Investigation into Airborne Dust in a Wool Textile Mill

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Airborne dust samples were gathered from the vicinity of various commonly performed processes in the wool-preparation industry. Samples of airborne wool dust were collected on membrane filters during the processing of wool lots. The chemical composition of the inorganic particles present in the total inspirable and respirable dust fractions was determined with the use of a Scanning Electron Microscope (SEM). The widely differing morphologies of the particles collected raise questions about the validity of trying to correlate minor respiratory symptoms with dust concentrations, as some particle types will penetrate the respiratory system more easily than others. The results are discussed with respect to the sampling methodology used.

Keywords: airborne dust, wool, textile mill, SEM.

1 Introduction

Dust is generally defined as an aerosol of solid particles, mechanically produced, with individual diameters of 0.1 μm upwards [1]. Exposure limits have been defined for many kinds of industrial dusts dispersed in workspaces, as a function of the health hazard they present, with the aim of protecting workers from possible respiratory diseases. The ISO and the ACGIH (American Conference of Governmental Industrial Hygienists) definitions of inspirable [2] dust are the mass concentration of ambient airborne particles inspired through the nose and mouth, during breathing, which is available for deposition anywhere in the respiratory tract. The aim of this work is to deepen the understanding of the factors relevant to this problem by conducting a survey of the nature of airborne wool dust in an industrial environment.

Wool in its raw state contains a variety of associated materials, which are regarded as impurities [3]. Amongthese, mineral impurities, such as dust and dirt, are picked up by the animal from the pasture during its growth and may account for 5–20 % of raw weight. Most foreign inorganic materials are removed by scouring. However, a certain amount remains as a deposit on the fiber surface or trapped within the entangled fiber mass and becomes a preferential target of the strong mechanical stresses developed during carding [4].

Substantial quantities of airborne dust are generated during the processing stages of wool textiles, especially during combing and carding operations. In these processes, dust is associated with the raw material and also arises as a consequence of the mechanical stresses to which the fibers are subjected. During carding and combing, about 40 % of the fibers are broken under normal operating conditions [5], developing fragments in the form of airborne dust.

2 Aims of the current project

The aims of this present investigation were as follows:

- to collect samples of the dust produced by different processes in a wool textile mill,
- to obtain quantitative data on the dust present in the working atmosphere,
- to identify components in the dust which could possibly pose particular health hazards,
- to produce a size distribution of the dust particles,
- to advise the wool-processing industry of the results of the project with regard to improving the health of the workforce, thus leading to a reduction in working time lost through illness.

3 Experimental details

3.1 Sampling techniques

The gravimetric concentration of airborne dust in an occupational environment is determined by drawing a measured volume of air through a filter medium, and calculating the mass of dust collected on the filter by weighting the filter before and after sampling.

In the current embodiment, the sampling apparatus consists of a pump that produces a defined air volume flow through a filter assembled in a duct. The air intake was regulated to simulate the aerodynamic conditions of human breathing (air velocity 1.1–1.2 m/s). The filters used were relatively flat and easy to coat with electrically conducting material, and all particles were easily visible. In addition, they had pores of a precisely controlled size (0.8 μm) and it was possible to measure this size directly by microscopy, thereby providing an independently measured lower boundary to the dust-particle size collected.

The time for collection needed to be as long as possible to maximize the quantity of dust collected, but short enough to allow several samples to be collected. Thus a sampling period of 20 minutes was used. The samples were gathered by simply positioning the sampling head with the pump running in the working region of the process in question. The primary concern of this project was to explore the nature of the dust rather than the quantity. It was therefore not considered necessary to sample throughout a shift. After collection, the samples were placed in static-neutralizing conductive pots and taken back to the laboratory for analysis.

The Chemical Substances TLV Committee of ACGJH recommends the following definitions [6] for particulate materials, which are intended to correspond to the fractions which penetrate to specific regions of the human respiratory system:

- inhalable dust fraction: (corresponds to the total inspirable fraction) for those materials that are hazardous when deposited anywhere in the respiratory tract,

- thoracic dust fraction: for those materials that are hazardous when deposited anywhere within the lungs, airways and the gas exchange region (bronchiolar and alveolar tract),
- respirable dust fraction: for those materials that are dangerous when deposited in the unciliate gas exchange region of the lungs (alveolus).

Such definitions ignore exhalation loss: they represent conventional diameter size ranges correlated with experimental curves for penetration into the respiratory system of spherical aerosol particles of density 1 g/cm^3. Airborne dust sampling instruments and their operating characteristics make reference to these recommended values.

3.2 Sampling methodologies

Three analytical techniques were used, as follows:

(i) Scanning, Electron Microscopy (SEM) allowed the morphology of the dust to be explored and facilitated both size and X-ray analyses. To prepare the sample for microscopy, it was gold-coated in order to prevent charging when exposed to the electron beam.

(ii) Size analysis involved measuring of the particles.

(iii) In X-ray analysis, the electron microscope was used to bombard the target with a beam of electrons.

The ACGHI quantitative definition of the inhalable dust fraction is the mass fraction of particles that are captured according to the collection efficiency, defined as follows, regardless of the sampler orientation with respect to wind direction [6]:

$$E = 50\left(1 + e^{-0.06d}\right) \pm 10 \quad \text{for } 0 < d \leq 100\ \mu\text{m}$$

where E = collective efficiency (%)
d = aerodynamic diameter (μm), defined as the diameter of a sphere of density 1 g/cm^3 having, in the gravitational field, the same aerodynamic behavior (terminal velocity in air) as the examined particle.

The membrane filters containing the airborne wool dust were analyzed with a scanning electron microscope (SEM). Small filter sections (approximately 8 × 8 mm) were cut out with a razor blade from the center of each filter. After coating with a thin gold film, the mounted filter sections were first observed at low magnification and then scanned at 2000×. Ten to 20 fields were selected, according to the particle density, in such a way as to exclude specimen edges, ensuring that the same distance existed among consecutive fields, and that each part of the specimen surface was sampled.

4 Results and discussion

Collection efficiencies representative of several sizes of particles are shown in Table 1.

The particulate produced during wool processing is formed by organic and inorganic components, present at the same time on the filter surface. The former have morphological and chemical characteristics that can interfere with the analysis of the latter. Microscope magnification is a critical parameter which enables the detection of dust particles and distinguishes them from filter surface features. Since the average size of inorganic particles is rather small, and some of them have a diameter lower than 1 μm, the minimum magnification was set to 2000×, in order to miss a significant part of the smallest particles. Most of these small particles were found to be characterized by a relatively high concentration of Ca.

The area of the section removed from the membrane filter represented about 5 % of the total area where the wool dust was collected. In order to ascertain whether inorganic dust particles were homogeneously distributed all over the filter surface, we cut three subsamples (inner, middle, and outer) along a radial direction and analyzed about 100 particles for each section. The results of chemical analysis showed that neither the relative elemental abundance nor the detection frequency of different particle types (Table 2) changed significantly from one section to the other. This indicated sampling one section in the middle of the membrane filter was enough to obtain a complete and exhaustive description of the average chemical composition of the inorganic dust fraction.

The minimum number of fields and particles to be analyzed for each filter section, as well as the field position within the section area, were determined as follows. 100 and 10 fields were scanned on two different sections from the same membrane filter. About 1400 and 150 particles were detected and analyzed, respectively. The results reported in Table 3 show that the two sets of data are very similar. The analyses of 10 fields, corresponding to about 150 particles,

Table 1: Particulate Mass [%] for several sizes of particles in each of the respective theoretical mass fractions

Particle aer. diam. [μm]	**Inhalable part. mass** [%]	**Particle aer. diam.** [μm]	**Thoracic part. mass** [%]	**Particle aer. diam.** [μm]	**Respirable part. mass** [%]
0	100	0	100	0	100
1	97	2	94	1	97
2	94	4	89	2	91
5	87	6	80	3	74
10	77	8	67	4	50
20	65	10	50	5	30
30	58	14	23	6	17
40	54	16	15	7	9
50	52	18	9	8	5
100	50	25	2	10	1

Table 2: Elemental composition (count %) and detection frequency [%] of inorganic particles in different sections of the same membrane filter

	Outer Section	Middle Section	Inner Section
Elements	**Counts %**	**Counts %**	**Counts %**
Al	3.0	4.0	3.0
Si	19.0	16.0	22.0
S	7.0	4.0	5.0
Ca	4.0	2.0	4.0
Fe	62.0	68.0	59.0
Others	5.0	6.0	7.0
Particle Type	**Counts %**	**Counts %**	**Counts %**
SLM particles			
Si-Fe-K-Ca-Al	29.3	28.2	28.3
SiZi-P-Zr	6.8	5.2	7.5
Si	9.5	13.5	13.7
Ca	0.8	2.5	1.8
HM particles			
Fe	34.4	29.9	28.3
Fe-S	11.1	11.0	11.9
Fe-X	8.1	9.7	8.5
Total No. of Part	123	91	156

SLM – Silicates and Light Metals Particles, **HM** – Heavy Metal Particles

Table 3: Elemental composition (count %) and detection frequency [%] of inorganic particles as a function of the number of fields scanned

Elements	100 Fields/Count %	10 Fields/Count %
Al	3.0	3.0
Si	22.0	22.0
S	5.0	5.0
Ca	4.0	4.0
Fe	58.0	59.0
Others	8.0	7.0
Particle Type	**%**	**%**
SLM Particles		
Si-Fe-K-Ca-Al	28.1	28.9
Si-P-Zr	6.7	7.7
Si	9.3	13.5
Ca	1.6	1.3
HM Particles		
Fe	33.0	28.8
Fe-S	11.0	11.5
Fe-X	10.3	8.3
Total No. of Part.	1398	156

SLM – Silicates and Light Metal Particles,
HM – Heavy Metal Particles

permits characterization of the sample with an accuracy which is not significantly improved by a tenfold increase in the number of fields.

As regards to the field position, the entire section area was divided into 15–20 regions (according to dust density) with animaginary grid, taking care not to include filter edges. One field was then selected and scanned in the center of each grid unit, the distance between adjacent fields being at least five times the field width. This approach reduced the influence of poor local homogeneity and allowed a reproducible characterization of the inorganic material collected on the filter surface to be achieved. In fact, adjacent fields may sometimes differ in particle density, especially for those particles whose detection frequency is quite low.

The constituent particles of each sample fell into several broad groups, from long fibers, several millimeters in length, to fragments of cortical cells, whose longest dimension was less than 5 μm. Representative particles appear in the electron micrographs shown in Figures 1–3.

5 Conclusions

The dust was found to fall broadly into four categories:

(i) long fibers, with lengths greater than 500 μm,

(ii) fiber fragments, much shorter lengths of fiber with length/width ratios of less than 10/1 and scales,

(iii) mineral dust particles, less than 50 mm in the longest dimension but usually around 20 μm, and

(iv) cortical cells with lengths of 50–100 μm, but with widths of less than 5 μm.

Inorganic components were found in the earlier stages of processing, but these decreased in quantity with further

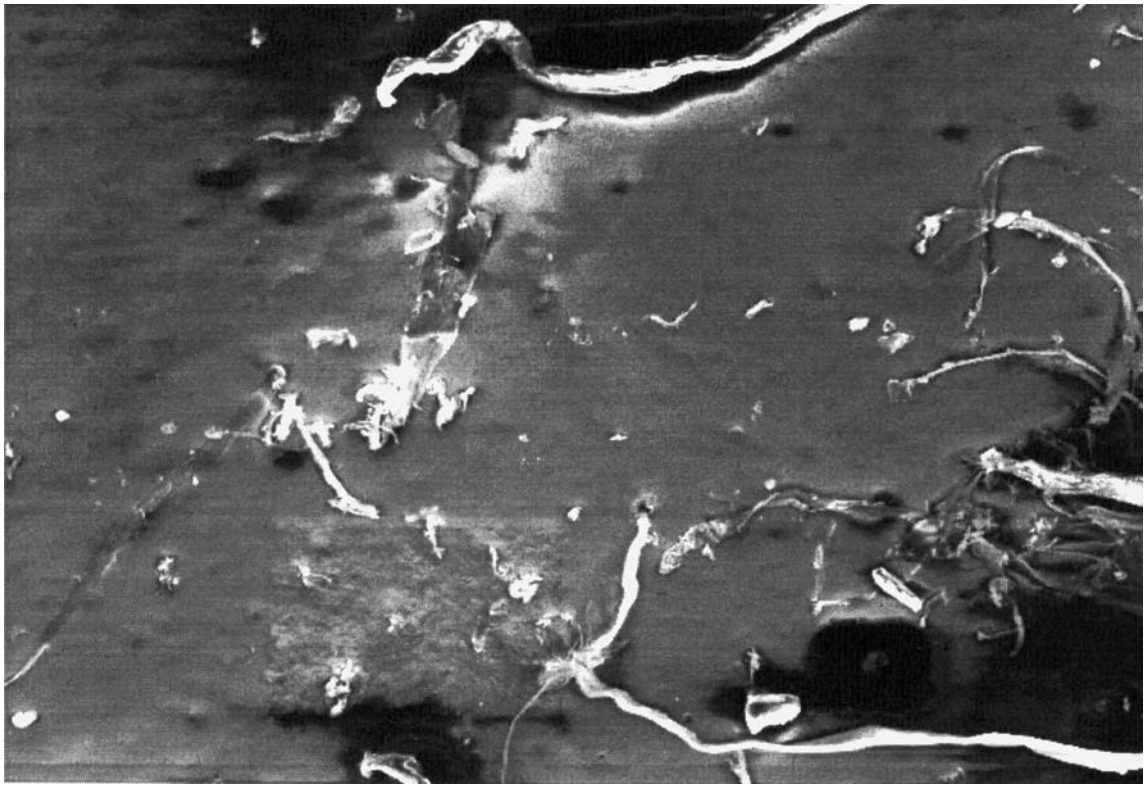

Fig. 1: Electron micrograph

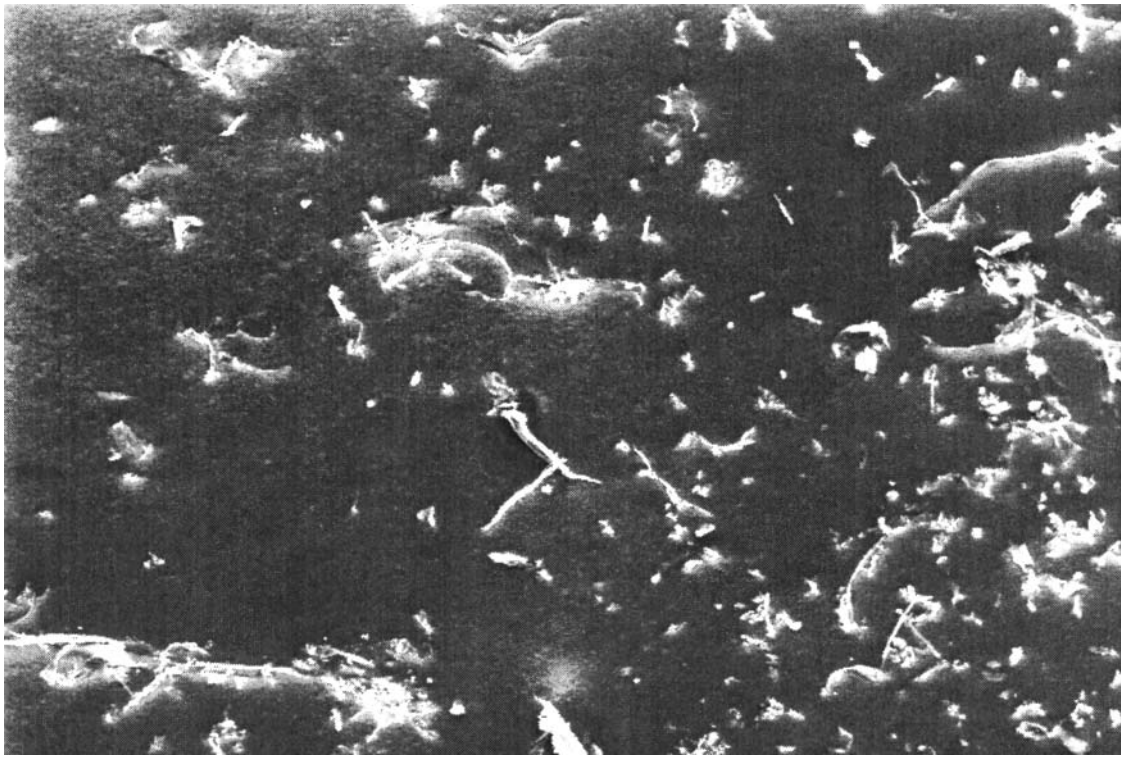

Fig. 2: Electron micrograph

treatment. They were identified as soil minerals, but residues from suint and compounds from skin-wool processing were shown to be present in some batches, even after scouring.

Of the inorganic components, the most common substances were silica, presumably from sand, and aluminum silicates, often containing trace amounts of sodium, magnesium, iron and calcium, presumably from clay, both major constituents of soil. In this study it was found that dust on ledges caused damage to the lungs of rodents. The ledge dust was found to contain microscopic growths, possibly of a type of fungus which can produce allergy-inducing spores. These may cause respiratory symptoms. In the light of this, regular

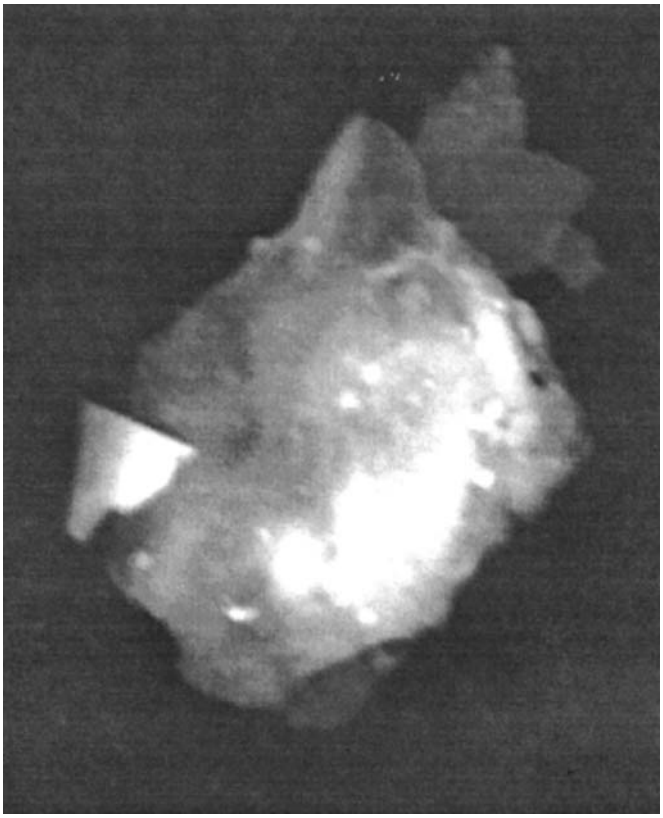

Fig. 3: Electron micrograph

fettling of machinery and cleaning of the mill in general would seem to be desirable, especially in warm and humid environments.

Acknowledgment

The author would like to thank the management and staff of Iran Barak company for the generous assistance provided during dust collection.

References

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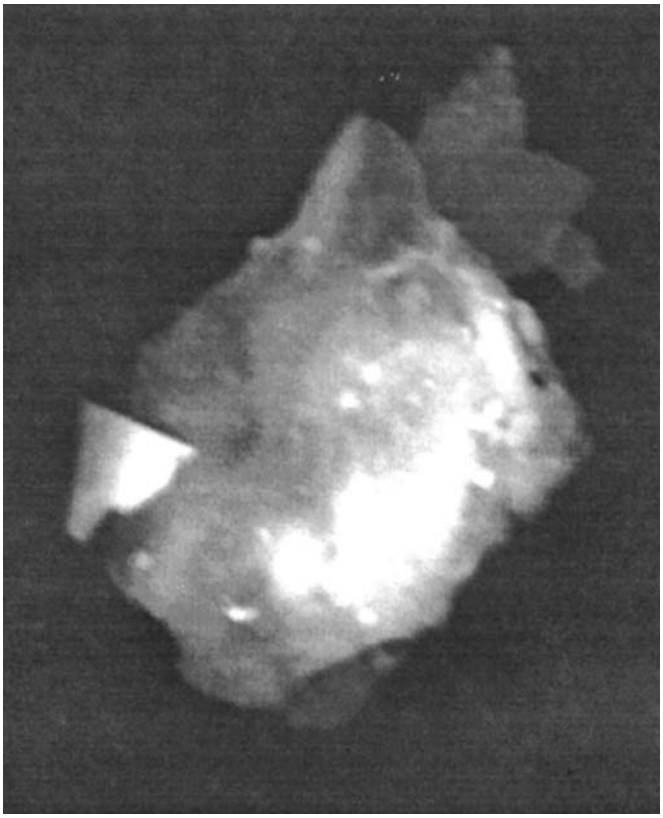

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