Potential Biases Arising in the Use of Cascade Impactors to Estimate Respiratory Tract Deposition Patterns of Lead–Acid Battery Plant Aerosols

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The region of the respiratory tract where inhaled particles deposit can have important implications for the causation of local or systemic toxic effects. For most aerosols of occupational importance, respiratory tract deposition can be predicted from the aerodynamic diameter of the particles. With the advent of cascade impactors, particularly those of personal sampler size, the determination of the aerodynamic diameters of aerosols has become more common. Some limitations of cascade impactor use are well recognized (e.g., particle bounce and substrate overloading) and are generally correctable. However, two important limitations of the instruments may not be receiving adequate attention: relative humidity effects on potentially hygroscopic aerosols and the collection characteristics of fibrous aerosols as compared to their actual deposition site potential. The results of this study, when compared to results of previous controlled laboratory trials, suggest that, while potentially hygroscopic lead aerosols from lead-acid battery plant operations do not appear to be affected by changes in plant environmental humidity levels, the potential exists for significant size changes upon inhalation. Secondly, fibers were detected in aerodynamic size ranges that would be associated with deep lung deposition; however, upon microscopic examination, these same fibers would actually be predicted to deposit in the upper airways. This study suggests that the physical–chemical properties and morphological features of an aerosol should be carefully considered by industrial hygienists before cascade impactors are used in attempts to predict the effects of inhaled aerosols. **Hodgkins, D.G.; Robins, T.G.; Hinkamp, D.L.; Levine, S.P.; Schork, M.A.; Krebs, W.H.: Potential Biases Arising in the Use of Cascade Impactors to Estimate Respiratory Tract Deposition Patterns of Lead–Acid Battery Plant Aerosols. Appl. Occup. Environ. Hyg. 7(3): 180–190; 1992.**

Introduction

The deposition of inhaled particles in the human respiratory tract is dependent upon a combination of factors that include particle morphometry, patterns of air flow, and physical factors acting on the particles.[1,2] The site(s) of deposition in the respiratory tract may have important implications on the potential for the contaminant to cause a toxic response.[1–4] The ability of contaminants to produce local toxic effects will be dependent on deposition at the target region (e.g., alveolar deposition for most pneumoconiosis-producing dusts). For inhaled systemic toxins such as lead, which have site-dependent absorption characteristics, deposition patterns will largely determine bio-active dose.

Since the Kehoe[5] lead uptake studies, later expanded upon by other investigators,[6–10] it has been shown that humans absorb lead differently depending upon whether the absorption is through the lung or the gastrointestinal tract. Particle deposition studies have shown that small lead particles which deposit in the gas exchange region of the lung are absorbed with essentially 100 percent efficiency. In contrast, larger particles deposited in the upper respiratory tract and the conductive air ways of the lower respiratory tract are removed by mucociliary transport and subsequently swallowed, ultimately being available for absorption in the gastrointestinal tract at approximately 10 percent efficiency. These deposition/absorption characteristics of lead exposure were recognized by the Occupational Safety and Health Administration when it promulgated the Lead Standard (29 CFR 1910.1025).[11,12] Although the Standard does not require the determination of aerosol particle size to determine compliance with the regulatory provisions, the model used to select the permissible exposure limit (PEL) for lead was selected from a model that incorporated theoretical particle size considerations.

The majority of nonfibrous airborne particles of interest in the work environment are classified in the size range

of 0.01–100 μm in diameter.[3,4] For particles larger than approximately 0.5 μm, impaction and sedimentation are the primary deposition mechanisms. The deposition site of particles that deposit either by impaction or sedimentation is most closely related to the particle's aerodynamic diameter.

In 1945, May[13] introduced a sampling device, a cascade impactor, that collected particles fractionated according to their aerodynamic diameters. It was not until more recently, however, that widely commercially available, multistage impaction devices were made small enough to be worn easily by workers and had flow rates (e.g., around 2 L/min) which allowed for the use of personal sampling pumps.[13–15] These developments are resulting in the industrial hygienist's increased use of impactors and of the impactor data to more accurately predict the potential effect of exposure to contaminants with deposition site dependence.

Overloading of the impactor substrates and particle bounce have been generally recognized as potential limitations of the use of impactors to collect aerosols.[13] Although overloading of the substrates can be a somewhat difficult problem to diagnose, it generally can be corrected by reduced sampling time. Particle bounce can be substantially reduced by changing to "softer" substrates (e.g., filters) or by the application of coatings to the substrate surfaces.[13–16] Two other important limitations of impactors and/or impactor data, while recognized in the theoretical literature, may not be receiving adequate attention by the practicing industrial hygienist. These limitations concern humidity-dependent changes in aerosol size of particles that are hygroscopic and the behavior of fibrous particles in these collection devices.[17–27]

Hygroscopic particles have the potential to increase in aerodynamic diameter as environmental humidity levels increase.[17–21] Moreover, such particles may increase in size upon inhalation and contact with the water-saturated air within the respiratory tract.[1,2] Thus, a consideration of aerodynamic diameter distributions under differing relative humidities may be important in accurately predicting respiratory tract deposition sites.

When collected by cascade impactor, fibrous particles of any length can be expected to distribute on the basis of aerodynamic diameter.[3,4,13–15] Relatively short, inhaled fibrous particles should deposit in the respiratory tree as predicted by their aerodynamic diameter. However, as fiber length increases, an additional respiratory tract deposition mechanism, interception, becomes increasingly more influential.[1,2,23,27] As a result, the data provided by cascade impactor sampling of longer length fibrous aerosols may be unreliable as a predictor of respiratory deposition.

In a previous study, Hodgkins *et al.*[28] reported the lead particle size distributions associated with five major operations in two lead–acid battery plants. These distributions were determined by the use of personal cascade impactors. In that present study, the issues of variations in lead particle distributions due to changes in plant humidity levels and of the collection of potentially fibrous aerosols by cascade impactors were investigated. The battery paste material contained from 10 to 14 percent, by weight, concentrated sulfuric acid, a hygroscopic material. In addition, three known potential sources of fibrous particles were present. The paste contained small amounts of sawdust and polyester fiber which had been added to assist in the electrochemistry and stability of the paste material. Further, when the paste was applied to the metal grid in plate pasting, a paper wrap was used on both sides of the plates.

Methods

Plant/Operation Selection

Five manufacturing operations from two different battery plants were selected for the study. The five operations included plate pasting, offbearing, encapsulation, stacking, and cast-on-strap. These operations and the operational flow of the battery manufacturing operations studied have been previously described.[28] The two plants were designated Plant A and Plant B. Plant A is located in the rural midwestern United States, while Plant B is located in an eastern U.S. urban area. Plant A is a modern structure with a flat roof and year-round, tempered makeup air. Plant B is an older "bay style" plant, having a high bay–low bay roof structure with many windows and tempered makeup air provided only in cool weather. In warmer weather, Plant B would be considered an "open" plant as the bay and side windows are opened to assist in temperature control. Both plants produced only batteries for starting automobile, truck, and boat engines. Production processes were similar with differences present primarily in the relative placement of equipment. Maximum battery production by each plant over two work shifts was reported to be 12,000–14,000 per day.

Air Sampling

Marple eight-stage Personal Cascade Impactors (Model 298, Andersen Samplers, Inc., Atlanta, Georgia) attached to SKC Universal Flow Sampling Pumps (Model 224-PCXR7, SKC Inc., Eighty-Four, Pennsylvania) were placed on workers for lead concentration sample collection. For scanning electron microscopy (SEM) samples, a Marple six-stage impactor (Model 296) was used. A flow rate of 2 L/min was used for all tests. At this flow rate, the eight-stage impactors had cut points (particle size for 50 percent collection) of 0.52, 0.93, 1.55, 3.5, 6.0, 9.8, 14.8, and 21.3 μm.[14,15] The six-stage impactor lacked the upper two stages eliminating the 21.3 and 14.8 μm cut points. Mylar substrates (Andersen stock # C-290-MY) followed by a polyvinylchloride (PVC) back-up filter (Andersen stock # F-290-P5) were used in all samplers. The potential for particle bounce in lead concentration sample collection was minimized by spray-coating the substrates with silicone (Hercules Industrial F.D.A. Silicone, The Richardson Co., New York, New York). Substrates used for SEM analysis were not coated due to anticipated interferences in analysis.

To minimize contamination, the impactors were prepared and unloaded off site. In addition, each impactor

TABLE I. PbA Levels ($\mu g/m^3$) at Selected Operations

Operation	Season	Mean[A]	S.D.[B]	Range	Operation	Season	Mean[A]	S.D.[B]	Range
Plant A					Plant B				
Paste Machine	W	36.8	16.1	15.1– 54.1	Paste Machine	W	63.4	31.1	41.6–108.4
	S	24.5	15.2	12.6– 46.7		S	166.9	193.3	30.4–447.5
Plate Offbearer	W	15.4	2.8	12.4– 18.8	Plate Offbearer	W	47.8	24.0	30.5– 72.8
	S	14.2	5.6	10.3– 22.4		S	21.5	6.3	12.9– 26.5
Encapsulation	W	30.7	12.8	20.5– 49.4	Encapsulation	W	16.6	5.6	9.2– 21.9
	S	57.1	30.4	24.1– 86.8		S	14.4	1.8	11.7– 15.5
Plate Stacker	W	12.1	5.2	7.3– 16.8	Plate Stacker	W	18.6	2.5	15.0– 20.7
	S	12.7	3.4	9.7– 16.6		S	29.8	9.9	21.2– 43.2
Cast-on-Strap	W	91.2	28.2	60.9–128.5	Cast-on-Strap	W	45.2	42.3	23.4–108.2
	S	147.7	140.0	16.9–282.7		S	132.1	116.3	41.0–293.6

[A] = mean of four samples.
[B]S.D. = standard deviation.

was transported to and from each plant in an individual, press-lock-style plastic bag. New bags were used each day. A daily field control impactor for lead concentration analysis was prepared, transported, and unloaded in conjunction with the sample impactors. All impactors were cleaned daily by first wiping with an acetone-saturated cloth and then by triple rinsing in a distilled water, ultrasonic cleaner bath.

Five samples were collected from a single job category on the same day; four for lead concentration analysis and one for SEM analysis. All samples were collected on the first shift. Worker sampling time for lead concentration analysis was targeted to be at least seven continuous hours to match the requirement of the Lead Standard.[11] Mean collection times were 6.96 hours (std. dev. = 0.36) for the winter study and 6.86 hours (std. dev. = 0.42) for the summer study. A total of 80 samples were collected for lead analysis, and a total of 20 samples were collected for SEM analysis. The winter samples were collected in February and March 1989, and the summer samples were collected in July and August 1989.

Sample Analysis

Following sample collection, each substrate designated for lead concentration analysis was placed in a nitric acid-cleaned, screw-capped vial for transport to the laboratory. Once in the laboratory, the vials containing the Mylar substrates served as sample preparation vials for atomic absorption spectrophotometric analysis. Two ml of concentrated nitric acid was added to each vial. This was followed by a 5-minute water bath sonication. Eight ml of distilled water was then added to each vial prior to aspiration into a Perkin Elmer Model 5000 Atomic Absorption Spectrophotometer (Perkin Elmer, Inc., Norwalk, Connecticut). Analytical studies indicated 98 percent lead recovery from the coated substrates. In the laboratory, the back-up filters were prepared for atomic absorption analysis using NIOSH P&CAM #173 techniques.[29] The laboratory performing the analyses was American Industrial Hygiene Association-accredited and Proficiency Analytical Testing-approved for lead analysis.

The Mylar substrates and back-up filters designated for SEM analysis were placed in 47-mm Petri dishes (Gelman Sciences, Inc., Stock # 7231, Ann Arbor, Michigan) for transport to the laboratory. An antistatic solution (Static Guard, Alberto-Culver Co., Melrose Park, Illinois) was sprayed on the outside of the Petri dishes to minimize displacement of the substrates due to static charges during transport. SEM analyses and photographs were made using a DS-130 Scanning Electron Microscope (International Sci-

TABLE II. Mass Median Aerodynamic Diameters (MMADs) with Associated Humidity Levels

Operations	Season	MMAD (μm)	GSD[A]	RH[B]	Operations	Season	MMAD (μm)	GSD[A]	RH[B]
Plant A					Plant B				
Paste Machine	W	23.4	3.1	28	Paste Machine	W	13.2	2.9	25
	S	13.8	4.1	63		S	16.0	3.1	47
Plate Offbearer	W	10.9	4.5	29	Plate Offbearer	W	17.5	3.0	13
	S	9.8	3.8	64		S	16.0	3.0	43
Encapsulation	W	19.8	2.6	19	Encapsulation	W	13.2	3.7	36
	S	14.0	2.7	62		S	14.7	2.3	40
Plate Stacker	W	12.0	5.2	12	Plate Stacker	W	13.7	2.5	22
	S	12.1	3.7	52		S	13.8	2.2	69
Cast-on-Strap	W	17.8	2.2	13	Cast-on-Strap	W	15.0	2.9	28
	S	15.0	2.2	48		S	23.9	2.6	67

[A]GSD = geometric standard deviation.
[B]RH = relative humidity.

entific Instruments, Inc., Malpitas, California).

Humidity Measurement

Psychrometric wet bulb and dry bulb measurements were made with either a Bendix Model #566 powered psychrometer (Bendix, Baltimore, Maryland) or a Taylor Model 1328 sling-psychrometer (Thermometer Corporation of America, Arden, North Carolina). Two to four separate measurements were made during each sample collection period. Relative humidity levels were determined by nomographs supplied by the psychrometer manufacturers.

Results

Relative Humidity Studies

Table I presents a summary of the air lead concentration levels from both the winter and summer studies. Although point estimates of the seasonal means varied substantially for some plant/job combinations (e.g., paste machine and cast-on-strap in Plant B), intraplant comparisons (t-tests) of the concentration levels in each job category revealed no difference was present between the seasonal results at the 5 percent significance level.

The mass median aerodynamic diameters (MMADs), geometric standard deviations (GSDs), and associated relative humidity (RH) levels for the selected operations appear in Table II. The variation in the GSDs to as high as 5.2 was suggestive of polydisperse, possibly multimodal, aerosol size distributions in some job categories. This was further evidenced by the curvatures present in some of the lognormal probability plots of the size distributions; an example of which is seen in Figure 1 for the stacking operation. The plots for the other four job categories have been presented elsewhere.[28,30] Further characterization of the aerosol distributions was not performed; however, modified Kolmogorov–Smirnov tests of the intraplant size distributions within each job category revealed no statistically significant difference between the seasonal results.[31]

In Plant A, winter RH levels varied from 12 to 29 percent with summer levels ranging from 48 to 64 percent. In Plant B, winter RH levels varied from 13 to 36 percent with summer levels varying from 40 to 69 percent. As shown in Table II, within each plant, intrajob comparisons of the RH changes indicated an increase of 11–333 percent from winter to summer. It is notable that no consistent relationship between MMAD and RH was observed, i.e., the MMAD was higher (often marginally) with higher RH in six of the ten job–plant combinations and lower in the other four, based on a paired t-test comparing the winter to summer MMADs in each job category.

Fiber Studies

Figure 2 presents SEM photographs of bulk materials used in the battery plate paste and on the pasted plate. As shown in the figure, bulk materials with apparent fibrous morphological features included the polyester fibers added to the paste and paper used to cover pasted plates. Wood fibers (from sawdust), which were expected to be found in the Batrolife material, were not detected.

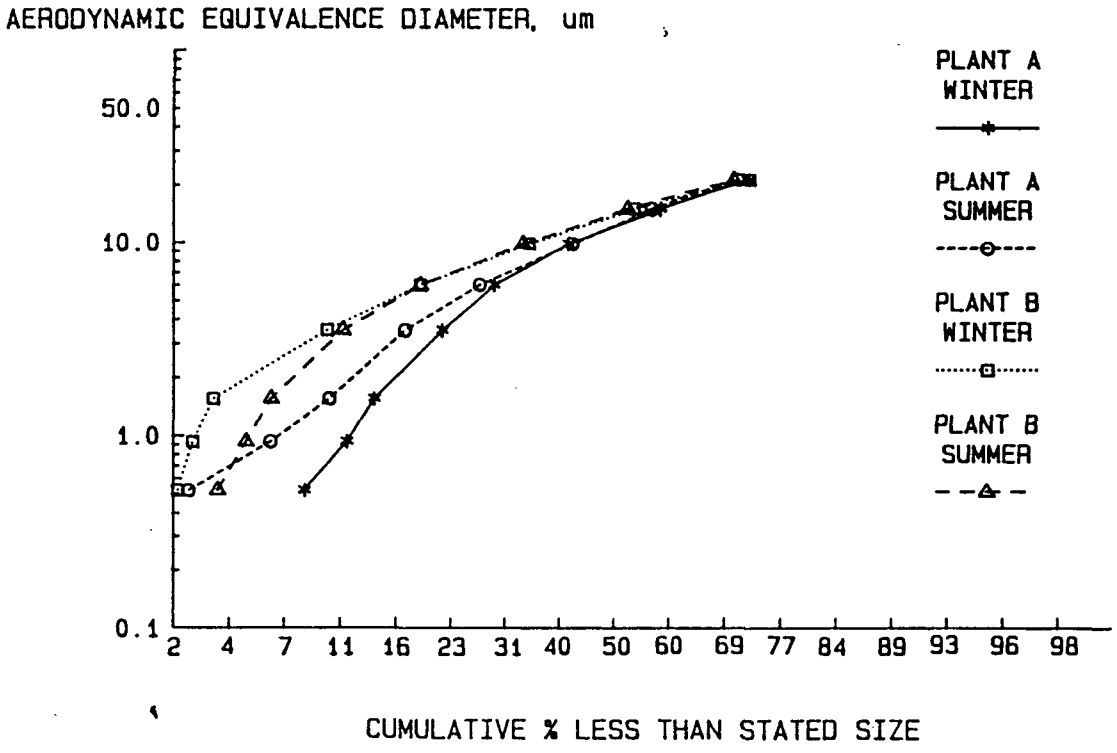

FIGURE 1. Lead aerosol distributions, stacker. Each line represents mean of four samples per job.

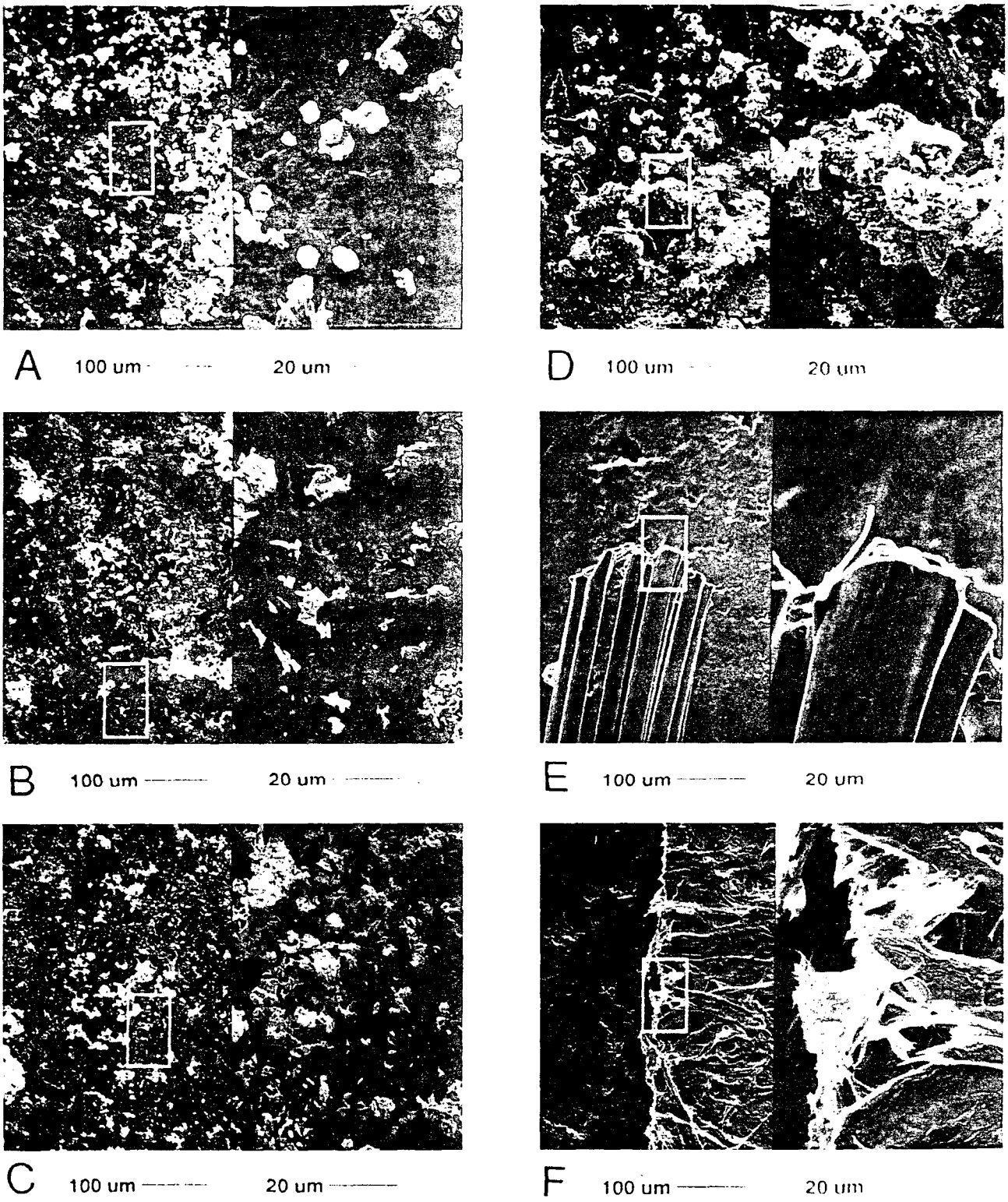

FIGURE 2. SEM photomicrographs, battery plate bulk materials. A: bulk lead oxides; B: positive paste; C: negative paste; D: batrolife material; E: polyester fiber filler; F: plate paper wrap.

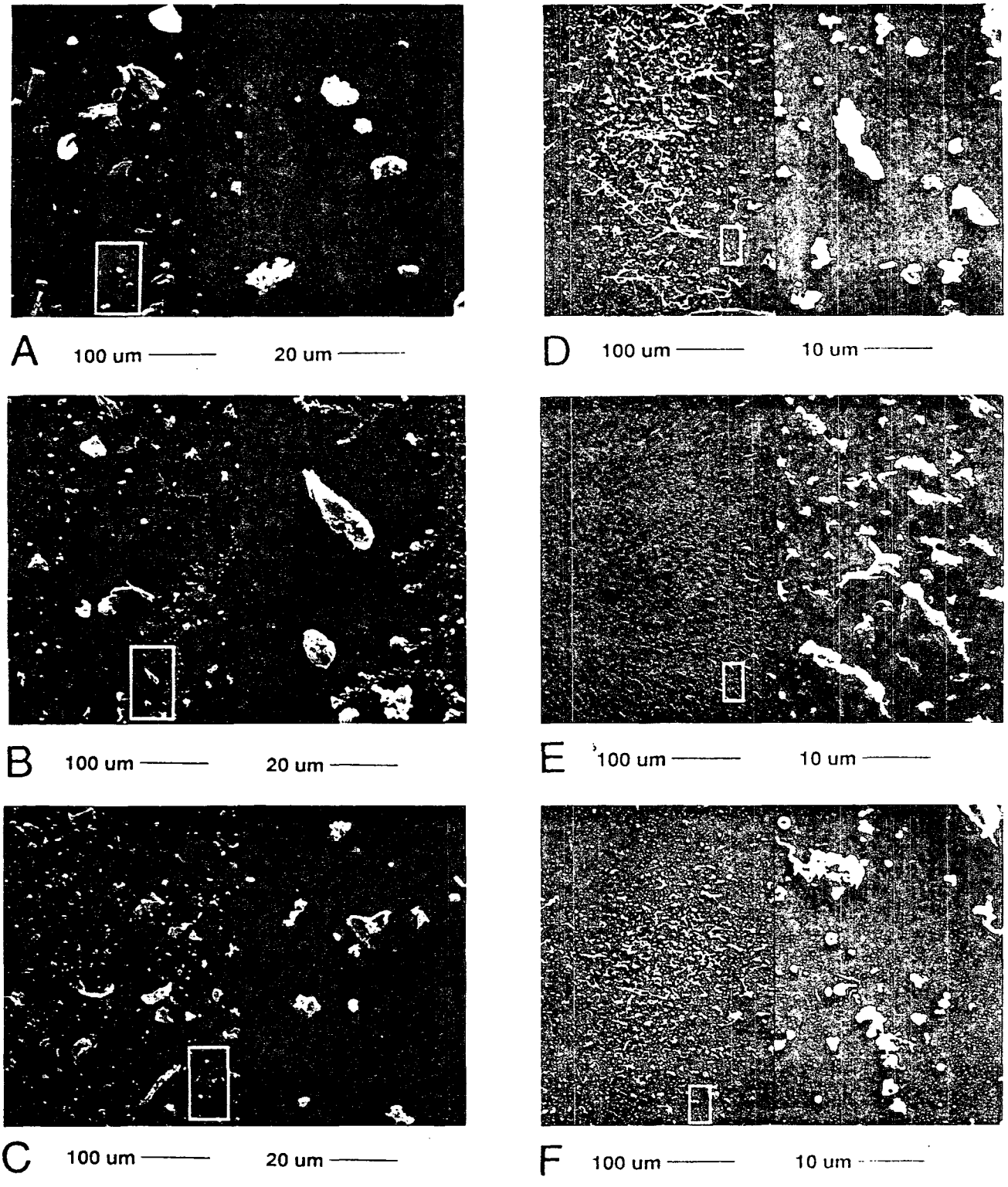

FIGURE 3. SEM photomicrographs, Plant B stacker, winter. A: stage 3 substrate (>9.8 μm); B: stage 4 substrate (6.0–9.8 μm); C: stage 5 substrate (3.5–6.0 μm); D: stage 6 substrate (1.55–3.5 μm); E: stage 7 substrate (0.93–1.55 μm); F: stage 8 substrate (0.52–0.93 μm).

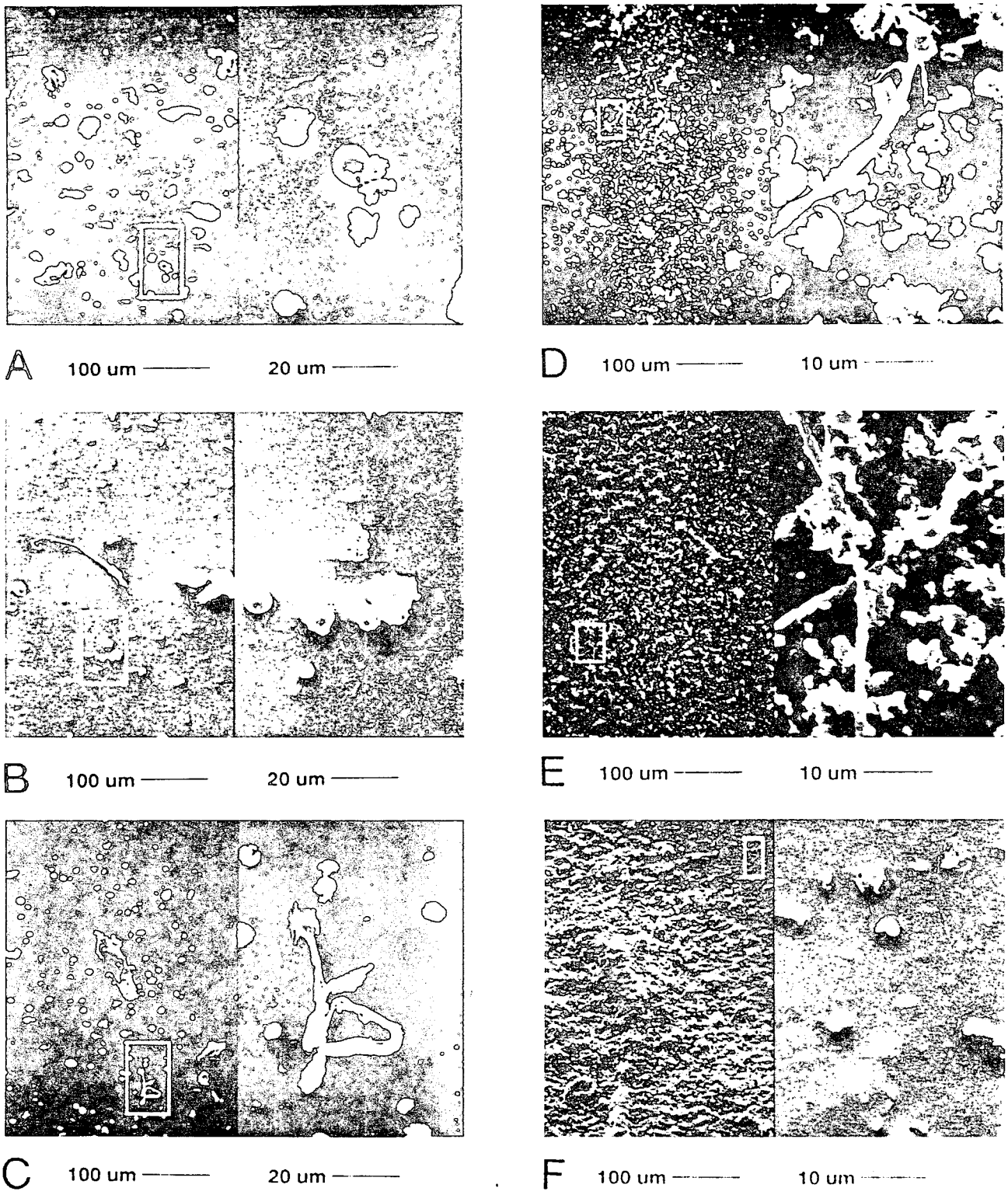

FIGURE 4. SEM photomicrographs, plant A offbearer, summer. A: stage 3 substrate (>9.8 μm); B: stage 4 substrate (6.0–9.8 μm); C: stage 5 substrate (3.5–6.0 μm); D: stage 6 substrate (1.55–3.5 μm); E: stage 7 substrate (0.93–1.55 μm); F: stage 8 substrate (0.52–0.93 μm).

Figures 3 and 4 present examples of two electron-photomicrograph series of impactor substrates. Figure 3 is a series from the Plant B stacker operation, and Figure 4 is a similar series from the Plant A offbearer operation. The upper three stages of the impactors (aerodynamic diameters greater than 3.5 μm) appeared to collect primarily nonfibrous particles. The shapes of many of the particles observed on the upper stage substrates were similar to particles of bulk lead oxides seen in Figure 2.

As shown in Figures 3 and 4, a significant number of fibers were present on both stages 6 and 7. Stage 6 collected particles with aerodynamic diameters of 1.55–3.5 μm. Stage 7 collected particles of 0.93–1.55 μm in aerodynamic diameter. On stage 6, some fibers were as long as 200 μm in actual length with geometric diameters of approximately 1 to 2 μm, and on stage 7, some fibers approached 100 μm in length with similar geometric diameters. Based on morphologic similarities, the fibers appear to have originated from the paper coating placed on the pasted plates. Detailed chemical analysis was not performed on the identified fibers because of the difficulty in isolating fibers for X-ray emission analysis and the limitation of the analytical instrumentation to detect only elements above silicon in atomic number.

Discussion

The potential for the lead-containing aerosols in battery plants to be affected by environmental humidity levels is suggested by review of literature on sulfuric acid and sulfuric acid-containing aerosols.[17–21] RH variation is used in sulfuric acid generators used for animal exposure studies.[17,18] Theoretical and experimental particle growth studies suggest that pure sulfuric acid particles can grow as much as 220 percent in diameter with RH changes from 0 to 90 percent. A 48 percent relative increase in diameter is possible with RH changes from 0 to 50 percent.

The behavior of sulfuric acid-containing, mixed aerosols is more complex. No specific studies have been performed on sulfuric acid-containing aerosols in battery plants; however, studies do exist on the effect of RH on some mixed aerosols containing the acid.[19–21] Tang *et al.*[20] report that the growth of mixed salts of ammonium sulfate and sulfuric acid may be influenced by the mixtures' propensity to deliquesce (change abruptly from crystal to droplet). Changes in the diameter of the mixed salts as related to changes in RH appears as a step function rather than as a smooth curve as suggested for pure sulfuric acid. Figure 5, taken from Tang *et al.*, illustrates the phenomenon and compares the diameter curve for pure sulfuric acid particles to the curves for a mixture containing sulfuric acid.

Hanel and Lehmann[21] studied environmental aerosols, some of which contained from 0 to 24 percent, by mass, sulfuric acid in RH levels varying from 60 to 90 percent. Mixtures of aerosols containing sulfuric acid with sodium nitrate, ammonium sulfate, and/or ammonium nitrate were measured in the ambient environments of Mainz and Deuselbach, Germany. The aerosols were described as originating from combinations of background and industrial sources. Again, particle growth was suggested to be a more complex function than that of the pure acid aerosol. The maximum and minimum aerosol size changes for the studied aerosols appear in Figure 6.

In the current study, a consistent RH effect on the potentially hygroscopic lead aerosols collected in this study was not detected. This finding is, of course, bound by the conditions of the study for RH readings of 12 to 69 percent and, thus, may be seen as consistent with the previous results reported in the literature cited above. Of note are the substantial increases in particle diameter observed by Tang *et al.*[20] and Hanel and Lehmann[21] in the 70 to 90 percent RH range. This suggests that the aerodynamic diameter of lead-bearing particles in the air of battery plants may increase significantly upon inhalation and contact with the water-saturated air of the respiratory tract. In Mor-

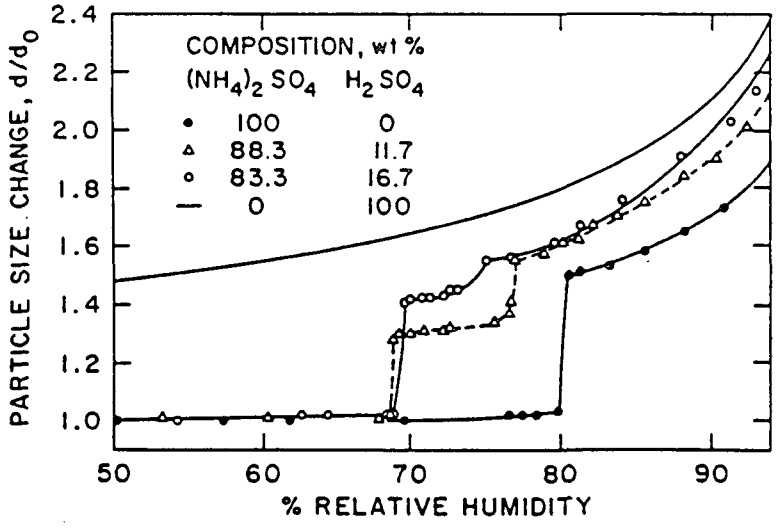

FIGURE 5. Ratio, d/d_0, of particle diameters as a function of relative humidity. (From Tang *et al.*).[20]

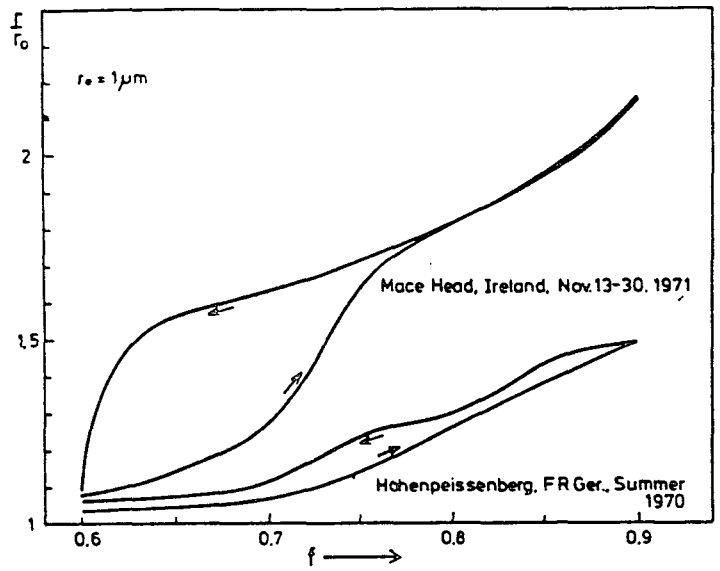

FIGURE 6. Ratio of particle radii, r/r_0, as a function of relative humidity, f (From Hanel and Lehmann).[21] The aerosol types selected demonstrate the approximate difference between maximum and minimum increase of size.

row's[32] extensive reviews of this subject, factors affecting growth of hygroscopic particles in the respiratory tract included the ambient temperature and humidity, the concentration and specific affinity for water of the hygroscopic species in a particle, the relative humidities present in different regions of the respiratory tract, and the initial size of a particle upon inhalation. More recently, Larson[33] modeled the effects of ambient RH, particle size, and endogenous respiratory levels of ammonia on the behavior and ultimate dose of inhaled sulfuric acid mist.

What is evident in these studies of hygroscopic particles is that the general effect on the particles in respiratory tract is growth. Morrow[32] suggests, in a general model of particle growth in the respiratory tract, that a 10 μm hygroscopic particle may grow as much as 40 percent in diameter in a typical 2-second inspiratory phase, while a 1-μm particle may grow as much as 500 percent under the same conditions.

These studies suggest a critical difference could occur between actual and cascade impactor-predicted deposition of particles exhibiting hygroscopic behavior. To determine the extent to which this phenomenon is occurring in the aerosols present in the current study would require the ability to monitor the actual change in the aerodynamic diameter of the particles present in the battery manufacturing environment upon exposure to the conditions present in the respiratory tract during a single breath. In any event, the potential for change in aerodynamic diameter of hygroscopic particles in the respiratory tract needs to be considered by any industrial hygienist deciding to use cascade impactors for field studies. This issue has not been discussed typically in manuals and texts that include information on cascade impactor use and data interpretation.[13,15,34-36]

The similar morphology of the particles collected on the upper three stages of the impactors to that of the bulk lead oxides is consistent with the measured lead particulate distributions. These distributions indicate that, on average, greater than 90 percent of the lead mass was found in particles with aerodynamic diameters greater than 3.5 μm. These distributions would be expected in view of the lead oxide particle's mean geometric diameter of approximately 3.0 μm (provided by plants) and lead dioxide and monoxide densities of approximately 9.5 times that of a unit density sphere.[3,4,37] Although the substrates used in the SEM samples were uncoated, differences in particle bounce for the lead oxide particles between the coated and uncoated substrates should have been minimal. Hinds *et al.*[16] reported no difference in the collection of lead dioxide particles on either coated or noncoated impactor substrates. Moreover, because some of the particles in the current study were most probably liquid-coated, particle bounce was unlikely.

The finding of long fibers on the lower stages of the impactors is of particular importance to hygienists planning to use cascade impactors to evaluate workplace aerosols containing a significant fibrous fraction. It has been suggested that fibers 200 μm in length and 1 μm in geometric diameter would, upon inspiration, be deposited in the bronchial tree as a result of interception.[1] Yet, in this study, fibers (and the associated mass of material) of approximately these same geometric dimensions would have been predicted to deposit in the alveoli of the lung based on where they were collected in the impactor. Particle bounce might have played a role in fiber collection on the lower substrates; however, this seemed unlikely. Particle bounce has been most closely associated with hard, solid particles, e.g., brass grinding dust, and not with soft materials that have the ability to deform on contact.[13,16] Long fibers of paper or polyester origin should not have been

severely affected by bounce.

Deposition studies of fibrous materials in humans is largely limited to postmortem studies of respiratory tract tissues.[23] As a result, animal studies currently present the best information on fiber deposition in respiratory systems. A recent model of deposition of fibers in the rat lung has been developed by Asgharian and Yu.[27] The model illustrates the potential effect of interception of fibers in the upper airways versus deposition by impaction, sedimentation, and/or diffusion and was shown to be in good agreement with separate experimental studies in which rats were exposed to asbestos and glass fibers. Figure 7 illustrates the effect of interception on fiber deposition in the tracheobronchial region.

The model without interception is consistent with the finding in the current study of long, thin fibers primarily on the lower stages of the impactor. What is apparent in comparing the models is the significant increase in deposition of fibers by interception, particularly as fiber length increases beyond 10 μm. Thus, the region of respiratory tract deposition of these longer fibers predicted by only gravimetric and/or chemical analysis of impactor substrates may diverge significantly from actual deposition. Cautionary notes regarding the use of impactor data, when a substantial fraction of the aerosol may be fibrous, were not found in the operations manual provided by the manufacturer for the impactors used in this study nor in other informational sources on the uses of cascade impactors.[13,15,34-36]

Conclusion

This study focussed on two aspects of the use of impactors that may not be receiving the adequate attention by the users of the equipment. First, the possible aerodynamic size changes of a potentially hygroscopic aerosol under differing ambient humidity conditions were investigated. The lack of effect in a range of 16–69 percent RH is consistent with experimental studies of complex hygroscopic aerosols containing sulfuric acid. However, these same experimental studies highlight the potential for divergence of aerodynamic diameter upon exposure to water saturated air in the respiratory tract.

Second, the collection characteristics of impactors as related to a fibrous-bearing aerosol were explored. The findings suggest that fibers of relatively large length to diameter ratios, e.g., 200 μm length and 1 μm diameter, are collected by impactors in aerodynamic classifications which suggest deep lung deposition. A significant proportion of fibers of these dimensions, however, would likely deposit in the upper airways due to interception.

This study points to the importance of understanding the physical–chemical and morphological features of aerosols when using cascade impactors to predict deposition in the respiratory tract. It suggests that the hygienist planning to use cascade impactors fully consider the characteristics of an aerosol to avoid potential biases in application of results in predictions of exposure effects.

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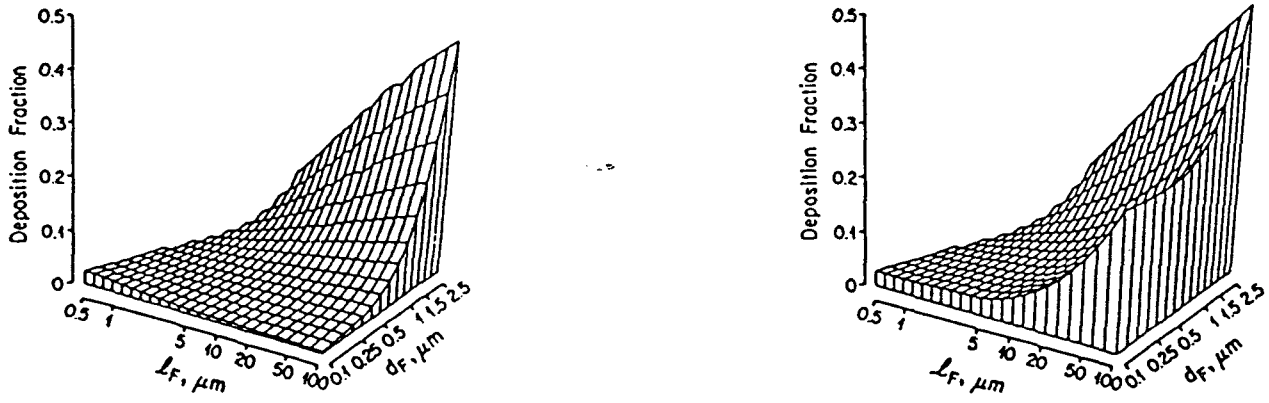

FIGURE 7. Tracheobronchial deposition model in rats, effects of interception; l_f = fiber length; d_f = fiber diameter (from Asgharian and Yu).[27]

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