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A MORE RATIONAL METHOD FOR SAMPLING OF AIRBORNE FIBROGENIC DUST IN EPIDEMIOLOGY OF PNEUMOCONIOSES

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ABSTRACT

Current sampling instruments of respirable dust (RD) may over estimate the inhaled dose by up to 400% depending on the size distribution of airborne dust. This limitation and the practice of assigning a single value for RD to all jobs regardless of the level of activity are incompatible with the advances in occupational epidemiology. A new dust sampler designed to estimate pulmonary deposition (PD)was developed to alleviate these limitations. The device consists of a 10 mm cyclone followed by a single-nozzle one stage impactor. The dust fraction of interest is collected by impaction on a 10 mm diameter microscope cover slip. Estimation of PD is obtained by selecting the appropriate air flow rate and diameter of impactor so that the combined performance will simulate the bell shaped curves of

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PD at various respiratory frequencies and tidal volumes. To obtain better matching of PD. This configuration was selected, rather than two impactors in series,(impactors have sharp cut- off curves). A cyclone can also collect large amounts of dust without overloading. Performance of the sampler was evaluated using monodispersed aerosols 1.1,2.7,4.7,9.8, um and geometric standard deviations 1.2. The results indicate that PD is estimated very closely by the new sampler.

INTRODUCTION

The predominat purpose of occupational epidemiology is the search for causal associations between diseases and environmental exposure. Thus, a dose- response relationship is derived that specifies the amount of the causative agent needed to lead to a stated incidence of the effect. The contribution of the industrial hygienist is to evaluate the environmental exposure to determine the dose received by every individual of the population under investigation.

Early studies in south Africa in 1939 showed that the dust in silicotic lungs constitutes a size selected of the particles originally inhaled. (13) In the United States, Sayers and Jones indicated that the most important particles contributing to silicosis risk, fall within the range of 1-3 um (17). These factors together with the discovery of significant differences with patticle size in the free silica content of heterogeneous dusts emphasized the need for selective sampling and analysis of airborne particulate matter in the working environment. In 1948 Hatch and Hemeond suggested the use of a two stages,dust sampler, where the collection characteristics of the first stage would approximate those of the upper respiratory tract and the fraction collected in the second stage would represent particles deposited in the pulomonary air spaces(6). In Britain, the horizontal elutriator was adopted by the British Medical Research Council (BMRC) as the instrument of choice and its performance characteristics were selected for the definition of the respirable fraction of airborne dust(14). In the U.S., a different definition of the respirable fraction of airborne dust cloud was established by the Atomic Energy Commission (AEC) in 1961, "Respirable Dust" was defined as that portion of the inhaled dust which penetrates to the non-ciliated portions of the lung (7). It was derived from the data published by Brown et al on pulmonary deposition (2). Several attempts were subsequently made to match the AEC curve with the performance characteristics of cyclone collectors. In 1968, the American conference of Governmental Industrial Hygienists (ACGIH) modified the AEC curve to take into consideration the actual penetration of cyclone collectors (22).

Lippmann reviewed the literature on size selective sampling techniques and he indicated that the differences between these various methods may reach up to 35%.
In conclusion, Lippmann stated that, "It is apparent from

the preceding discussions that the various definitions of respirable dust are somewhat arbitrary". The BMRC and AEC definitions are based upon the aerosol which reaches the alveolar region. Thus, they do not predict alveolar deposition, since part of the aerosol which penetrates to the alveoli remains suspended in the exhaled air. The proportion which does not deposit is a variable which depends on particle size."(8).

Mercer evaluated the performance of two-stage samplers. He compared the results to the predicted pulmonary deposition based on the ICRP model (21) and found that the fraction collected on the second stage is over three times the amount of pulmonary deposition (15).

MATERIALS AND METHODS

Monodisperse aerosols; 1.1,2.7,4.7 and 9.8 um aerodynamic diameters and geometric Standard deviation 1.2, as determined by light microscopy, were used. The density of particles were calculated 1.4g/cm^3 using Stăn et al (20) and Sehemels (18) method. These aerosols were generated using a May Spinning top Generator (12), which was adjusted to Spin at 78000 RPM, the particles were produced by injecting a solution of 7 to 1 uranine and methylene-blue in 60% alcohol, to the top of the disc at constant flow rate of 0.57 ml/min. This solution has been extensively used in aerosol research with satisfactory results (4,18).All aerosols were dispersed uniformly inside an air tight chamber 90x90x130 cm.

Fourteen samples were collected simultaneously using six duplicated Cyclon+impactor in series and two filters alone. sampling rate was 1.8 Lpm as recommended for 10mm cyclones and also personal samplers(15). The impaction stage was a 10mm diameter microscope cover slip coated with 5% Dow Corning Hi-vac Silicon grease to prevent particle reentrainment. Sampling train was as follows:

- Filter for total dust concentration inside the chamber
- Impactor+filter, to determine impactors efficiency.
- Cyclon + impactor+ filter to measure cyclone and impactors efficiency.
- Cyclon+ filter to check cyclon efficiency.

The impaction Stages were placed in 50ml. beakers and 1ml. chloroform was added to each beaker. The uranine was separated from grease in ultrasonic bath.(this method of separating was devoloped during this experimet that could recover uranine from cover slip more quantitatively than other recommended methods).Ten ml.0.1 N Sodium hydroxide was added to each beaker and the amount of collected uranine was measured by spectrofluorometry at 450 nanometer excitation and 511 nanometer emission by Aminco Bowman Spectrofluorometer.

RESULTS

The new dust sampler consists of two stages; a 10mm Dorr Oliver Cyclon and a single stage impactor.Six impactors of different nozzle diameters were used in this study to evaluate the validity of concept of their design, which was based on criteria presented by Marple and Wilieke (10).

The dimensions were selected so that the impactors would be opperated at flow rates (Q) within the range induced by personal sampling pumps (Reynolds number (Re) for the jet velocity (V) would range 500 to 5000(1). The nozzle diameters were: 0.139,0.159, 0.179,0.198,0.218 and 0.238 centimeters. The throat length to jet diameter ratio (T/W) ranged from 0.668 to 1.14 and jet to plate distance to jet diameter ratio(S/W) also ranged from. 0.668 to 1.4. S/W was specifically chosen to be >0.5 So that matching imperfection would have a negligible effect on the value of stokes number. Fig 1 shows Schematic view of the impactor. and table 1 indicates the characteristics of all six impactors.

The performance of impactors and impactor-cyclone combination was evaluated by collecting some 495 samples of different particle Sizes and different combinations. and their efficiency was measured by quantitative analyses of uranine. Figur 2 shows efficiency of impactors as function of square root of stokes number ($\sqrt{STK}$).This is a dimensionless particle size which has been convenienlty used by authors (11,3).($STK=\rho_p CV.D_p/18u:W/2$) where (C) is Cunningham slip correction factor and D_p is particle diameter). The result shows the collection efficiency of impactors is a function of the Stokes number, the Reynolds number and the physical configuration of the impactors. However the 50% efficiency is associated with a square root of Stokes number value of 0.475. The particle collection efficiencies of the six Impactors are displayed in Figure 3. In these figures 50% cut size corresponds to particles of 1.55 um and impactor nozzle of 0.139 cm. In figure(4) the net effect of the theoretical collection efficiency of the 10mm cyclone and the efficiency of the six impactors is presented. This family of six curve have a skewed bell shape similar to that of pulmonary deposition which will be discussed later.

It is clear that efficiency would alter with changing flow rate. Thus pulmonary deposition under any given conditions can be Simulated by selecting the appropriate nozzle size and air flow rate.

DISCUSSION

The current methods are associated with several disadvantages(1). They measure penetration rather than deposition, and consequently overestimate particle deposition, 2) the extent of overestimation is not consistent for all sizes, which inturn will depend on the size distribution of airborne dust and, 3) They provide a single value for all exposed workers regardless of their age, height, weight or level of work load. Most of these factors have been shown to affect pulmonary function (3,6,19) and consequently it would be expected to affect pulmonary deposition.

Figure 5 shows the discrepency between the performance of respirable dust samplers (AEC and ACGIH definitions) and actual pulmonary deposition values recently determin-de by Lippmann for nose and mouth breathing (8) as Well as those of Heyder et al (cited by Glind meyer) for:1) mean residence time (MRT) of 4 second and mean flow rate (MFR) of 250 cm^3/sec and, 2) MRT=2 sec.and MFR=750 cm^3/ sec(5).

Ohman, in his Yant Memorial Lecture on silicosis, pointed out that the current practice of constructing the workers exposure using respirable dust without regard to their level of activity and consequently their pulmon-ary ventilation rate, is inadequate. He suggested that pulmonary ventilation associated with each work load should be taken into consideration during construction of dose- response relationship (16).

Two illustrations which are presented in Fig 6, indicate, that the actual performance of the cyclone and 0.179cm diameter nozzle closely approximates pulmonary deposition for Lippmann's mouth breathing and Heyder's MRT= 2 sec. and MFR= 750 cm^3/sec. Similarly, the perfor-mence of the cyclone and 0.238 cm diameter nozzle matches very closely Lippmann's nose breathing pattern. Matching the 4 sec MRT and 250 MFR deposition curve could most Probably be achieved by operating the cyclone at a lower flow rate in conjungtion with the 0.139 cm diameter impac-tor. The experimental data presented above illustrates the soundness and feasibility of the concept of the sam-pler and it is clear that its performance is closer to pulmonary deposition than any of the current sampling methods.

Table 1. Dimensions of Impactors, Jet Velocities and Associated Reynolds Numbers

Impactor No.	Jet Diameter W, cm	T/W*	S/W*	Jet Velocity** V, cm/sec	Re**
I	0.139	1.14	1.14	1977	1835
II	0.159	1.0	1.0	1511	1604
III	0.179	0.888	0.888	1192	1425
IV	0.198	0.803	0.803	974	1288
V	0.218	0.729	0.729	804	1170
VI	0.238	0.668	0.668	674	1071

* T = S = 0.159 cm.
** Values calculated for Q = 30 cm3/sec.

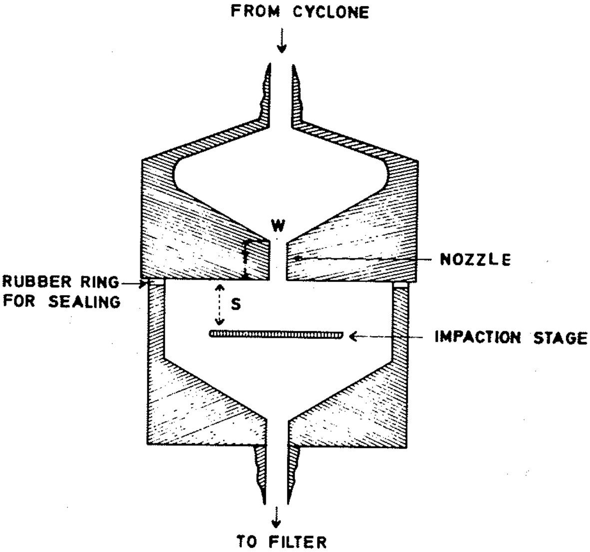

FIG. 1:

SCHEMATIC DIAGRAM OF IMPACTOR

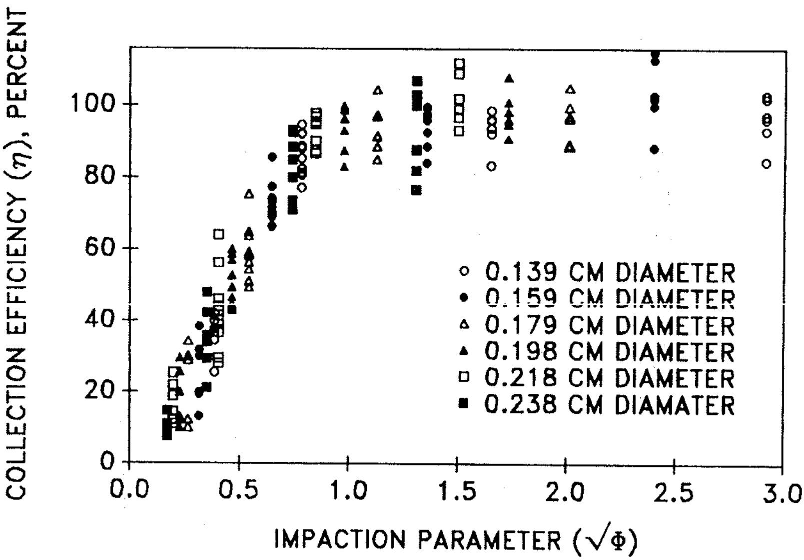

FIG. 2:

PERFORMANCE CHARACTERISTICS OF 6 IMPACTORS

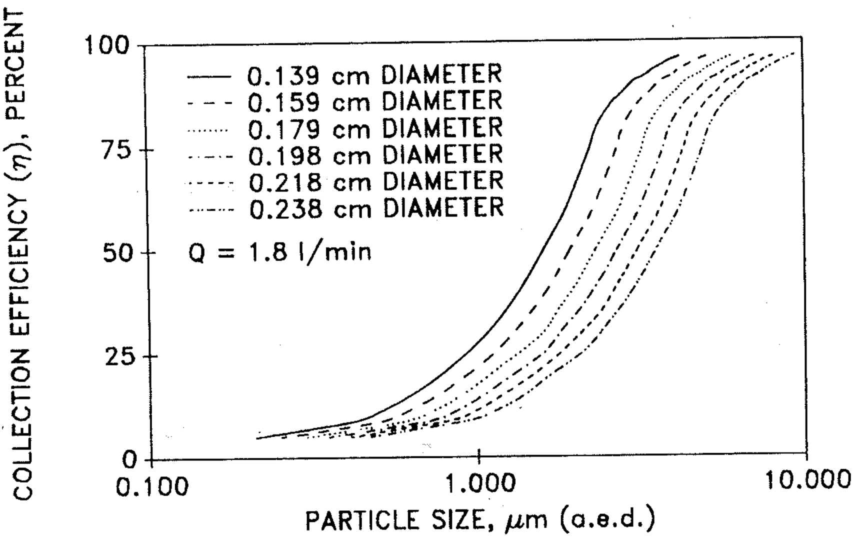

FIG.3:

COLLECTION EFFICIENCY VS PARTICLE SIZE FOR 6 IMPACTORS

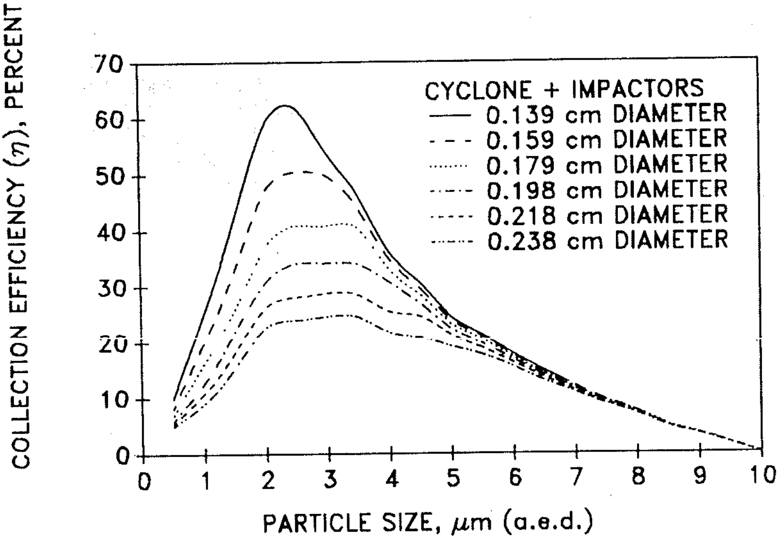

FIG.4:

EXPECTED COMBINED PERFORMANCE OF CYCLONE AND 6 IMPACTORS

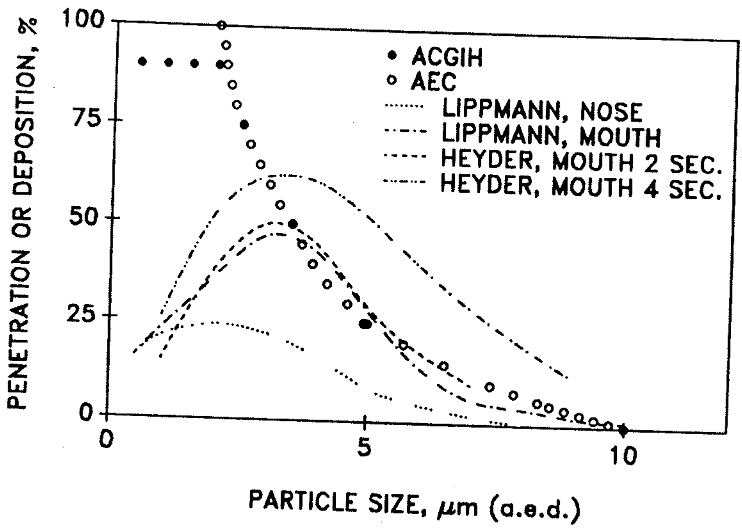

FIG. 5:

CYCLONE PENETRATION AND PULMONARY DEPOSITION FOR MOUTH AND NOSE BREATHING

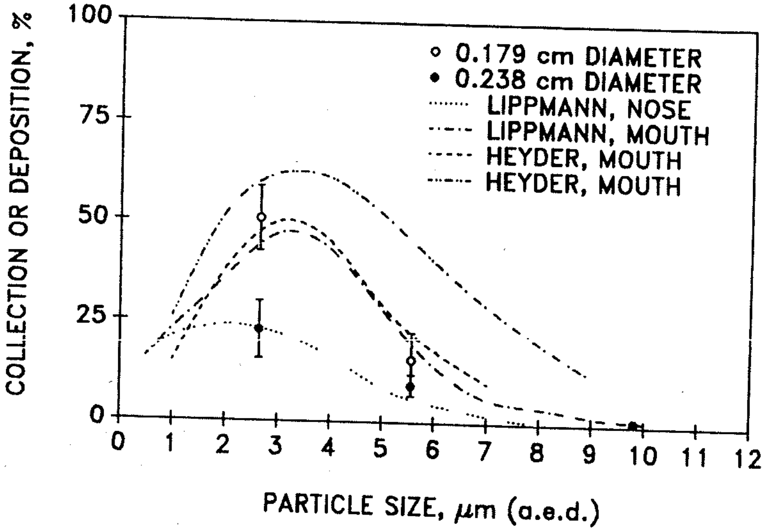

FIG. 6:

SAMPLER PERFORMANCE AND PULMONARY DEPOSITION FOR MOUTH AND NOSE BREATHING

REFERENCES

1. American Confrence of Governmental Industrial Hygienists, (1987): Thresshold limit values for 1987.
2. Brown, J.H.,Cook, K.M., Ney,F.G. and Hatch.,T. (1950): Influence of Particle Size Upon the Retention of Particulate Matter in the Human Lung. Am.J.Pub.Health 40: 450.
3. Chan T.L. and Lippmann M.(1980): Experimental measurements and Emperical modeling of the Regional Deposition of Inhaled particles in Humans; Am.Ind. Hyg. Assoc.J. 41: 399.
4. Corn, M. and Esmen, N.A.(1976): Aerosol Generation: Handbook on Aerosols. Dennis, R., Ed., TID-26608, USERDA.
5. Glindmeyer, H.W.(1981): Predictable confusion.J.Occup. Med. 23: 845.
6. Hatch, T. and Hemeon, W.C.L.(1948): Influence of particle Size in Dust Exposure. J.Ind. Hyg.Toxicol.30: 172.
7. Heyder, J., Gebhart, J.,and Stahlhofen,W. (1980): Inhalation of Aerosols: Particle Deposition and Retention. In: Generation of Aerosols and Facilities for Exposure Experiments. Willeke, K., Ed., Ann Arbor Science, Ann Arbor.
8. Lippmann, M.(1977): In Handbook of Physiology,Section 9, Reactions to Environmental Agents. Lee, D.H.K.,Falk, H.L., Murphy,S.D., Geiger, S.R., Eds., Bethesda:American physiological Society.

9. Lippmann, M.(1983): Size-Selective Health Hazard Sampling. In: Air Sampling Instruments for Evaluation of Atmospheric Contaminants. Lioy.P., Ed., PP H-2,6th Edition. Cincinnati: Am.Conf. Govern.Ind.Hyg.

10. Marple, V.A.,and Willeke, K.(1975): Inertial Impactors: Theory, Design and Use. In:Fine Particles, Liu, B.Y.H., Ed., Academic Press, New York.

11. Marple, V.A. and Willeke, K.(1978): Inertial Impaction In: Lundgren D.A.,Lippmann M., Harris F.S., Clark W.E. eds. Aerosol measurment, Florida, University Press, 90-109.

12. May,K.R.(1966): Spinning- Top Homogeneous Aerosol Generator with Shock- Proof Mounting.J.Sci.Instrum. 43: 481.

13. McCrea.J.(1939):The Ash of Silicotic Lungs.Publs.S. African Med.Res.

14. Medical Research Council(1953):Dust Subcommittee, Industrial Pulmonary Disease Comm., Recommendations of MRC Panels Relating to Selective Sampling,Minutes of Joint Meeting London, March 4.

15. Mercer, T.T.(1966): Air Sampling Problems Associated with the Proposed Lung Model.Presented at 12th Annual Bioassay and Analytical Chemistry Meeting.Gatlinburg, TN.

16. Ohman,K.H.G.(1987): Prevention of Silica Exposure and Elimination of Silicosis.Am.Ind.Hyg.Assoc.J. 39/847.

17. Sayers, R.R.and Jones, R.R.(1958): Silicosis and Similar Dust Diseases, Medical Aspects and Control. Pub.

Health Repts. (US)53:1453.

18. Sehemel, G.A.(1967): The Density of Uranine Particles produced by Spinning Disc Aerosol Generator. Am.Ind. Hyg. Assoc. J.28: 491.
19. Stahlhofen, W., Gebhart J. and Heyder J. (1980): Experimental determination of the Regional Deposition of Aerosol Particles in Human Respirotory Tract, Am. Ind. Hyg. Assc. J. 41: 385.
20. Stein F., Esmen N., and Corn M.(1966): The Density of Uranine Aerosol particles, Am.Ind/Hyg. Assoc. J. 27: 428.
21. Task Group on Lung Dynamics Committee II-ICRP (1966): Deposition and Retention Models for Internal Dosimetry of Human Respiratory Tract. Health Physics 12:173.
22. Threshold Limit Values of Airborne Contaminants for 1968. Cincinnati (1968): Am. Conf. Govern. Ind.Hyg.