osmonics Inc., Minnitonka, MN) for Coulter analysis and sodium fluorescein from glass fiber type A/E filters (Pall Corporation, Ann Arbor, MI) for fluorometric analysis.

Polydisperse Al_2O_3 particles were used as an aerosol in this study, however, any non-soluble polydisperse solid particle can be used as the test aerosol when a Coulter analyzer is used. One test with the polydisperse aerosols gives information on a range of particle sizes. However, solid particles may overestimate sampler efficiency at larger particle sizes due to bounce and re-entrainment.The use of monodisperse liquid particles provides a more conservative estimate of sampler efficiency, but requires more time for testing each size separately.

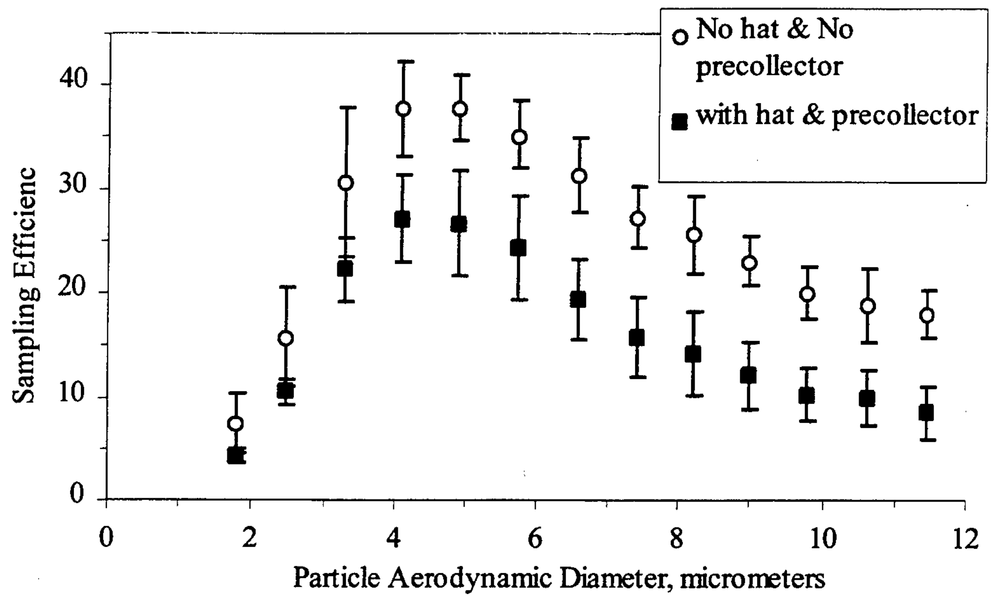

Figure 14. Sampling Efficiency of SCP 1021 Sampler with and Without the Rain Cap and the Pre-Collector with an Air Flow Rate of 1350 L/min.

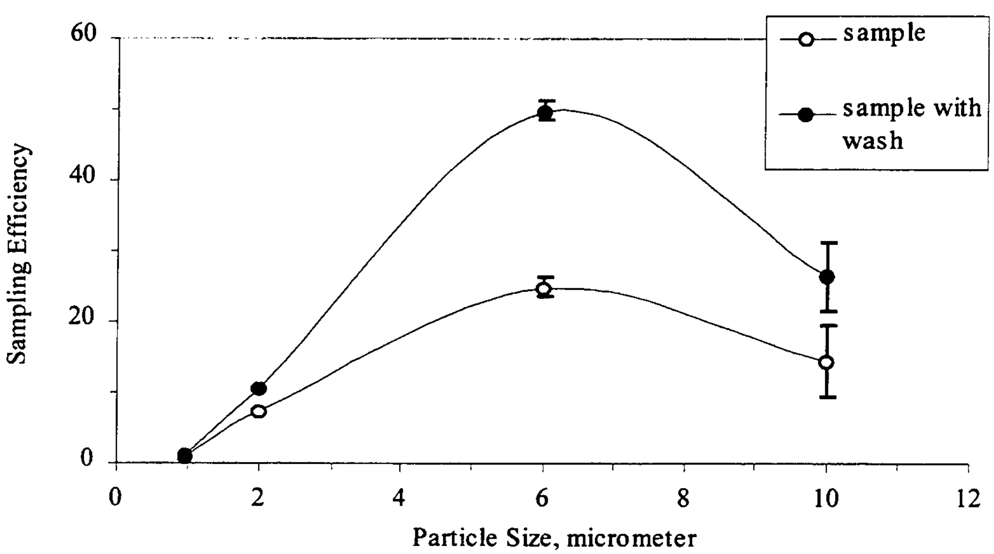

Figure 15. Sampling Efficiency of SCP 1021 Sampler with and Without the Stem Wash Added to the Sampler with an Air Flow Rate of 1000 L/min.

Monodisperse liquid fluorescent oleic particles generated by a VOAG pass through a neutralizer before they enter the chamber to reduce the charge on the particles. By comparison, the Al_2O_3 particles were not neutralized after aerosolization. The effect of charged particles on overall sampling efficiency of a sampler is unknown though for particles greater than 6 μm, charge attractions should be minor compared to air drag and inertial forces. Future tests, using test aerosols, however, should neutralize the Al_2O_3 particles before the particles enter the chamber to be used as a test aerosol.

Visual inspection of 6μm particles showed that significant amount of particle loss occurred in the long stem that transported the aerosol to the liquid in the collection cup. Washing of this stem and subsequent analysis of the wash water showed that a significant amount of fluorescein was deposited on the stem for some particle sizes.

5. CONCLUSIONS

The SCP 1021 sampler was characterized at the U.S. Army Edgewood Chemical Biological Center. The sampler collects the aerosol into a liquid. Therefore, it can be used as a bio-aerosol collector. The sampler is a high volume flow rate (1000 L/min) sampler that is heavy (80 lb 11 oz) and large (18 ¼ x 16 ½ x 29 ½). Power consumption of the sampler is 495 Watt. The following conclusions were reached from conducting this study.

(a) The sampling efficiency curves for solid and liquid particles have a peak at approximately 5 - 6 μm.

(b) There are no significant differences between the sampling efficiencies for 1000 and 1350 L/min air flow rates.

(c) There is no difference in sampling efficiency between the liquid and solid particles for particles smaller than 6 μm. However, large (> 6 μm) solid particles bounce when they hit surfaces and are carried by the air to the collection site, resulting in a higher sampling efficiency.

(d) Removing the inlet cap and the pre-collector increases the sampling efficiency for particles larger than approximately 4 μm.

(e) Washing the final stage stem shows that there is significant particle loss in the stem that takes the aerosol to the liquid impaction/bubbling site.

LITERATURE CITED

Kesavan, J., and Doherty, R.W. (2000a), *Use of Fluorescein in Aerosol Studies*, ECBC-TR-103, U.S. Army Edgewood Chemical Biological Center, Aberdeen Proving Ground, MD.

Kesavan, J., and Doherty, R.W. (2001), *Comparison of Sampler Collection Efficiency Measurements Using a Polydisperse Solid Aerosol and a Monodisperse Liquid Aerosol*, ECBC-TR-137, U.S. Army Edgewood Chemical Biological Center, Aberdeen Proving Ground, MD.

Kesavan, J., and Doherty, R.W. (2000b), *Density Measurements of Materials Used in Aerosol Studies*, ECBC-TN-003, U.S. Army Edgewood Chemical Biological Center, Aberdeen Proving Ground, MD.

Kesavanathan, J., and Doherty, R.W. (1999), *Test Procedure for Removing Polystyrene Latex Microspheres from Membrane Filters*, ECBC-TN-001, U.S. Army Edgewood Chemical Biological Center, Aberdeen Proving Ground, MD.

Olan-Figueroa, E., McFarland, A.R., and Ortiz, C.A. (1982), "Flattening Coefficients for DOP and Oleic Acid Droplets Deposited on Treated Glass Slides," *Am. Ind. Hyg. Assoc. J.* Vol 43, pp 395-399.

Vincent, J.H. (1989), "Experimental Methods in Aerosol Sampler Studies," *In Aerosol Sampling Science and Practice*, pp 53-54, John Wiley and Sons, New York, NY.

Witham, C.L. and Gates, R.W. (1983), "Dry Dispersion with Sonic Velocity Nozzles," *In Dissemination Techniques for Aerosols*, pp 11-28, Deepak Publishing, Hampton, VA.