CHARACTERIZATION OF THE AIRBORNE FIBROUS COMPONENT OF COTTON-RELATED DUST IN TEXTILE OPERATIONS

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Abstract

Sampling for airborne particulates was carried out in the vicinity (work area) of a card processing cotton. Sampling was carried out using both a standard vertical elutriator (VE) cotton dust sampler and a personal dust sampler. Filter samples were collected over a range of sampling times and were analyzed with a transmission light microscope attached to an image analysis system. The system was programmed to measure the number and size (area, length, breath, and aspect ratio) of respirable particulates collected on the filter surface. Special attention was given to the characterization of the fibrous-like components of the airborne dusts meeting the WHO definition of a fiber (length > 5µm with corresponding width < 3 µm and aspect ratio > 3:1). Preliminary results indicate: a) an absence of birefringent cellulosic-type particles (i.e., no cotton fiber fibrous fragments); b) the average size of dust sampled by the VE is somewhat larger than the dust sampled by the personal monitor; and c) despite large differences in sampling times, the personal monitor collects approximately the same concentration of fibrous particles (fibers per cm^3 of air) as does the VE.

Introduction

The U.S. Environmental Protection Agency (EPA) under the Toxic Substances Control Act (TSCA) is evaluating with the help of a contractor, Syracuse Research Corp., whether inhalation of inorganic and organic fibers (naturally and synthetically manufactured), including cotton can cause health problems similar to those caused by asbestos. Workers in cotton-dust related worksites have never been reported to have health effects similar to those caused by asbestos. In addition, U.S. OSHA regulations for cotton dust (29CFR 1910.1043) after 15 years of rulemaking are not to protect against asbestos type respiratory disease health effects.

The deposition of inhaled fibers is a function of fiber diameter and density as well as length and aspect ratio (length to diameter). The definition of a fiber as used for counting purposes according to the World Health Organization (WHO) and the UK Health and Safety Executive (HSE) is that of a particle of length > 5 µm and diameter < 3 µm, with aspect ratio > 3:1 as measured by phase contrast optical microscopy (PCOM) using the membrane filter method (M. Meldrum).

The objective of this preliminary research project is to evaluate various methods to characterize the respirable airborne fibrous component (in fibers/cc) of cotton-related dust in textile operations.

Generally, the characteristics of the cotton dust collected using a vertical elutriator (VE) cotton dust area sampler with those of dust collected simultaneously by a personal monitor at the same location are compared. In this preliminary study, image analysis and polarized light microscopy (PLM) were used to characterize the size, shape, and nature of cotton dust collected in a model card room using these sampling devices. PLM was chosen over PCOM because cellulosic cotton fibers are birefringent, thus fragments of cotton fiber would be easily identifiable by PLM. The amount of the cotton dust collected by each sampler that is considered respirable fiber by the WHO definition is determined.

Experimental Equipment

Standard Vertical Elutriator (VE) - Shown in Figure 1, the VE collects respirable dust (about < 15 µm; as defined by the U.S. OSHA Cotton Dust Standard, 29CFR 1910.1043) that has been separated from total dust by elutriation or settling. Sampling rate is 7.2 liters per minute (lpm) with the dust collected on a 37 mm mixed cellulose ester (MCE) filter disc.

Personal Monitor (PM) - Shown in Figure 2, the PM consists of a light-weight ESCORT ELF™ sampling pump with 2.5% regulation of sampling flow rate. The pump is attached to a 10 mm cyclone assembly that passes only respirable particles and allows them to be impacted onto a 25 mm MCE filter disc (29CFR 1910.1043, Appendix A).

Image Analysis System (IAS) - Shown in Figure 3, a Leica Model Quantimet 600 high resolution image analysis system operating in the Windows 95 environment with QWIN v. 1.05 software. The system is equipped with a high resolution black and white CCD camera.

Microscope - Also visible in Figure 3, a Nikon OPTIPHOT POL2 polarized light microscope using a Nikon PlanApo 20x objective and transmitted light from a halogen bulb.

Procedures

Tests were conducted in the model card room at USDA-ARS-CQRS, Clemson, SC. The equipment was operated so as to maintain a constant dust level of 1.0 mg/m^3 as measured by the VE. Dust was sampled using the VE operated side-by-side with the PM. Tests were run in

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duplicate for varying durations including 15 min, 30 min, 1 hr, 2 hr, and 3 hr. The dust laden filters from both the VE and the PM were prepared for image analysis by cutting them into four pie-shaped sections each. A section is placed on a standard glass microscope slide and several drops of methyl ethyl ketone are applied to the section to clarify the MCE material and permanently adhere it to the slide.

Results

Portions of the filters from each test were examined under the light microscope to determine which sampling times yielded levels of particle loading suitable for image analysis. It turned out that the filter loading for the VE run for 15 min appeared to be at about the same level as for the personal monitor run for 3 hr. Typical fields of view from the image analyzer are shown for the VE run for 15 min and for the personal monitor run for 3 hr are shown in Figures 3 and 4, respectively.

Total Dust

These preliminary studies are based upon image analysis of approximately 1000 dust particles collected on the filters. Statistics for the significant particle parameters for the personal monitor are given in Table 2. Parameters measured include particle area, length, width, and aspect ratio. Values are given for the statistical mean, standard deviation, maximum, and minimum of the data set. Similar values for the results obtained from the VE filter are given in Table 3. In general most of the particle statistics are higher for sampling with the VE than with the personal monitor. The image analyzer also measures the distribution of particle size parameters. In Figure 5 we have plotted the distribution of areas of particles collected by the personal monitor as compared with the distribution of areas of particles collected by the VE. The two curves are rather similar. Particle areas are distributed over a rather wide range and both distributions are skewed toward the smaller sizes. It is noted that the VE does exhibit slightly higher percentages of larger particles especially in the 6 to 18 μm^2 range. Similar results are seen in Figure 6 where we have plotted the distribution of lengths of particles collected by the personal monitor as compared with the distribution of lengths of particles collected by the VE.

Fibrous Dust Component

One of our objectives in this study was to consider a sub-population of the total dust obtained with the two samplers that would be considered to be fibrous. A widely-held definition (WHO) of a fibrous particle is one that has a particle length > 5 µm with a corresponding width < 3 µm and an aspect ratio > 3:1. It was a simple matter to sort the Excel spread sheet data on the total particle characteristics to find the sub-population of particles that would fit the definition of being fibrous. As shown in Table 4, quite a significant portion of the dust particle population fit into the "fibrous" category. Table 4 lists two parameters:

$$\text{Area (\%)}=100*[\text{area of fibrous particles/area of all particles}] \quad (1)$$

$$\text{Number (\%)}=100*[\text{number fibrous particles/number all particles}] \quad (2)$$

From this table we see that, based upon both area and number, slightly more than half of all particles collected by the personal monitor are fibrous in nature and that the VE dust collection represents a significantly higher proportion of fibrous dust particles. In Table 5 we compare the mean values of particle parameters for the fibrous component of dust sampled by the personal monitor and the VE. Here we see significantly higher values for both mean particle area and mean particle length when comparing results from the VE with the personal monitor. Let us now consider again the distribution of particle parameters for this fibrous component of the dust. In Figure 7 we have plotted the distribution of areas of fibrous particles collected by the personal monitor as compared with the distribution of areas of fibrous particles collected by the VE. The two curves are more dissimilar than they were in Figure 5. Particle areas are distributed over a rather wide range and distributions from the personal monitor are skewed to even smaller areas than for the VE. The VE exhibits higher percentages of larger particles especially in the 10 to 35 μm^2 range. In Figure 8 we have plotted the distribution of lengths of fibrous particles collected by the personal monitor as compared with the distribution of lengths of fibrous particles collected by the VE. The overall shape of the two length distribution curves are quite similar.

Fibrous Particle Concentration

Because of the wide disparity in sampling times (15 min for the VE versus 3 hr for the personal monitor) in order to obtain similar dust loadings, we developed an equation to calculate the particle concentration sampled by each monitor.

$$N = [n*AF/nf *af]/[Ts*Sr] \quad (3)$$

where: N = particle concentration (#/cc)
n = number of particles imaged
AF = total filter area (mm)
af = area of individual image analysis field (mm)
nf = number of image analysis fields measured
Ts = sampling time (min)
Sr = sampling rate (liters/min)

Substituting the appropriate values for the personal monitor and the VE for their respective tests into Equation 4 yields the following concentrations:

$$N \text{ (personal monitor)} = 1.27 \text{ fibers/cc} \quad (4)$$

$$N(VE) = 2.13 \text{ fibers/cc} \quad (5)$$

The fact that the values from Equations 4 and 5 are of the same order of magnitude gives a certain amount of credibility there. Any differences could possibly be justified by the disparity in the sampling times (15 min for the VE vs. 180 min for the personal monitor).

Cellulosic Materials

It is well known that the cotton fiber is birefringent (ASTM D 1442-93, 1993) which implies that cotton fibers or significant fragments of cotton fibers should appear as illuminated when viewed in the polarized light microscope. As discussed above, all filter samples were routinely viewed through a polarized light transmission microscope with the polars crossed above and below the sample. The results from this procedure are that only a few full cotton fibers were seen and that no birefringent cellulosic fragments that would be of a critical size (fibrous by the WHO definition) were observed . In fact, those particles that exhibited fibrous-like characteristics appeared mostly to be microbiological in nature being possibly associated with fungal hyphae and other fungal and bacterial fragments.

Conclusions

1) The modern image analysis system affords us the opportunity to easily characterize the morphology of airborne cotton-related dust collected on filter samplers.

2) The VE and personal monitor collect total dust having very similar general size distribution characteristics.

3) The VE collects a slightly larger size of particles than does the personal monitor.

4) The VE collects a slightly somewhat larger size of fibrous-like particles than does the personal monitor.

5) Despite large differences in sampling times, the personal monitor collects approximately the same concentration of fibrous particles (fibers per cm^3) of air as does the VE.

6) An absence of birefringent cellulosic-type respirable particles were detected on filters (i.e., no cotton fiber fibrous fragments).

7) More studies concerning the airborne fibrous component of cotton-related dust in textile operations are necessary. The next phase will compare the VE with the NIOSH 7400 sampler which is used to sample for asbestos.

References

M. Meldrum, HSE (1996). Review of Fibre Toxicology, EH 65/30, UK, p. 1.

Table 1. Sampler Operating Parameters.

Parameter	Personal Monitor	Vertical Elutriator
Sampling Rate (lpm)	2	7.2
Filter Size (mm)	25	37
Duration (min)	225	15

Table 2. Statistics of Particle Parameters for the Personal Monitor Sampling Cotton Dust.

Statistic	Area (μm^2)	Length (μm)	Width (μm)	Aspect Ratio
Mean	4.3	3.74	0.85	5
Std. Dev.	7.93	3.91	0.46	4.55
Max	194.4	57.1	5.09	43.9
Min	2.42	1.36	0.34	1

Table 3. Statistics of Particle Parameters for the VE Sampling Cotton Dust.

Statistic	Area (μm^2)	Length (μm)	Width (μm)	Aspect Ratio
Mean	10.9	5.86	1.07	5.67
Std. Dev.	37.9	9.24	0.74	4.08
Max	666.1	142.9	7.47	52.6
Min	1.15	1.36	0.34	1

Table 4. Area and Number Fraction of Particles With Lengths > 5.0 μm and Widths < 3.0 μm.

Parameter	Personal Monitor	VE
Area (%)	59.69	87.45
Number (%)	52.76	68.43

Table 5. Comparison of Mean Values of Particle Parameters for Particles With Lengths > 5.0 μm and Widths < 3.0 μm.

Parameter	Personal Monitor	VE
Area (μm^2)	4.85	13.9
Length (μm)	5.13	7.35
Width (μm)	0.71	0.99
Aspect Ratio	7.39	7.2

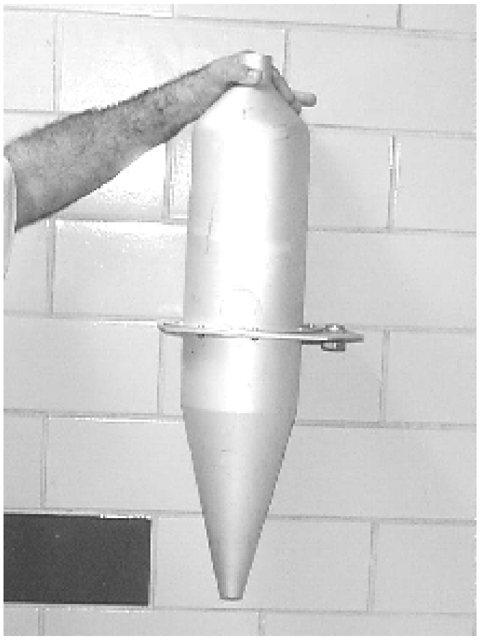

Figure 1. Vertical Elutriator Air Sampler

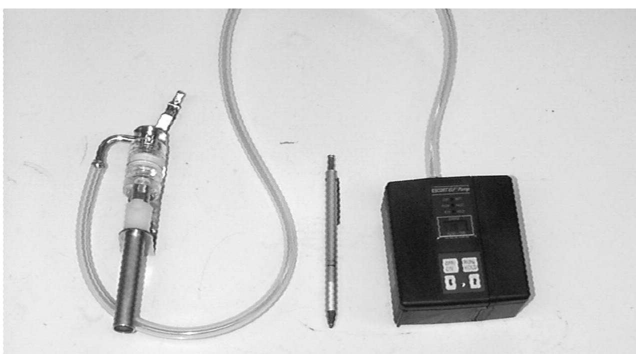

Figure 2. Personal Monitor with Pump and Cyclone Pre-cutter.

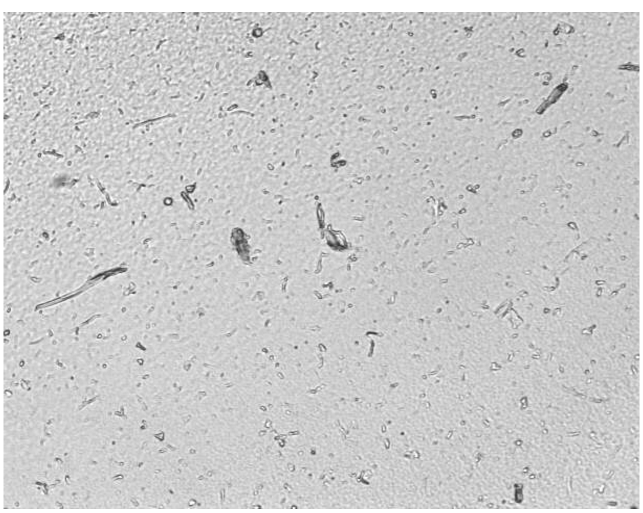

Figure 3. Image of Dust Collected with Personal Monitor.

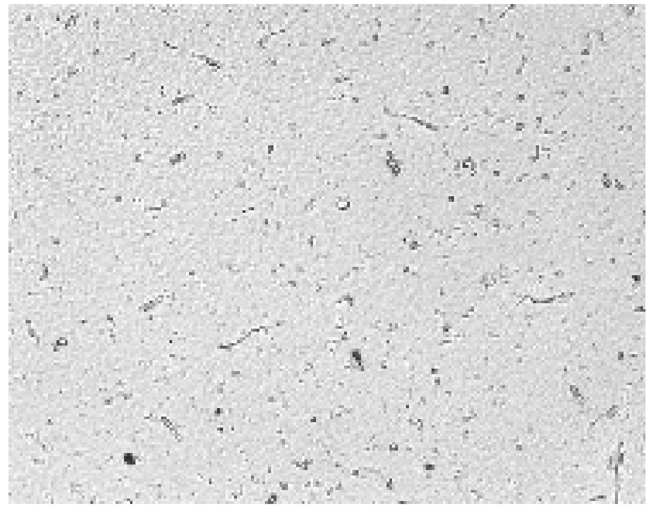

Figure 4. Image of Dust collected with the Vertical Elutriator

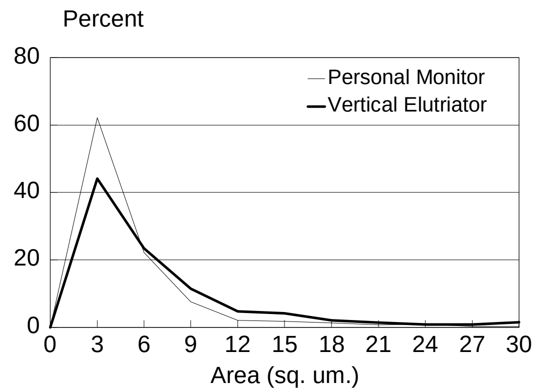

Figure 5. Distributrion of areas of particles collected on the personal monitor vs. The vertical elutriator.

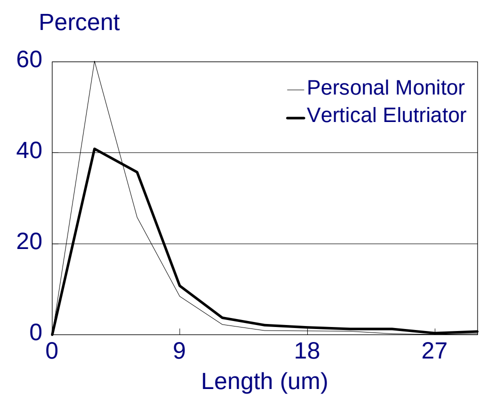

Figure 6. Distribution of lengths of particles collected on the personal monitor vs. the vertical elutriator.

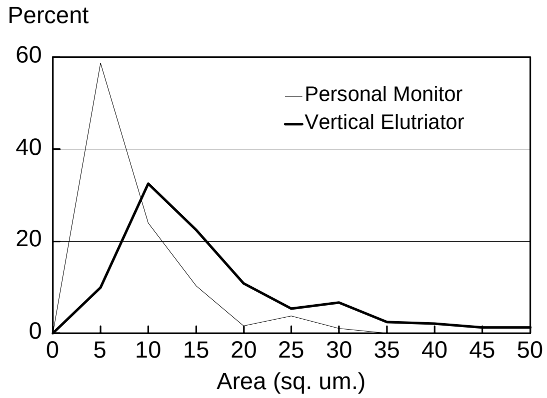

Figure 7. Comparison of distributions of particle areas for particles with lengths > 5.0 um and widths < 3.0 um.

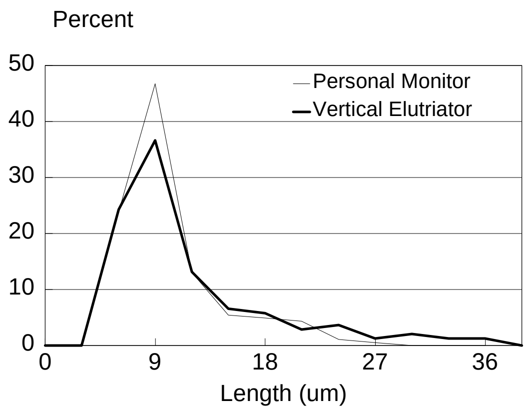

Figure 8. Comparison of distributions of particle lengths for particles with lengths > 5.0 um and widths < 3.0 um.