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PREDICTING MASS LOADING AS A FUNCTION OF PRESSURE DIFFERENCE ACROSS PREFILTER/HEPA FILTER SYSTEMS

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DISCLAIMER

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INTRODUCTION

The purpose of this work is to develop a methodology for predicting the mass loading and pressure drop effects on a prefilter/ HEPA filter system. The methodology relies on the use of empirical equations for the specific resistance of the aerosol loaded filter as a function of the particle diameter. These correlations relate the pressure difference across a filter to the mass loading on the filter and accounts for aerosol particle density effects. These predictions are necessary for the efficient design of new filtration systems and for risk assessment studies of existing filter systems. This work specifically addresses the prefilter/HEPA filter Airborne Activity Confinement Systems (AACS) [Tinnes and Petry, 1986], [Petry, et al, 1985], at the Savannah River Plant. Other applications include air pollution control in factories, buildings or facilities where large quantities of aerosols may be released and must be contained. The AACS consists of a two-stage prefilter/HEPA filtration system in which the demister/prefilter is designed primarily to remove water droplets, but will also remove any other large aerosol particles, thereby reducing the mass loading on the High Efficiency Particulate Air (HEPA) filter and extending the service life of the HEPA filter.

In order to determine the mass loading on the system, it is necessary to establish the efficiency characteristics for the prefilter, the mass loading characteristics of the prefilter measured as a function of pressure difference across the prefilter, and the mass loading characteristics of the HEPA filter as a function of pressure difference across the filter. Furthermore, the efficiency and mass loading characteristics need to be determined as a function of the aerosol particle diameter. A review of the literature revealed that no previous work had been performed to characterize the prefilter material of interest.

The mass loading capacity of the HEPA filter was previously studied [Novick et al., 1990 and 1991], [Bergman, 1978], [Gunn and Eaton, 1976], and correlations were obtained that allowed the prediction of either the final pressure difference across a loaded HEPA filter or the maximum mass that could be loaded onto a filter for a specified pressure difference. The experimental data from Novick, et al, for the specific resistance were found to be well correlated with the mass median particle diameter and independent of the particle density.

In order to complete the foundation of information necessary to predict total mass loadings on prefilter/HEPA filter systems, it was necessary to determine the prefilter efficiency and mass loading characteristics. The measured prefilter characteristics combined with the previously determined HEPA filter characteristics allowed the resulting pressure difference across both filters to be predicted as a function of total particle mass for a given particle distribution. These predictions compare favorably to experimental measurements (±25%).

THEORY

The total efficiency of a filter can be described by combining the individual theoretical efficiencies due to impaction, interception and diffusion. Theoretical equations exist for each of these mechanisms, but usually semi-empirical equations are used to improve the accuracy of the predicted efficiency. The combined single fiber efficiency is generally determined as the sum of the efficiency of each collection mechanism. Equations for the most important mechanisms, impaction [Strauss, 1975], diffusion [Strauss, 1975] and interception [Hinds, 1982] are given.

$$\eta = \eta_I + \eta_D + \eta_I \qquad (1)$$

where

$$\eta_i = \psi^3 / \{ \psi^3 + (0.77\ \psi^2 + 0.22)\}$$

$$\psi = \rho V d_p^2 C / 18 \mu d_f$$

$$\eta_D = 6\ Sc^{-2/3}\ Re^{-1/2}$$

$$Sc = \mu / \rho D$$

$$Re = V \rho d_f / \mu$$

$$\eta_I = \{1/(2\ Ku)\}\ \{2\ (1+R)\ [\ln\ (1+R)] - (1+R) + [1/(1+R)]\}$$

$$Ku = \alpha_f - [(\ln \alpha_f) / 2] - (3/4) - (\alpha_f^2 / 4)$$

The theoretical collection efficiency of the filter (E) is then determined from the following equation given by Hinds [1982],

$$E = 1 - e^{-(f \eta)} \qquad (2)$$

where

$$f = 4 \alpha h / \pi d_f (1 - \alpha_f)$$

h = depth of filter material = 5.08 cm (2 in)

These theoretical efficiency equations hold for both solid particles as well as liquid particles providing the particle sticking coefficient is unity.

A simple model describing the total pressure increase across a filter due to solid particle mass loading can be written as the sum of the pressure increase across the clean filter plus the pressure increase across the filter cake due to particle loading. [Wakeman, 1986]

$$\Delta P = \Delta P_0 + \Delta P_c \qquad (3)$$

This simple model is appropriate for HEPA filters because their high collection efficiency causes a particle cake to rapidly form on the surface of the filter. From D'Arcy's law, ΔP_0 can be written in terms of the gas media velocity times a constant and the gas media velocity times the mass loading per unit filter area times another constant. The first constant, K_1, depends upon the physical characteristics of the filter media such as the fiber diameter, filter porosity and thickness. The other constant, K_2, is identified as the specific resistance of loading material on the filter and depends primarily upon the particle diameter.

$$\Delta P_0 = K_1 V$$

$$\Delta P_c = K_2 V M / A \qquad (4)$$

K_2 can be experimentally correlated with parameters that are known or easily estimated so that accurate predictions can be made for the pressure increase across a given filter as a function of mass loading. [Novick, et al. 1991] , [Bergman, et al, 1978], [Gunn and Eaton, 1976]

For a low efficiency filter, like a woven fiber prefilter, a particle cake never covers the entire surface of the prefilter. Most of the particles are removed inside the layers of the prefilter. As mass is collected on the prefilter, the specific resistance changes due to the particles becoming trapped inside the filter. The specific resistance, therefore, becomes a function of the particle mass per unit area being collected in the filter. A simple model can be postulated similar to that in Equation 4,

$$\Delta P = (K_{1P} + K_{2P} M/A) V \qquad (5)$$

where the subscript P denotes prefilter.

Mathematically, this equation is the same as Equation 3. As in the case of the HEPA filter model, an empirical correlation can be made that relates K_{2P} to the particle diameter of the challenge aerosol.

For liquid aerosol mass lengths, models that predict the pressure difference across a filter are very sensitive to the geometry of the filter. These models differ from the solid mass loading models because as liquid aerosol is collected on the filter, an equilibrium develops between mass collected and mass removed by drainage. Therefore, the total liquid mass collected no longer contributes to the pressure difference across the prefilter, once the equilibrium value has been attained.

$$\Delta P_{we} / \Delta P_0 = A_1 [(d_f / \alpha_f h)^{0.561} (A t \cos\phi / Q \mu)^{0.477}] \qquad (6)$$

Equation 6 relates the equilibrium pressure difference to the physical characteristics of the filter [Liew and Conder, 1985]. In general, the contact angle of the droplet with respect to the fiber is usually unknown. In addition, for the Savannah River prefilter, the effective fiber diameter is an uncertain quantity due to the stranded nature of the woven fibers.

EXPERIMENTAL

Particle collection efficiencies for the prefilter were tested using Savannah River Laboratory prefilter material. The prefilter is formed from individual teflon fibers with nominal diameters of 0.02 mm. The individual fibers are bundled into strands with resulting diameters ranging between 0.78 mm and 1.3 mm. The strands are woven into a mesh-like structure with the addition of fine stainless steel wire. The prefilter mat contains 24 layers (12 double layers) of this material which is compressed to a thickness of two inches with a stainless steel frame. Many of the fibers have been broken from the strands and protrude at various angles from the strands.

For both the efficiency and the mass loading tests, the prefilter material was cut to a 10.2 cm x 12.7 cm (4 in. x 5 in.) rectangle and stacked together in a metal holder designed to hold the 12 double layers of material. This arrangement was designed to maintain the prefilter mat thickness of 2 inches. A metal frame covered the edges of the prefilter mat in the holder, leaving a rectangular face area of 7.6 cm x 10.2 cm (3 in. x 4 in.).

In the AACS, standard prefilter size is 0.6 m x 0.6 m (2 ft x 2 ft) with an effective filtration area of 56.8 cm x 56.8 cm or 3210 cm^2. The nominal total flow rate through the AACS is about 100,000 to 120,000 cfm [Tinnes and Petry, 1986]. The flow is distributed through 5 sets of compartments, each with 20 prefilter assemblies and 32 HEPA filters. The lower AACS flow would result in a flow rate of at least 1000 cfm through each prefilter assembly. Therefore, the resulting gas velocity through the prefilter in the AACS can be calculated to be approximately 150 cm/sec. For the laboratory scale filter with an effective area of 77.4 cm^2 (12 in^2), the volumetric flowrate through the test assembly should be at least 24.6 cfm to simulate the AACS.

A HEPA filter with an effective filtration area (not cross sectional area) of 3855.5 cm^2 (4.15 ft^2) was used in the test system downstream of the 77.4 cm^2 prefilter. The volumetric gas flowrate was controlled at 25 cfm resulting in a HEPA media velocity of 3 cm/s. The filtration velocities through each test filter are the same as those through the AACS filters.

Tests were conducted to establish efficiency characteristics for the prefilter and to measure mass loading characteristics as a function of pressure difference across the prefilter in order to develop a methodology for predicting the mass loading and pressure drop effects on a pre-filter/HEPA filter system. To determine filtration efficiency of the prefilter for both solid and liquid particles, various nebulizing methods were used. A TSI Model 3075/3076 Constant Output Atomizer (COA) was used with a TSI Model 3071 Electrostatic Classifier (EC) to produce both solid and liquid particles with Mass Median Aerodynamic Diameters (MMAD's) less than 0.5 μm. Sodium chloride was chosen as the material for the small solid particles, and fluorescein was used as a tracer in solutions of ethylene glycol, diethylene glycol and dioctyl phthalate which were chosen for the small liquid particles. To generate solid and liquid particles greater than 1.5 μm a TSI Model 3450 Vibrating Orifice Generator (VOG) was used. A sodium hydroxide and water solution with fluorescein was used to produce the solid particles, and the same solutions as listed above were again used to produce the liquid particles. A 3-jet Collison Nebulizer was used with a TSI Model 3072 Evaporation/Condensation Aerosol Conditioner (E/C) to generate liquid particles in the range between 0.5 micrometers and 2.5 μm. Solutions of ethylene glycol, diethylene glycol and dioctyl phthalate with fluorescein tracer were again used to produce these liquid particles.

In tests utilizing sodium chloride particles, efficiencies were determined by counting particles with two Condensation Nucleus Counters (CNC), one sampling in the upstream flow of the aerosol and the other sampling in the downstream flow of the prefilter. Upstream and downstream particle counts were taken simultaneously for one minute. Several readings were taken to assure reproducibility and averaged to improve statistical accuracy. The downstream particle count was divided by the upstream particle count to determine the percent penetration of particles through the prefilter. The efficiency ratio was determined by subtracting the percent penetration from 100%.

In tests utilizing fluorescein as a tracer, the prefilter was rinsed in a sodium hydroxide/purified water solution following the test. The rinse solution was analyzed with the Model 111 Turner Fluorometer. The intensity of the light re-emitted by a sample exposed to a constant ultraviolet light source is directly proportional to the concentration of fluorescein in the solution. These fluorometric readings were multiplied by the amount of the rinse solution to obtain an equivalent mass. At least three rinses of each filter were made until the fluorometric reading was less than 10 times the background reading. The rinse results from each filter were summed to give separate equivalent mass results for the prefilter and the HEPA filter. The efficiency is the ratio of the equivalent mass on the prefilter to the total equivalent mass on the prefilter plus the HEPA filter.

Experimental measurements of the filtration efficiency as a function of particle diameter for both solid and liquid particles at a filtration velocity of 152 cm/s, are shown in Figure 1. Also shown in Figure 1 is a calculation of the expected theoretical efficiency based on Equations 1 and 2. The differences are primarily attributed to the non-uniform distribution of fibers in the prefilter due to its stranded construction.

The mass loading characteristics were determined as a function of pressure difference across the prefilter with respect to particle size and composition of the aerosol. The prefilter mass loading tests were done at a flow velocity of 152 cm/s. Pressure changes were monitored across the prefilter and across the HEPA filter. The clean prefilter and HEPA filter were initially weighed and placed into the test system. The filters were loaded with challenge aerosols until a desired total pressure difference across both filters was achieved. When the given target pressure difference was reached, both filters were carefully removed from the system and weighed again. The change in mass was used to determine the mass loading per unit filter area.

For liquid aerosol mass loading tests, the prefilter and HEPA filter were weighed when the first target ΔP was reached. The drainage of liquid from the prefilter was also collected and weighed as part of the mass collected on the prefilter. The filters were carefully replaced into the system and the test continued until the next ΔP was reached. This procedure was repeated until the final target ΔP was reached.

In contrast to the liquid tests, the solid particles mass loading tests each had to be started from ΔP_0, removed and weighed at the target ΔP, and new filters used for the next target ΔP. This procedure was required due to the change in particle cake structure of solid particles caused by handling the prefilters.

Three different aerosol generators were used to generate the three sizes of liquid particles. A BGI Inc. 6-jet Collison Atomizer was used to atomize a solution of 50% dioctyl phthalate (DOP) and 50% isopropyl alcohol generating particles with an MMAD of approximately 1.5 μm. To generate particles with an MMAD less than 1.5 μm, an evaporation-condensation aerosol generator was used in conjunction with a TSI Constant Output Atomizer (COA). The third liquid generation technique used three Bennett ultrasonic nebulizers to generate an aerosol with an MMAD greater than 1.5 μm. A graph of the mass loading versus the net pressure change for liquid particles is shown in Figure 2. Note that there is no change in ΔP with mass loading within the limits of the resolution of the pressure transducers.

Three distributions of solid particles were dispersed using a BGI Model WDF-II Wright Dust

Feeder. Aluminum oxide powder was chosen to produce the solid particle aerosol. The output aerosol particle size is solely dependent on the size of the powder used down to a limit of about 0.1 μm. Figure 3 shows a graph of the mass loading versus the net pressure change for solid particles.

The specific resistance of the prefilter was determined from data obtained in the mass loading tests for solid particles. This was done by dividing the slope of each curve on the graph in Figure 3 by the filtration velocity. This data is plotted against the mass median particle diameter (MMD) and shown in Figure 4. The data was analyzed with a linear least squares curve fit resulting in the correlation,

$$\Delta P_P = [\Delta P_0 + (0.0001103 / d_P + 4.427)\, M / A]\, V \qquad (7)$$

The MMD was chosen to describe the aerosol introduction, to be consistent with the HEPA filter correlation. This correlation will be used with the prefilter efficiency characterization to calculate the total predicted mass loading on a prefilter/HEPA filter system. To complete this calculation, the particles that penetrate the prefilter are loaded onto the HEPA filter and must be considered. Figure 5 presents the data that was used to previously determine the correlation for the specific resistance as a function of particle diameter for HEPA filters [Novick et al. 1990, 1991].

$$\Delta P_H = \Delta P_0\, V + (-1.586 \times 10^5 + 0.9494 / d_P)\, M\, V / A \qquad (8)$$

where the subscript H denotes HEPA filter and d_P is the MMD required to determine the specific resistance (K_2) of the HEPA filter .

This correlation allows the ΔP to be calculated for a given mass loading of an aerosol distribution with a known mass median particle diameter.

PREDICTING MASS LOADING ON PREFILTER/HEPA FILTER SYSTEMS

The mass loading on a prefilter/HEPA filter system can be predicted by empirical correlations for the prefilter efficiency, prefilter mass loading and HEPA filter mass loading. These correlations provide an accurate method of estimating the mass loading and final pressure difference across the prefilter/HEPA filter system. Separate expressions were developed for liquid and solid particles because of the difference in the structure of the accumulated particles on the filters.

Solid Particles

In order to model the behavior of the total aerosol mass collected on a system for a given pressure drop as a function of particle diameter, three fundamental equations are necessary. These equations will then be combined with the correlations developed experimentally. The total pressure difference in the prefilter/HEPA filter system can be expressed as

$$\Delta P_{SYSTEM} = \Delta P_H + \Delta P_P + (\Delta P_0)_H + (\Delta P_0)_P \qquad (9)$$

The efficiency of the prefilter can be expressed in terms of mass loading,

$$E = M_P / M_P + M_H \quad (10)$$

And the specific resistance of either filter can be expressed,

$$K_2 = (\Delta P - \Delta P_0)\, A / V M \quad (11)$$

From Figures 4 and 5 in the previous section, the specific resistance, K_2, can be correlated with the mass median aerosol diameter challenge in the prefilter and HEPA filter.

$$K_{2H} = -1.586 \times 10^5 + 0.9494 / MMD_H \quad (12)$$

$$K_{2P} = 4.427 + 0.0001103 / MMD_P \quad (13)$$

In this series of equations, the surface area, A, of the prefilter and HEPA filter are both known quantities. The velocity, V, through the prefilter and HEPA filter are parameters initially set for the system. The initial ΔP across the prefilter and HEPA filters are both measurable quantities based on the velocity. The final or design limit ΔP of the system is an assumed value based on the system that is being studied. The mass collected on the HEPA filter, M_H and the mass collected on the prefilter, M_P are both unknown quantities. The ΔP across the prefilter and the ΔP across the HEPA filter are also unknown quantities. Efficiency of the prefilter is a quantity established from the prefilter efficiency characteristics tests. The mass median diameter, MMD_P, of particles collected on the prefilter is a known value based on the measured or assumed aerosol distribution challenging the system. However, the particle size distribution, MMD_H, for the particles collected on the HEPA filter is an unknown quantity.

The key to solving the system of equations is to determine the MMD of the aerosol distribution reaching the HEPA filter. The first step is to divide the known or assumed initial aerosol distribution into segments. In this work, the initial aerosol distribution was assumed to be the average of the measured Mass Median Aerodynamic Diameters (MMAD's) for each distribution tested, and the geometric standard deviation was assumed to be 2.0. The reason the measured distributions were not used to generate the calculated values of mass loading and pressure difference was to provide an indication of the magnitude of the error that might be expected using this methodology in a predictive manner using reasonable initial assumptions. The segments of the initial distribution can be arbitrarily chosen. For our calculations, the mid points of each segment were based on the cut points (ECD's) of a cascade impactor. Once the midpoint of each segment is determined, the penetration efficiency of the particles in that segment can be determined for the efficiency curve of the prefilter. The penetrating aerosol distribution is determined by multiplying the efficiency by the quantity of aerosol in each segment. In this case, the mass of aerosol was used to define the distribution since the mass loading is the ultimate quantity of interest. Once the distribution of the aerosol that penetrates the prefilter, and therefore challenges the HEPA filter, is determined, the mass median diameter (MMD_H) of the distribution can be calculated. The specific resistance of the prefilter (K_{2P}) is determined for Equation 13 by calculating the MMD of the initial aerosol distribution from the known or assumed MMAD, by dividing the MMAD by the square root of the particle density.

Knowledge of the specific resistances reduces the problem to a set of four equations and four unknowns. The equations to be solved are (8), (9) and (10), where Equation (10) is written

once for the HEPA filter and again for the prefilter. The four unknowns are the mass collected in the HEPA, M_H, the mass collected on the prefilter, M_p, the final ΔP of the HEPA, ΔP_H, and the final ΔP of the prefilter, ΔP_P. A comparison between the actual masses collected on the filters in the laboratory experiments, and the masses that were calculated from the methodology presented above, is given in Table 1. Table 2 compares the calculated pressure increases and the measured pressure increases on the filters used in these experiments. The average of the absolute value of the differences between the calculated and measured masses is 11.7%. The corresponding average for the prefilter pressure increase is 16.8% and the corresponding average for the HEPA filter pressure increase is 20.6%.

Calculations predicting the mass loading capabilities for the AACS are based on the following initial conditions and assumptions.

Total ΔP of System:	ΔP_{System} = 1750 Pa
Initial ΔP across HEPA filter:	$\Delta(P_0)_H$ = 228.2 Pa
Initial ΔP across Prefilter:	$\Delta(P_0)_P$ = 187.9 Pa
Surface area of HEPA filter:	A_H = 2229.7 m^2
Surface area of Prefilter:	A_P = 32.12 m^2
Velocity through HEPA filter:	V_H = 0.0254 m/s
Velocity through Prefilter:	V_P = 1.76 m/s

The predicted total mass of solid particles collected by the system with a given total pressure drop of 1750 Pa, as a function of the MMAD is shown in Figure 6.

Figure 7 compares the predicted total mass of solid particles that are expected to be collected by the AACS when calculated using the above methodology to extrapolated experimental test data. The experimental data was scaled by the AACS/experimental filter area ratios to obtain the extrapolated AACS values.

Liquid Particles

A similar type of strategy can be developed for predicting the liquid mass loaded onto a system. However, in the liquid model an equation cannot be written for K_2 because no cake is formed. Instead, a graph of net pressure change versus the liquid mass loading on the HEPA filter, Figure 8, was used to determine an average mass loading for a liquid at a given ΔP regardless of the particle diameter. The assumption is that the liquid particles will coalesce and coat the fibers with a liquid film after attaining a critical volume. Therefore, the first order relationship between mass loading and ΔP should not be a function of droplet size. Note that since the prefilter drains excess liquid mass away from the prefilter fibers, the equilibrium pressure difference across the prefilter is a constant. Therefore, the HEPA filter always determines the limit of the system ΔP.

In addition, $\Delta P_P - (\Delta P_o)_P$ is assumed to be zero based on the results presented in Figure 2. This results in only two unknowns, ΔP_H which can now be calculated directly from Equation 8 with a known target pressure and initial pressure drops across the filters, and M_P which can be calculated directly from Equation 9 after determining the efficiency from Figure 1.

Using the AACS parameters as an example, the average mass loading per unit area of the HEPA

filter, for a pressure difference of 1550 Pa, is determined to be 0.018 g/cm^2. Since the total area of the HEPA filter media in the system is 22,297,000 cm^2, the amount of mass the HEPA filters in the system could collect is 401 kg. This amount of liquid mass depends only on the total HEPA filter filtration area and the design ΔP limit. The prefilter will remove mass in relation to its efficiency. For example, for a particle distribution with an MMAD of 1 μm, the prefilter efficiency is 0.68, as determined from Figure 1. Therefore, for a design limit system pressure difference of 1750 Pa across the prefilters and HEPA filters, the total mass of 1 μm aerosol that could be collected on the system is 1253 kg. The predicted total mass of liquid particles collected by the AACS with a given total pressure drop of 1750 Pa, as a function of the MMAD is shown in Figure 9. No comparison is made between the measured and predicted liquid mass loadings due to the number of common parameters.

CONCLUSIONS

As expected, this method of predicting the total mass of solid particles collected by a prefilter/HEPA filter system shows that the small particle region the system mass is limited by the specific resistance of the HEPA filter. As the particle diameter increases, the specific resistance of the prefilter becomes the dominating factor. Comparisons between the predictive model for solid particles with scaled aluminum oxide experiments results in the average of the absolute value of the difference between the mass predicted from calculations and the mass measured from the experimental data of 11.7%, with a standard deviation of ±15.7%.

Although this is not a completely independent comparison because of the experimental data used to determine K_2 for the prefilter, the remaining parameters are independent and lead to the conclusion that relatively accurate predictions of system mass loading can be made as a function of postulated particle diameter and density.

The predicted liquid mass loading on a system as a function of MMAD indicates that the higher mass loading in the small particle region is dominated by the HEPA filter. As the particle diameter is increased, the prefilter efficiency increases but the total ΔP is still controlled solely by the HEPA. Eventually very little aerosol reaches the HEPA filter so the total mass collected by the system becomes limited only by the capacity of the prefilter drain or trap.

The methodology presented in this paper allows predictions of pressure increases resulting from loading aerosols on a prefilter/ HEPA filter system as a function of particle size. The accuracy of these predictions is generally better than 25% which is significantly better than other methods of estimation. These results represent the boundary cases of mass loading on a system for pure solid aerosols and pure liquid aerosols, but do not necessarily represent the limits of mass loading for a mixed solid and liquid aerosol.

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NOMENCLATURE

A	=	surface area of the filter
A_1	=	Liew and Condor correlation coefficient
C	=	slip correction factor
D	=	diffusion coefficient
d_f	=	fiber diameter
d_p	=	diameter of particle
E	=	filtration efficiency
h	=	depth of filter material
K_1	=	constant depending on filter parameters
K_2	=	specific resistance of the cake
Ku	=	Kuwabara hydrodynamic factor
M	=	mass collected on filter
ΔP	=	total pressure difference
ΔP_c	=	pressure difference due to particle cake on filter
ΔP_0	=	pressure difference across clean filter
ΔP_{we}	=	equilibrium pressure difference across the wet filter
Q	=	volumetric gas flowrate
R	=	d_p/d_f
Re	=	Reynolds number
Sc	=	Schmidt number
t	=	surface tension of the liquid
V	=	velocity
α_f	=	filter solidity, or packing (volume) density
η	=	single fiber efficiency
η_i	=	single fiber efficiency due to impaction
η_d	=	single fiber efficiency due to diffusion
η_I	=	single fiber efficiency due to interception
μ	=	gas viscosity
ρ	=	particle density
$\varnothing$	=	contact angle of a droplet with respect to the fiber's surface
ψ	=	Stokes number

Table 1. Measured vs. Calculated Mass Loadings on the Prefilters and HEPA Filters Used in the Laboratory Tests

InitialMMAD (μm)	InitialMMD (μm)	Penetrating MMD (μm)	Calc. Efficiency	Calc. Prefilter Mass (g)	Calc. HEPA Mass (g)	Calc. Total Mass (g)	Meas. HEPA Mass (g)	Meas. Prefilter Mass (g)	Total Meas. Mass (g)	Calc. vs. Meas. Total Mass Difference (%)
3.34	1.69	.710	0.98	33.87	0.55	34.42	0.65	33.85	34.50	-0.22
3.16	1.60	.710	0.98	66.30	1.27	67.57	4.95	71.60	76.55	-11.73
3.13	1.58	.710	0.98	72.63	1.46	74.09	1.75	53.35	55.10	34.46
3.13	1.58	.710	0.98	121.40	2.44	123.84	6.25	106.35	112.60	9.98
2.65	1.34	.710	0.97	79.37	2.49	79.37	2.40	94.20	96.60	-17.84
1.38	6.99	.410	0.85	11.70	2.05	13.75	2.60	11.50	14.10	-2.49
1.35	6.84	.410	0.84	31.22	5.78	37.00	6.90	34.60	41.50	-10.84
1.21.	6.13	.410	0.81	20.00	4.67	24.68	4.65	21.90	26.55	-7.06
1.21	6.13	.410	0.81	13.32	3.11	16.43	3.60	16.35	19.95	-17.65
0.99	5.01	.330	0.74	4.50	1.62	6.11	1.95	4.45	6.40	-4.47
1.00	5.06	.330	0.74	7.92	2.80	10.72	3.35	7.75	11.10	-3.45
0.83	4.20	.330	0.66	12.02	6.22	18.24	7.25	12.10	19.35	-5.72
1.02	5.16	.330	0.75	14.15	4.83	18.99	5.65	9.40	15.05	26.16

|Difference| Average 11.7

Standard Deviation 15.7

Table 2. Measured vs. Calculated Pressured Increases across the Prefilter and HEPA Filters Used in the Laboratory Tests

Total System ΔP (Pa)	Measured $\Delta P_H - \Delta P_o$ or HEPA (Pa)	Measured $\Delta P_p - \Delta P_o$ on Prefilter (Pa)	Calculated $\Delta P_H - \Delta P_o$ on HEPA (Pa)	Calculated $\Delta P_p - \Delta P_o$ on Prefilter (Pa)	HEPA Difference (%)	Prefilter Difference (%)
930.00	93.00	492.00	50.63	463.27	-45.56	-5.84
1488.00	359.00	757.00	116.78	955.12	-67.47	26.17
1606.00	146.00	983.00	134.17	1055.73	-8.10	7.40
2405.00	385.00	1595.00	224.27	1764.63	-41.75	10.64
1953.00	173.00	1329.00	229.11	1307.79	32.43	-1.60
1134.00	306.00	266.00	345.13	372.77	12.79	40.14
2405.00	944.00	1050.00	972.43	1016.47	3.01	-3.19
1927.00	718.00	797.00	786.35	724.55	9.52	-9.09
1422.00	425.00	571.00	523.52	482.38	23.18	-15.52
957.00	332.00	226.00	342.63	198.27	3.20	-12.27
1355.00	625.00	332.00	593.29	345.61	-5.07	4.10
2365.00	1488.00	492.00	1318.72	630.18	-11.38	28.09
2047.00	1076.00	585.00	1025.03	605.87	-4.74	3.57
				|Difference| Average	20.63	12.89
				Standard Deviation	28.44	16.83

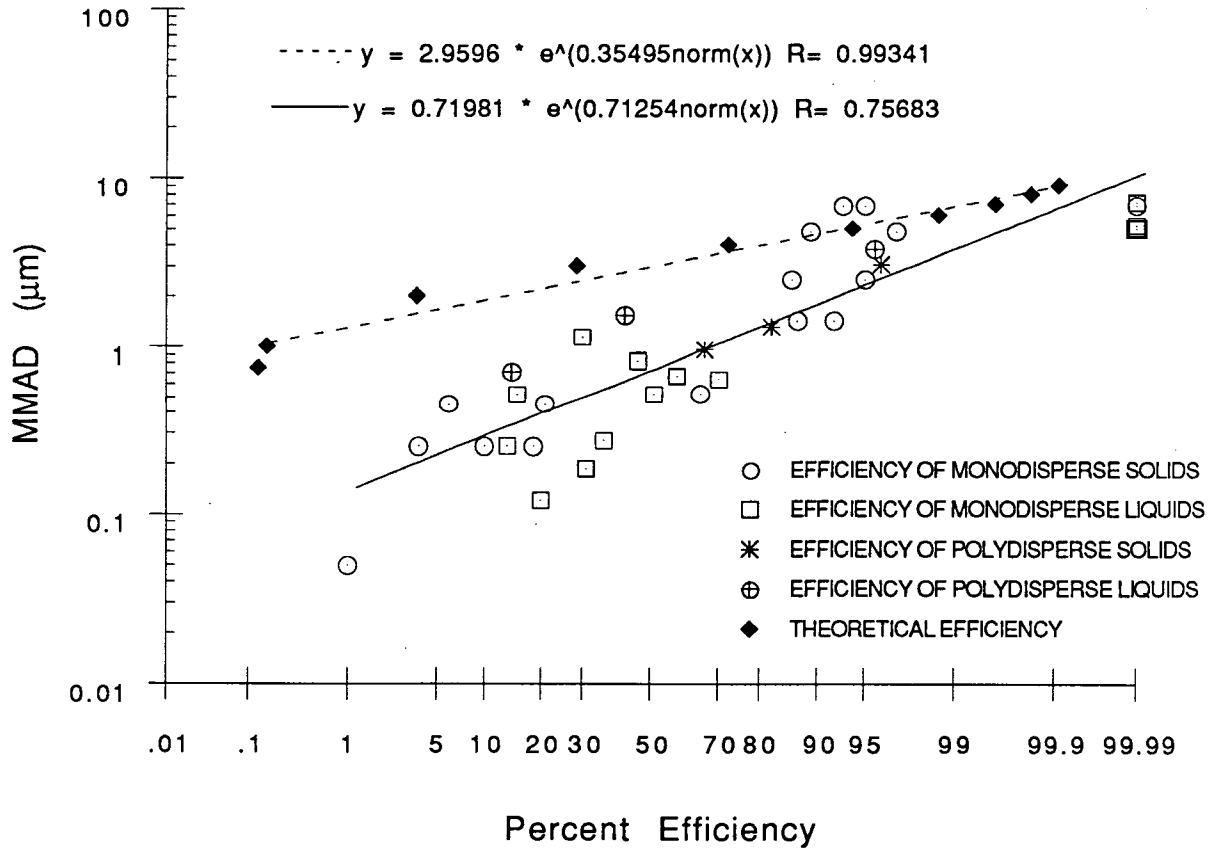

FIGURE 1 Theoretical and experimental collection efficiency curves for particles for the prefilter material at a face velocity of 152 cm/s. Experimental particle diameters are both solid and liquid particles.

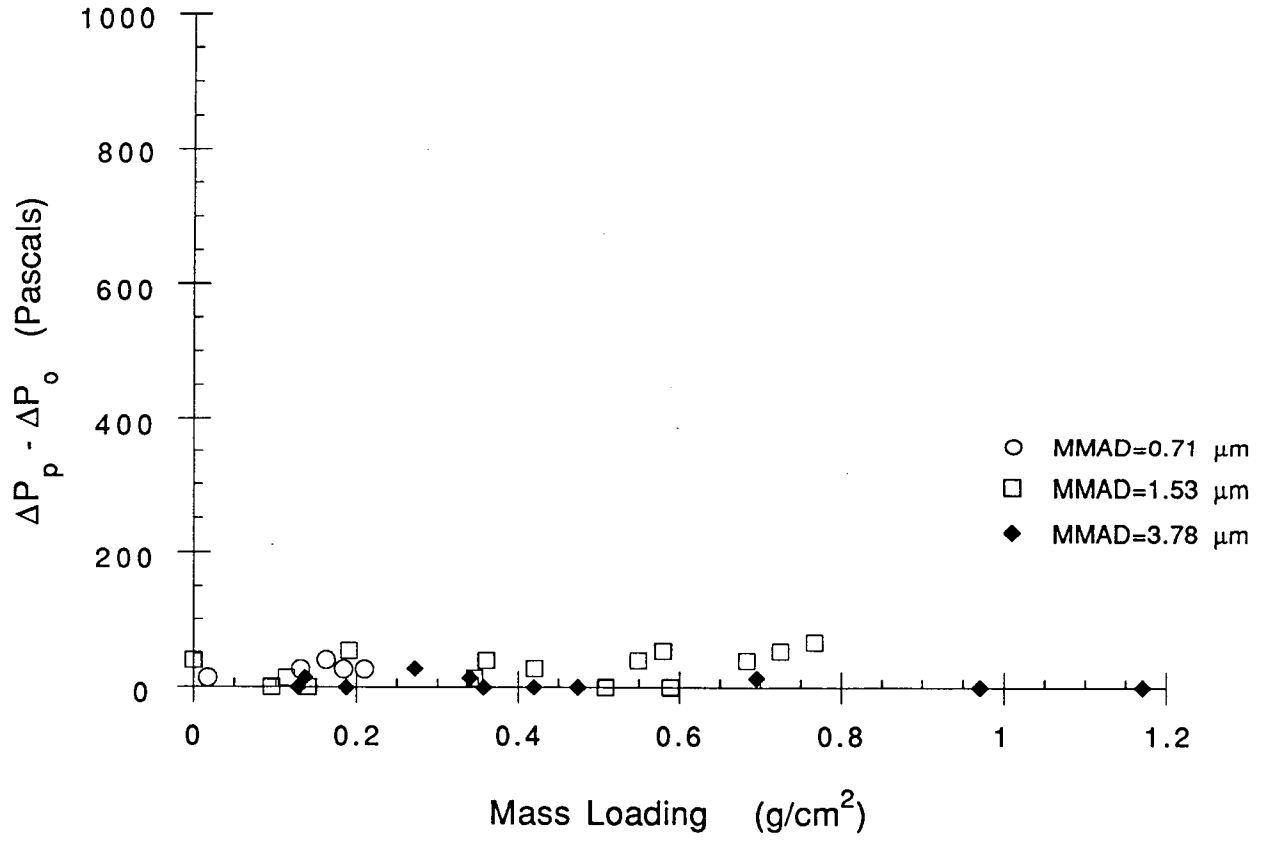

FIGURE 2 Mass loading -vs- net pressure change for liquid particles on the prefilter material at a face velocity of 152 cm/s. Three particle sizes were studied, each MMAD being the average of tests done for that specific size. Two liquid solutions were used, di-ethylene glycol and dioctyl phthalate.

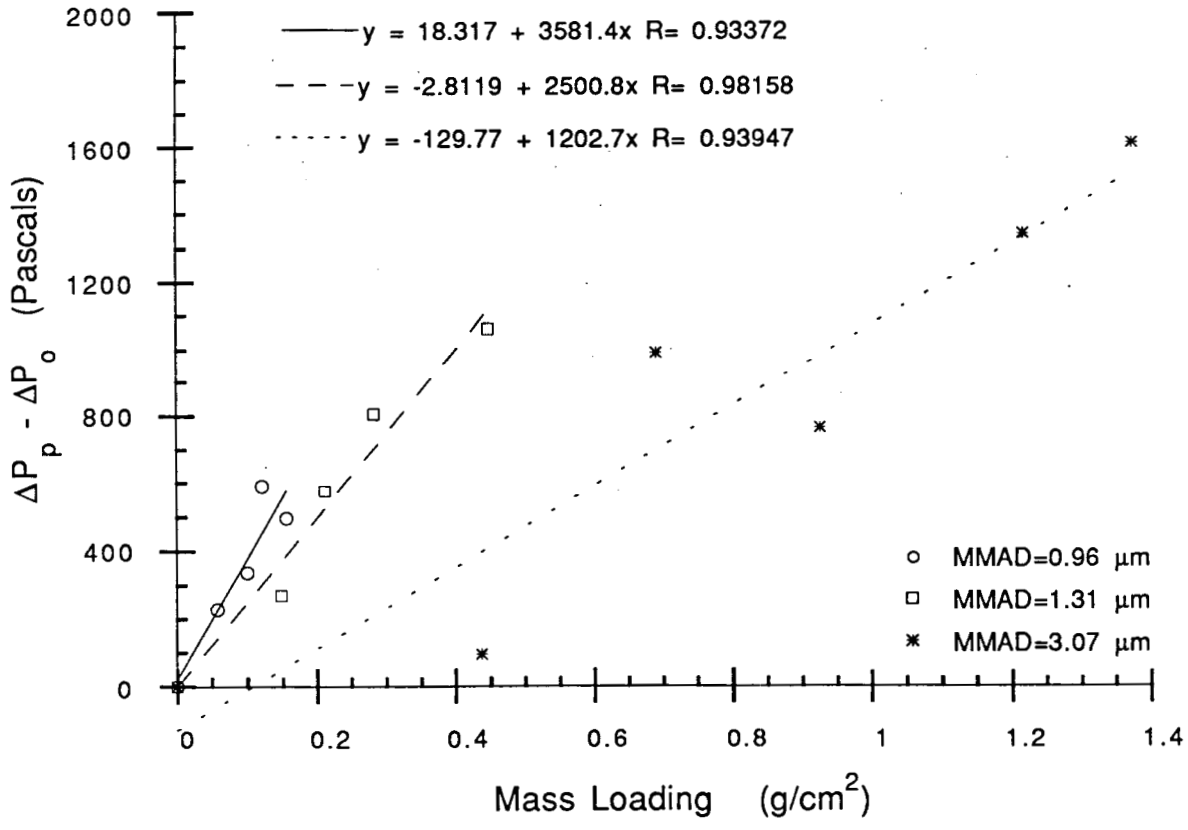

FIGURE 3 Mass loading -vs- the net pressure change for solid particles on the prefilter material at a face velocity of 152 cm/s. Three particles sizes of aluminum oxide powder were studied, each MMAD being the average of tests done for that specific size.

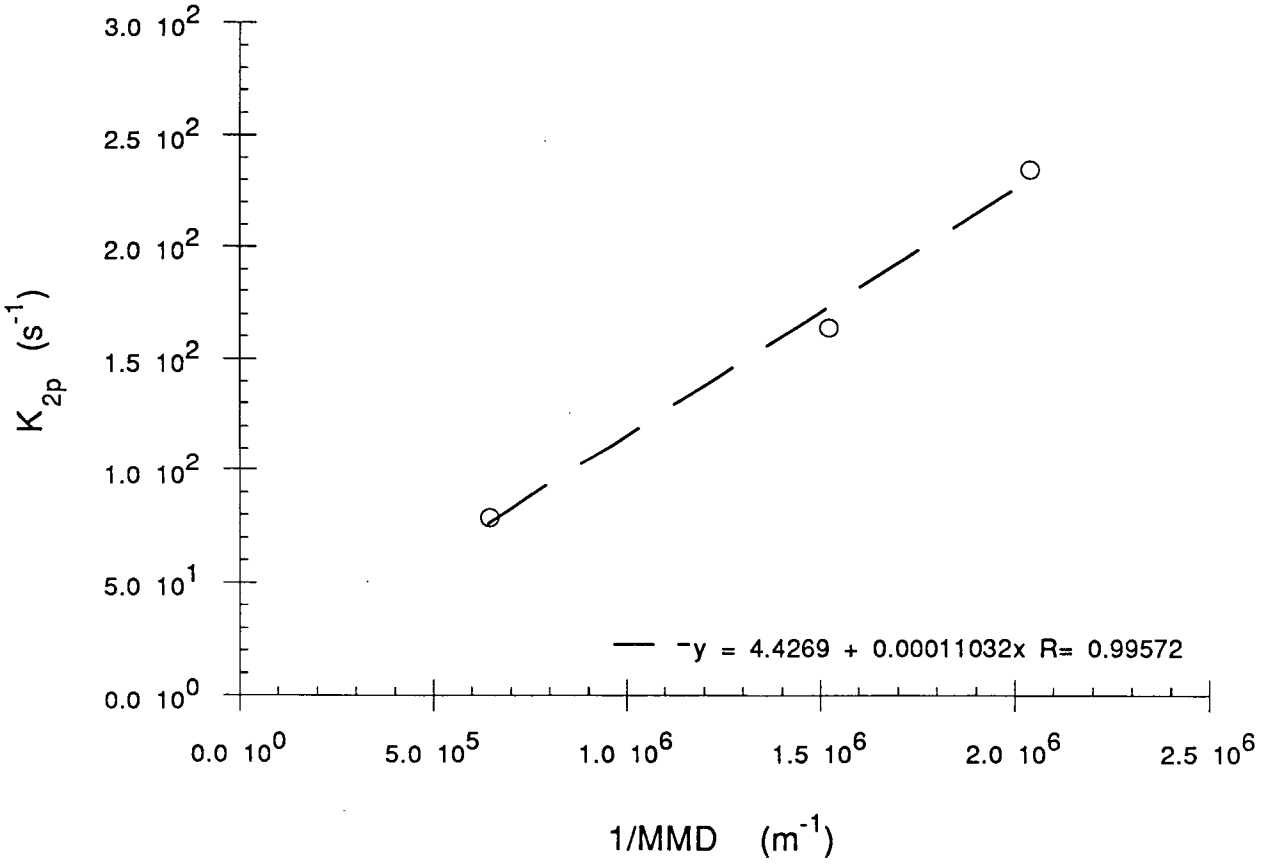

FIGURE 4 The specific resistance of aluminum oxide filter cakes plotted as a function of the inverse of the MMAD for the prefilter material.

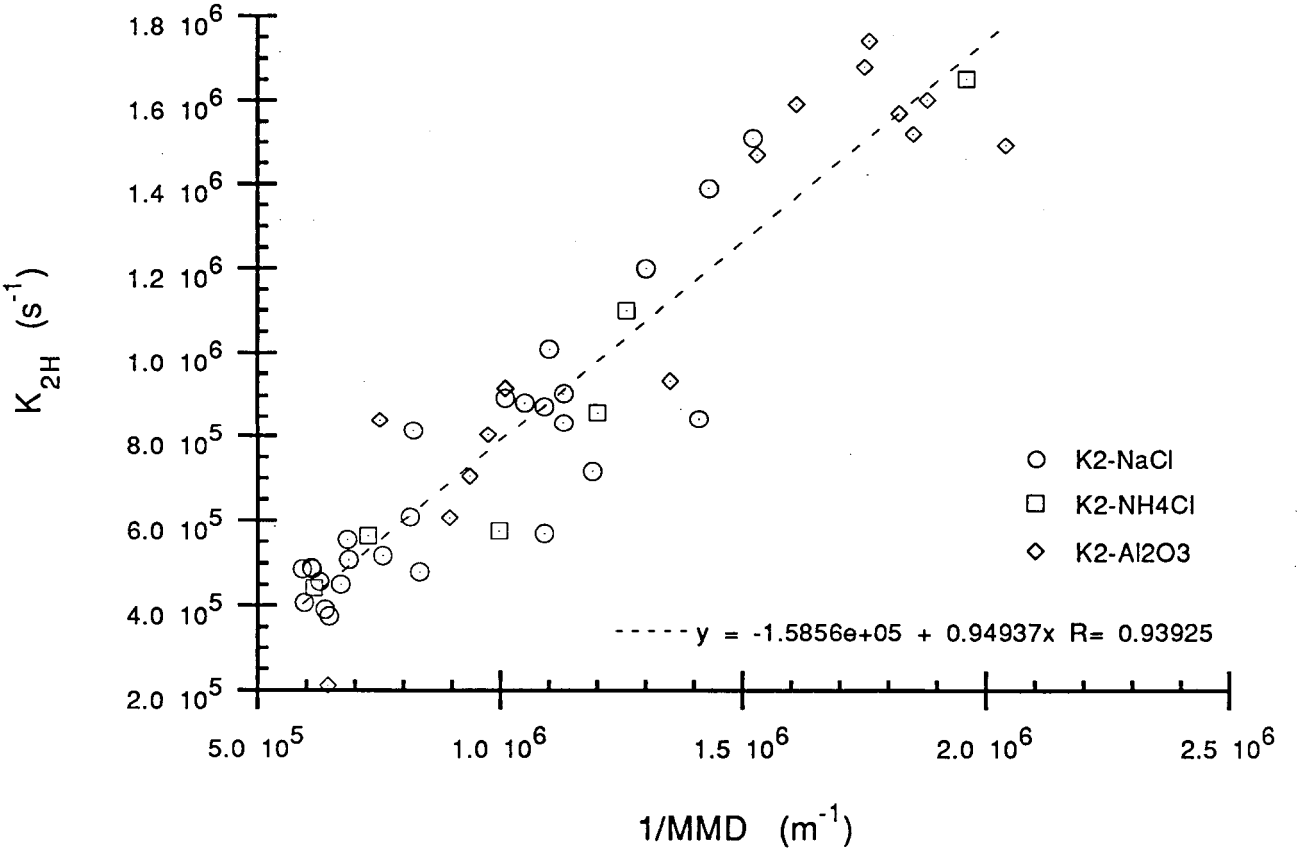

FIGURE 5 The specific resistance of sodium chloride, ammonium chloride and aluminum oxide filter cakes on the HEPA filter media plotted as a function of the inverse of the MMAD.

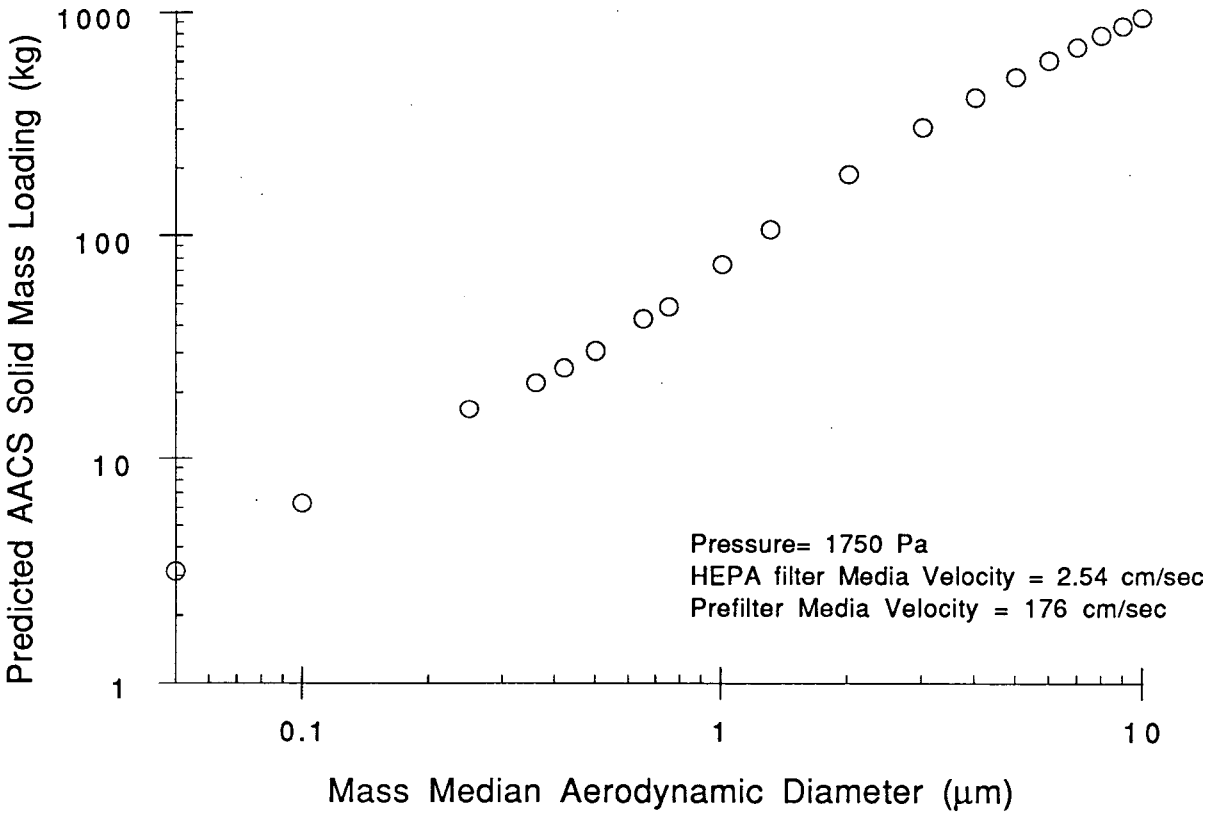

FIGURE 6 Predicted AACS mass loading for solid particles as a function of particle size.

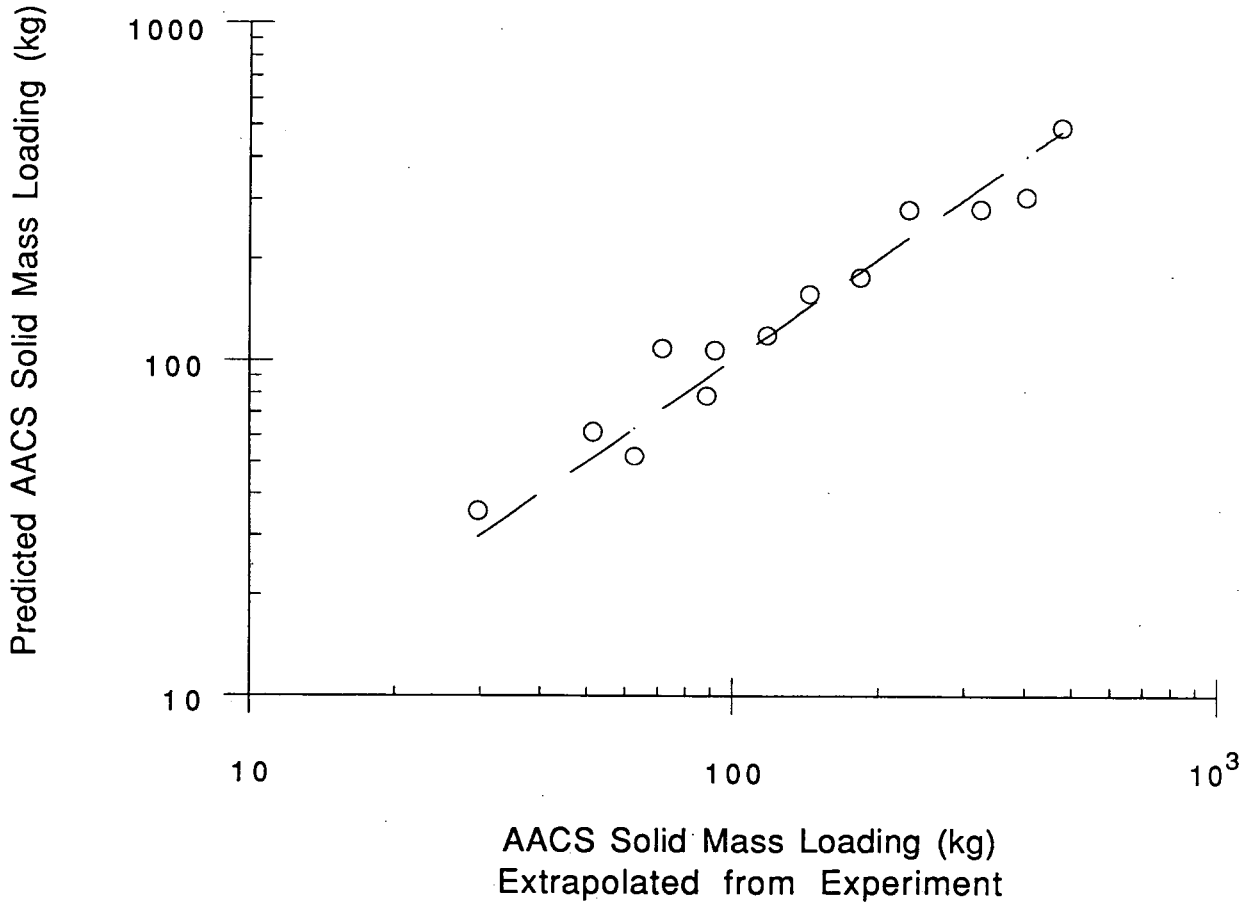

FIGURE 7 Comparison between the maximum solid aerosol mass loading predicted for the AACS determined by calculation and by extrapolation of the experimental results scaled by the respective AACS/Experimental filtration area ratios. The dashed line represents perfect agreement.

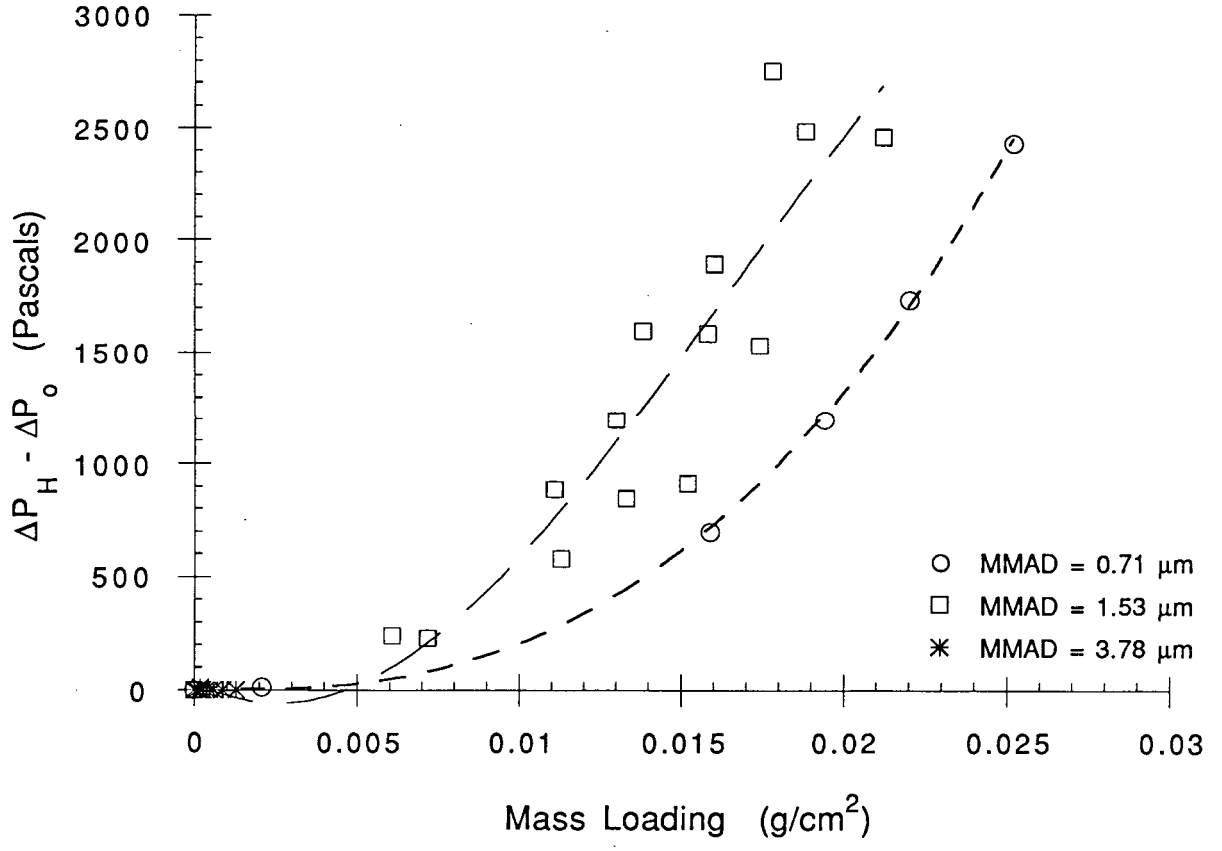

FIGURE 8 Mass loading -vs- net pressure change for liquid particles on the HEPA filter media at a face velocity of 3 cm/s. Three particle sizes were studied, each MMAD being the average of tests done for that specific size. Two liquid solutions were used, di-ethylene glycol and dioctyl phthalate.

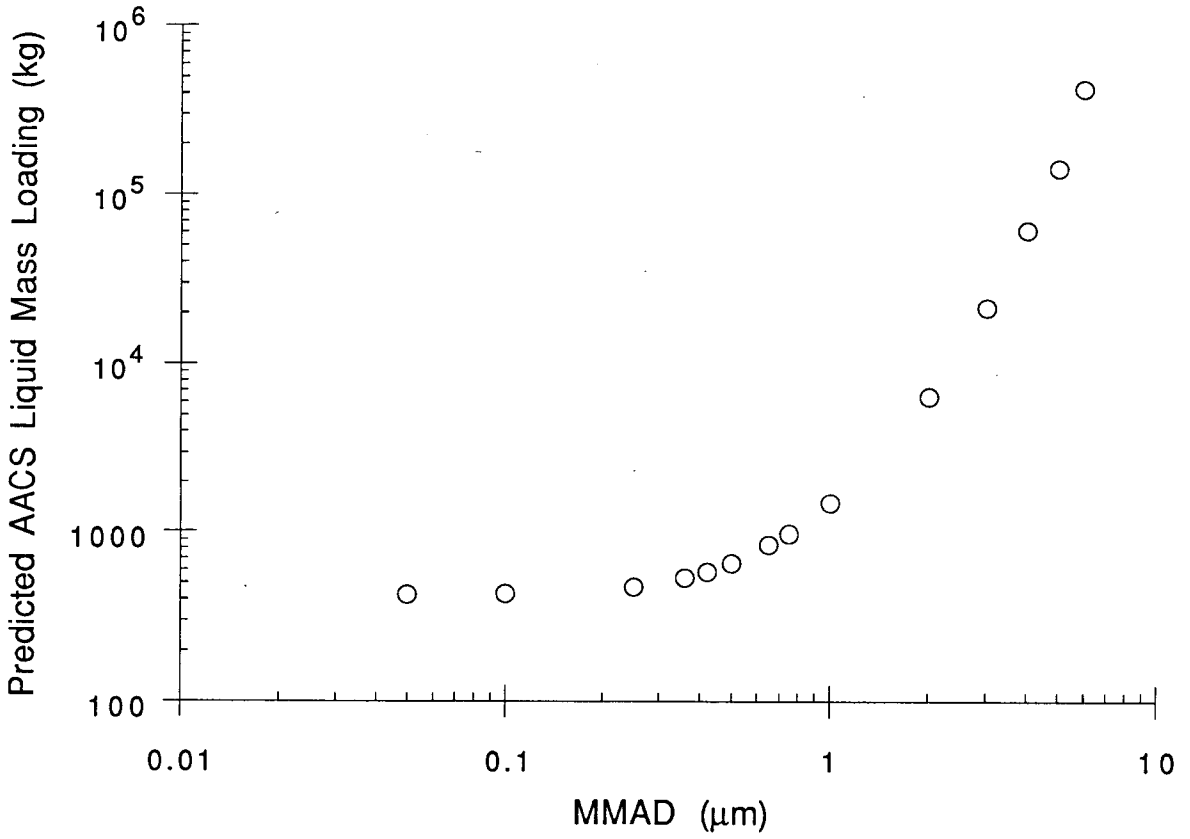

FIGURE 9 Predicted AACS mass loading as a function of liquid particle size based on experimental data from efficiency and mass loading tests for a total pressure difference of 1750 Pa, prefilter velocity of 152 cm/s and a HEPA velocity of 3 cm/s.