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The Measurement of Asbestos Dust

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Introduction

In recent years considerable progress has been made in the sampling and analysis of airborne dusts to provide some form of correlation between inhalation of dust and its biological effects and to provide more reliable data for improving dust control in factory atmospheres. Following the introduction of sampling instruments which collect only the respirable fraction of a dust cloud, it has been made possible to evaluate the samples by gravimetric or mass estimation, a process which for most particulates is simple and reproducible.

The Asbestos Problem

Because the respirability characteristics of compact, near-spherical particles are well established, it is possible to design prefiltering or elutriation systems which will ensure that only the respirable fraction of a dust cloud where the particles are of this type is collected in the instrument. Fibrous dusts, however, present special problems. The respirability of all dust particles is determined by their free falling speed in air, which in the case of fibres is related to their diameter, but their retention or otherwise in the human lung is dependent upon the length of the fibre. Thus, the lung clearance mechanisms will remove more of the respirable fraction if it is in the form of short fibres than would be the case for the same mass of long fibres, the diameter being assumed constant. It has been suggested that even allowing that an effective elutriator can be devised, the mass of fibre retained in the lung as estimated from the respirable mass collected by the sampling device is of doubtful reliability.

In the case of asbestos fibres, the elutriation problem is not insuperable for the amphiboles (amosite, crocidolite, anthophyllite) which are generally straight. Furthermore, once they enter the lung, their point of deposition, dependent on the fibre dimensions (diameter and length), is by and large predictable. This is not so for chrysotile, where the fibre shape (curvature) becomes important. The "curly" nature of the fibres affects elutriator performance and also the pattern of deposition in the lung. The difference in this respect between chrysotile and the amphiboles has been reported by *Timbrell*, who has demonstrated that the curvature in a fibre tends to reduce the efficiency of penetration and causes the fibre to be deposited higher in the respiratory tract.

Occupational Sampling of Asbestos

As the probable importance of the longer fibres in the fibrogenic effects of asbestos has been recognized for some considerable time, the asbestos industry has tended to concentrate on methods of sampling and analysis involving obtaining a sample suitable for microscopic analysis, where the long fibres could be recognized and classified. In the search for a suitable instrument, many dust samplers were tried and discarded for one reason or another. Instruments based on impingement tended to break up the fibre bundles and those based on thermal precipitation (except the long running Precipitator) appeared to be very inefficient collectors of the longer fibres. Eventually, the membrane filter method of sampling was chosen as the most likely system for asbestos fibres and development proceeded both in the U.K. and the U.S.A.

The principle of the method is that the dust sample is collected on a cellulose membrane filter of fine pore size. The filter is subsequently mounted on a microscope slide and cleared (i.e., rendered transparent) with a liquid of refractive index such that the contrast between the fibres and the background is not impaired. The sample is then counted at a magnification of about 500X and to further enhance the visibility of the fibres, a phase contrast microscope is used. For the purpose of analysis, a particle is defined as a fibre if its length is at least three times its diameter and if it is at least 5 μm in length. In addition, in the U.K. it is customary to set an upper limit on the diameter of 3 μm, on the grounds that fibres of larger diameter than this would not be respirable. The method has the great advantage that the asbestos fibres are easily recognized and this is essential where mixed dust is involved. The lower length limit of 5 μm was somewhat arbitrarily chosen in the early days of the development of the method, but it is significant that fibres which are retained over the long term, either free or as the cores of asbestos bodies, in the lungs of occupationally exposed persons, are generally longer than this.

The *Dust Measurement Working Group* of the *Asbestosis Sub-Committee of the Permanent Commission and International Association on Occupational Health* has recommended the membrane filter method for acceptance as the standard method for assessing occupational exposure to asbestos and measurements based on the method were used by the *British Occupational Hygiene Society* (1968) as the basis of its hygiene standard for chrysotile asbestos dust. Government controls on asbestos dust emission in both the U.K. and U.S.A. are also expressed in terms of fibre counts, to be obtained in the same way.

The membrane filter method possesses one important disadvantage in that the mounting and counting of the sample is a somewhat tedious operation. Means of speeding up the work have been sought and over the last few years the U.K. industry has made good use of an American instrument, the *Royco* Automatic Particle Counter for routine measurements in situations such as textile factories where the dust is almost entirely asbestos. This has been made possible because, while the *Royco* instrument depends for its function on light-scattering and, therefore, "sees" all dust particles which pass through the instrument, its size-discrimination facility can be adjusted to give the same numerical reading as would be obtained from a membrane filter sample taken in the same place and at the same time. Being fitted with an automatic print-out device, the necessary information is provided simply and quickly without the tedium of mounting the sample and counting under the microscope.

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While the *Royco* continues to be used for routine factory monitoring and engineering controls, the emphasis on the biological side has moved over to personal sampling, for which the *Royco* is not suitable, but for which the membrane filter method is ideal, being extremely portable. Epidemiological studies already planned will involve the collection and analysis of large numbers of membrane samples and this has led to a search for an instrument which will automatically count and size-select direct from the microscope slide. Among a number of instruments already examined, the Quantimet 720 (*IMANCO Ltd.*) is showing particular promise. Using a phase contrast microscope system with automatic focusing, the instrument should be able to deal unattended with a magazine load of microscope slides fed to it automatically by a suitable mechanism.

It is accepted that the membrane filter method may be criticized on the grounds that very fine asbestos fibres may not be seen in the optical microscope, even under the best viewing conditions. The investigation of alternative methods of analysis, usually based on mass estimation, is not being neglected, in spite of the difficulties associated with asbestos which have already been referred to. Methods so far tried include atomic adsorption spectroscopy (in which the magnesium in chrysotile can be estimated) and infra-red analysis. The most promising method explored so far, however, is based on X-ray diffraction, where even in a mixed dust sample the asbestos can be specifically identified by its crystal structure. Using an X-ray diffractometer under the best conditions it has been found possible to measure down to 10 µg of chrysotile asbestos in a sample where the asbestos represents as little as 10% of the total mass present.

Environmental Sampling of Asbestos

There has in recent years been considerable speculation concerning asbestos as a public health hazard in view of its widespread usage in a variety of forms, including brake linings, in spite of the fact that in the latter application it has been shown that the wear products contain little fibrous asbestos because of heat degradation. The emission of dust from plants manufacturing asbestos products has also been named as a potentially dangerous source of pollution.

The asbestos industry in the U.K. has, therefore, felt obliged to investigate the position and has instituted a program of measurements in the vicinity of its factories, and in selected urban and rural situations. It was quickly demonstrated that asbestos, if it was present at all, was in such small quantities that the standard sampling instruments and methods were completely inadequate. To obtain any measurable quantity of asbestos, it was obviously going to be necessary to sample very large volumes of air and if this was to be collected in a reasonable time, a high speed sampling instrument would be necessary. Such an instrument is the *Litton* Sampler, working on the principle of electrostatic precipitation and capable of sampling speeds up to 10 000 l/min of air. This means that sample volumes of a million litres (1000 cubic metres) can be collected in a reasonable time.

Even in these large volume samples, the estimation of the asbestos present has proved difficult. Where the total mass is above about 100 µg (i.e., 10^{-8} grams per cubic metre), the X-ray diffraction method has been used, but in many of the samples collected, no asbestos has been detected by this method. In these cases, it has been necessary to treat the sample by ultra-sound to disperse any asbestos present into its basic fibril form and estimate the mass using transmission electron microscopy. This method is capable of measuring asbestos concentrations as low as 10^{-10} g/m³ in a 1000 m³ sample, even in the presence of excessive amounts of other airborne solids.

To sum up, the combination of membrane filter sampling and optical microscope analysis is still considered to be the best system for monitoring asbestos dust in occupational situations. Mass estimation would have the great advantage of quickness, but it cannot be adopted with confidence, particularly for chrysotile, until a reliable elutriation system is available. Furthermore, because of the belief that the longer fibres may be of special significance as regards the health hazard, a technique based on sizing and counting of fibres must be of some merit. On the other hand, mass estimation is the only method available for assessing the asbestos content of general environmental atmospheres. Here the question of elutriation does not arise because it can be confidently assumed that all the fibres which remain airborne in these circumstances will be respirable. The concentrations of asbestos are so small that large volumes of air have to be sampled, but high speed samplers can be used, which is not the case for occupational situations. The fibres collected are generally too fine to be seen under the optical microscope, particularly in the presence of a high concentration of other atmospheric pollutants. The estimation of the asbestos has, therefore, to be made on a mass basis using X-ray diffraction or electron microscopy, depending upon the quantity collected in the sample.

The Handling and Manipulation of Asbestos-Reinforced Plastics

As an addendum to my paper, I have been asked to outline the precautions which should be taken in the handling and processing of asbestos-reinforced plastics materials.

The safe processing of asbestos-reinforced plastics materials is not difficult to achieve. Areas where asbestos dust might possibly be created are at the stage in the process before forming or curing and also where the formed product has to be sawn, drilled, or otherwise machined.

Situations in the first category can include the mixing of dry asbestos fibre with powdered resin to form flocks and the feeding of such flocks to moulds or pre-forming machines. Where these processes are on a considerable scale, it might be necessary to apply a simple exhaust or control system and similar precautions are advisable if large quantities of asbestos cloth have to be cut or otherwise handled before resinating.

It is more usual, however, for moulders to be supplied by the asbestos industry with felts or cloth already resinated. These materials give rise to no dust and are perfectly safe to handle, cut and manipulate in preparation for curing. The same applies to thermoplastic moulding materials which are generally supplied in pelleted form.

Once asbestos-reinforced plastics materials have been cured or formed, there are no problems in handling, but it may be advisable to take precautions where further processing, particularly machining, is involved. The operation may appear to be quite dusty, but it must be remembered that not all the dust produced from these composite materials is free asbestos. A good deal of it is resin or resin-encapsulated fibre. The latter has a high falling speed in air and is not generally considered to be respirable. Pure asbestos fibres of respirable size can, however, be released when the cutting tool breaks into the fibre bundles used as the reinforcement and into which the resin has not fully penetrated. We are, therefore, dealing with a mixed dust and the membrane filter method of sampling and analysis can be used with advantage because the free asbestos fibres are easily recognized.

It is not suggested that there is any health hazard associated with the occasional drilling or cutting of an asbestos-reinforced plastic material, but for operations on a factory scale the following

procedures are recommended:

1. For cutting, grinding, or other machining operations which are not continuous, the dust should be removed by means of a portable dust extraction unit. Vacuum cleaning equipment may be adapted for this purpose, provided that the filter system is of a good standard of efficiency. (The criterion usually adopted is that the asbestos dust concentration in the exhaust air must not be more than one-tenth of the MAC value in force.)
2. For large workshops with continuous operations based on fixed working positions or machines, fixed dust extraction equipment should be installed. High velocity/low volume systems can be used with advantage where the dust is being generated at a point, such as the tip of a tool.
3. Swarf and dust from machining operations should be regularly cleared from machines and their surroundings, using vacuum equipment which complies with the standard give in (1) above.
4. Where the end-product will not be adversely affected, wet processing will give a dust free operation.
5. Dust and swarf from extraction equipment should be collected whenever possible directly into impermeable bags which should then be sealed for disposal.

The only area remaining to be dealt with concerns the handling of the finished products. It is obvious that no hazard exists in normal usage, unless such usage involves a high degree of abrasion of the product. This is rarely likely to occur except for brake linings and, in this case, the high surface temperatures which are generated convert the asbestos into non-crystalline magnesium silicate which is believed to be biologically harmless.

To summarize, the handling and manipulation of asbestos-reinforced plastics composites does not present a serious health hazard and reasonable precautions will ensure that such materials can be handled with complete safety.

Summary

It is now well known that certain health hazards are associated with the inhalation of airborne asbestos dust, and regulations and controls to protect those exposed to such hazards are now being introduced in many countries. Such regulations are already in force in the United Kingdom covering all operations involving asbestos in which dust can be generated. The Asbestosis Research Council has studied the problems involved and the measures needed to comply with these regulations. One particular field of study has been the handling and manipulation of asbestos-reinforced plastic composites and it has been shown that reasonable precautions will ensure that such materials can be manufactured and processed with complete safety.

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Asbestos Content Determination by Optical, Chemical, Radiographic and Infrared Spectrographic Analysis Procedures

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It is widely known that the production of industrially finished goods which contain asbestos as an essential raw material is growing. In 1972 in West Germany alone, approximately 200,000 tons were consumed, of which approximately half went to the asbestos cement industry. In view of the growing number of lung cancer cases that can be attributed to breathing asbestos-containing airborne dust, the problem of quantitative asbestos content determination in compact material or in dust samples has taken on increasing importance as a means of evaluating the dangers involved [1].

Table 1 shows the definitive characteristics of the different types of asbestos [2].

As shown in Table 1, the left side describes the technically most important serpentine asbestos, or chrysotile, which is principally found in deposits and mines in Canada, South Africa, and the Soviet Union. The amphibole asbestos group appears on the right side, and of this group the technically important crocidolite, or blue asbestos, is also mined in South Africa and Canada. Aside from these, the South African amosite is of some economic value [3]. In summary, it can be stated that over 90% of the world production consists of chrysotile, the remainder being mainly crocidolite with minor quantities of amosite and anthophyllite. In contrast to the others, tremolite and actinolite have shown hardly any technical applications.

From the chemistry of serpentine asbestos, there is apparently a relationship with the concrete material kaolin $Al_4[(OH)_8 \cdot Si_4O_{10}]$, which possesses a silicate layer structure. If the four trivalent aluminum ions in the octahedral positions of the crystal lattice are replaced by six bivalent magnesium ions, deformation or warping of the serpentine layers can occur, leading to either a coiled formation or to a corrugated arrangement. In the former case, fibrous

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