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SOME OBSERVATIONS ON PARTICLE SIZE AND SIZE DISTRIBUTION

Paper presented at the Annual General Meeting of the Society on 9th May, 1964.

by

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SUMMARY

It is claimed that determination of particle size distribution is necessary for effective control of airborne dust. The size distribution is shown to be dependent on the definitions of a particle and of particle size. Linear dimensions and shape are interrelated concepts. There are numerous ways in which the diameter of an irregularly shaped particle can be defined. Those of importance to the dust investigator are discussed.

Samples of airborne dust exhibit varying degrees of agglomeration. This is discussed in relation to the question of deciding what is to be regarded as one particle. The definition of a particle is usually chosen to suit the techniques used. As a result observed size distributions depend to a large extent on the methods used for their determination. The consequences of present techniques for determining size distributions by microscopy are discussed in relation to the pathogenic effects of dust. It is concluded that the present state of knowledge regarding the biological effects of dust is inadequate for the purpose of deciding on the most appropriate dust sample assessment techniques.

It is claimed that the formulaters of size distribution laws have not given sufficient consideration to the dependence of size distributions on the definitions of a particle and of particle size. This may be one reason why few observed size distributions correspond accurately to any of the known distribution laws. In view of the poor fit generally obtained, readers are warned against the practice of making deductions from curves fitted to observed distributions without performing X^2 tests. One of the reasons advanced for the practice of making calculations from fitted curves rather than from the observations themselves is that the effects of statistical fluctuations due to a limited sample are thereby minimized. A more reliable solution would appear to lie

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in taking bigger samples. This is easily achieved by the use of diffraction techniques. Agglomerates would appear to have a larger surface area than individual particles of the same size. If the prevailing belief that toxicity is proportional to the surface area of particles retained in the lung is correct, then the degree of agglomeration should be measured. This cannot conveniently be done by microscopy but the possibility of using the diffraction size-frequency analyser for this purpose is outlined.

By using an elutriator to simulate alveolar retention, it may be possible to obviate the need for determining size distributions. This procedure has a number of disadvantages, chief of which is that the characteristics of elutriators are profoundly influenced by external air currents.

It is concluded that many problems remain to be solved before really effective dust control can be achieved. In particular, there is a need for more research on alveolar retention and on the biological effects of dust particles and particularly of agglomerates.

INTRODUCTION

Unfortunately owing to the very short notice which I was given of this meeting, I have not been able to prepare as many slides or to assemble as much experimental data as I would have liked. The term observations in the title is used in the sense of " remarks " rather than of experimental results and this address is intended to raise questions rather than to answer them. Also I have no doubt that there are some present who are more qualified than I to discuss some of the points raised and I hope these people will contribute to the discussion.

The size distribution of a particulate solid often has an important influence on its physical, chemical and biological properties. Consequently, there are a great many applications, both in science and in industry, where a knowledge of the size distribution is essential. One such application occurs in the mining industry where mining operations give rise to harmful clouds of airborne dust. The size distribution is required both for assessing the toxicity of the dust and for determining the effectiveness of dust prevention measures.

The toxicity of a given amount of airborne dust depends on its size distribution for two reasons. One is that the alveolar rentention of dust particles is markedly dependent on particle size. The other is that the toxicity of a dust particle once it is lodged in the lung also varies with particle size.

Owing to the large variation in the size distributions of airborne mine dust and the marked dependence of toxicity on particle size, it is essential, in assessing the effectiveness of dust prevention methods, to compare size distributions. Comparison of number counts only has ofen been used in the past but this practice is to be deplored as it may easily give misleading results.

In the past improvements in mining techniques have taken place slowly. As a result dust conditions have not been subject to rapid change. With the increasing concentration of effort on research we may expect that changes in mining methods will occur more frequently in the future. Changes in mining methods usually bring about changes in dust production. Unless the dust production aspect is given special attention in the design of mining machinery, increased mechanization usually means increased dust production. This will create new problems for the dust technologist and for the mine ventilation official. The dust technologist will be required to develop effective dust prevention devices for a variety of new machines while it will be the duty of the mine ventilation official to ensure that men are not exposed to dangerous levels of dustiness under changing conditions. In order that both should be able to perform their functions effectively present methods of routine dust measurement, long recognised as inadequate, will soon have to be superseded. Methods which give more information quickly and accurately will be needed.

The present paper is devoted to a consideration of some of the more fundamental questions connected with accurate dust measurement. It is shown that *particle size* may be defined in a great variety of ways, the most appropriate definition depending on the use to be made of the measurements. Before particle sizes can be measured the question " What is a particle? " has to be answered. The observed size distribution is shown to be a function of both these definitions. It is claimed that the formulaters of mathemathical expressions intended to represent observed size distributions of airborne dust have not given sufficient consideration to this aspect. The inadequacy of existing size distribution " laws " is demonstrated and, owing to the large variations in observed size distributions, some doubt is expressed as to the value of such laws. Finally, some consideration is given to the problem of determining size distributions for the purpose of dust hazard assessment and dust control.

There is another aspect of the problem of dust in mines which has received little attention in the past. This is the harmful effect of dust on machines. Quartz dust is known to be highly abrasive even when the particle size is very fine. With the trend towards increased mechanization this aspect of the dust problem may deserve more attention in the future. The emphasis in the present paper is on the exposure of men to dust and this other aspect of the problem is not dealt with.

PARTICLE SIZE

Before we can a give a meaning to particle size distribution we must consider what we mean by particle size. For certain regularly shaped objects the size can be specified unambiguously by giving one perimeter. For example if I state that the diameter of a certain sphere is five inches then I leave you in no doubt as to its size. You will understand that its surface is 25 π square inches and that its volume is $\frac{12}{6}$ π cubic inches. Also given the side of a certain cube its linear dimensions, area and volume will have been specified unambiguously.

A rectangular prism, on the other hand, requires three parameters to specify its linear dimensions. A knowledge of these three parameters is also sufficient to enable one to calculate its area and volume. Other polyhedra may require still more parameters to specify their linear dimensions.

The above examples are useful in that they illustrate the dependence of linear dimensions on shape. For the diameter of a sphere to be meaningful it was necessary to specify the shape of the latter. Similarly with the side of a cube, if we did not know the shape of the object to which this dimension referred it would be meaningless. In general, for polyhedra it is necessary to specify both the lengths of edges and at least some of the angles between them. This is true of the two examples given, the statement that the dimensions refer to a cube or a rectangular prism implying that certain angles are 90°.

For an irregularly shaped object the specification of its diameter would be meaningless unless this term had been previously defined. For example if I were to state that the diameter of an irregular chunk of rock was five inches you would be in doubt as to my meaning until I had defined what I meant by the diameter. Now there are a great many ways in which the diameter of an irregular body could be defined. A rather obvious one is to define its diameter as the diameter of a sphere of equal volume. This definition, which we will call the volume diameter, is usually of use only when some ready means of measuring the volume is available. If, for instance, you were observing a dust particle with a microscope and you wanted to know its volume diameter, you would be faced with the problem of measuring its volume. Even if you could measure its volume and so determine its volume diameter, the only information this parameter would convey would be the volume and that the surface area was not less than that of a sphere of the same diameter.

Before considering a few of the other types of diameter let us consider our problem a little more closely. I have stated that there are two main reasons for wanting to know the size distribution. The first is in connection with the alveolar retention of dust. Several alveolar retention curves have been published. It is not clear to me exactly how these curves are obtained and there appears to be some doubt about the exact shape of the curve. The curves are usually plotted in terms of Stokes diameters and I have gained the impression that it is this parameter which is important. Once a dust particle is in the lung its toxicity is believed, in the present state of knowledge, to be roughly proportional to its surface area. For this purpose we would require to measure a parameter which would give us the surface area of the particle. However, it must be borne in mind that our knowledge of both the retention of dust in the alveoli and of its toxic effects are incomplete and that the above views may have to be revised at some stage in the future.

The Stokes diameter referred to above is the diameter of a sphere which moves with the same terminal velocity as the particle in a fluid in a uniform field of force. This definition only applies to cases where the flow of fluid past the particle is irrotational. The Stokes diameter conveys no information other than the terminal velocity of the particle in a fluid. This quantity is, however, of interest to us as it gives the rate of sedimentation of a dust particle. Unfortunately, the only way of measuring Stokes diameters is to measure the terminal velocities of the particles. This requires large samples and is time consuming. However, for large populations, it may be possible to obtain a statistical relationship between the distribution of Stokes diameters and the distribution of some other dimension which may be more conveniently measured.

Another diameter which is widely used in the mining industry in this country and in Great Britain is the projected area diameter. This is the diameter which one usually attempts to measure when making particle size measurements with the microscope. It is the diameter of a circle of the same area as the orthogonal projection of the particle onto the microscope slide. The importance of this diameter is that it is about the nearest we have been able to get to measuring the surface area. Knowledge of the projected area diameter of a particle enables one to calculate its projected area. The ratio of projected area to surface area is observed to vary greatly from particle to particle. It may be reasonable to assume that for a given type of dust the average ratio may be sensibly constant from one dust sample to another. This is the basis on which dust samples are at present compared. However, the average ratio for mica particles appears to be quite different from that for quartz particles and variations in the proportions of quartz and mica as well as other minerals may tend to invalidate this assumption. Owing to the lack of a reliable method of measuring surface area it has not been possible to investigate this. In any case mica is much less toxic than quartz and this variation in the toxicity of different minerals seems to be more important than variations in the ratio of projected area to surface area. This raises the important question of mineralogical composition which will be briefly mentioned again towards the end of the lecture.

Thus measurement of projected area diameters is not an entirely satisfactory method of obtaining an estimate of the surface area, even where a ratio of surface area to projected area has been obtained by some method, but it is probably the best method at present available. The projected area diameter conveys no information about the volume or mass of the particle. While these are at present not considered very important in determining the toxicity of rock dust, in view of the incomplete state of our knowledge, I feel it may be advisable to seek some method which would give us this information as well. It is, of course, not essential that all dimensions should be specifiable in terms of one parameter.

Various other diameters have been defined for irregularly shaped particles. None of these is of very great interest to us. There is, however, one other way of somewhat vaguely specifying the size and shape of a particle which I have not seen mentioned before. This is by giving the distribution of chord lengths parallel to a certain direction. The method is of interest to me because, in principle at least, it is possible to determine this distribution by certain diffraction techniques.

DEFINITION OF A PARTICLE

Having given some consideration to the meaning of particle size it is necessary to consider another question which is, in a sense, more fundamental. This is the question " What is a particle? "

Various definitions of a particle have been given. These are usually in terms of intermolecular forces. Such definitions are seldom of much use for practical purposes. The microscopist, for example, is hardly in a position to investigate intermolecular forces in the course of routine size-frequency determinations.

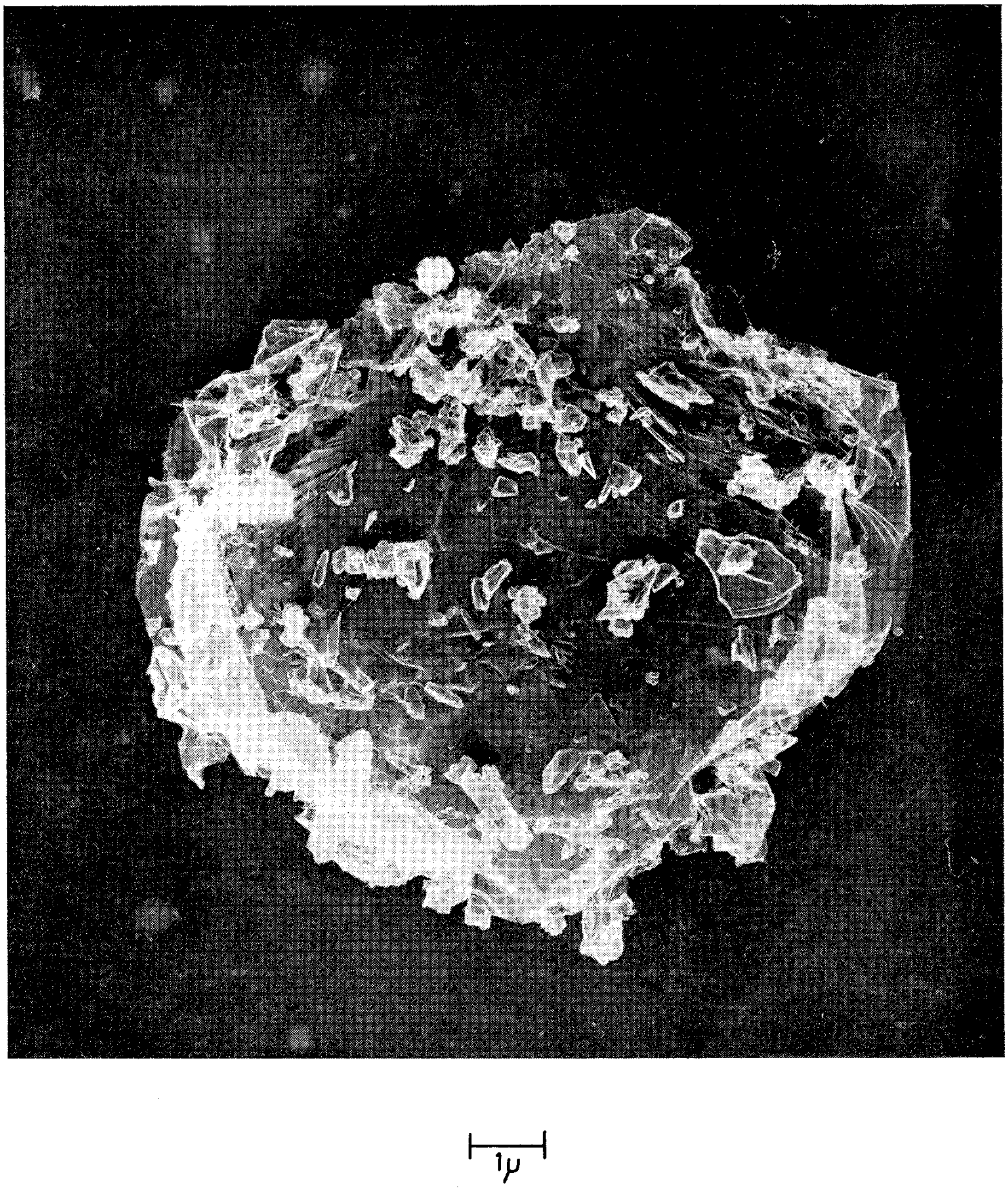

Fig. 1. Electron micrograph of carbon replica of part of a sample of tipping dust showing smaller particles adhering to the large particle.

The criteria used in microscopy for deciding what is one particle are usually as follows:—

(1) Particles which appear to overlap are considered to be one particle.

(2) Particles which do not overlap and whose closest edges appear to be resolved are considered to be separate particles.

These are criteria which are easy to apply in practice and which lead in many instances to reproducible results, but it is as well to examine some of their consequences. Fig. 1 is an electron micrograph of part of a thermally precipitated sample of tipping dust. The large particle in the centre has a projected area diameter of 8 μm. It will be seen that this particle has a number of what appear to be smaller particles adhering to their surfaces. (" Particle " is, of course, used here, not in the sense defined for microscopy, but in what I think is the more commonly accepted sense.) A rough count of the small particles indicates that there are about 150 of them. Since only one half of the particle is visible this would indicate that there are probably about 300 such particles. It is worth noting that there are practically no other small particles in the field. This would indicate that agglomeration has taken place while the 8 μm. particle was suspended in the air and is *not* due to the smaller particles being deposited on top of the large one in the thermal precipitator. Another example, also from a sample of tipping dust, is shown in Fig. 2. It will be seen that there are fewer adhering particles in this case. This illustrates the variability of the degree of agglomeration. Particles larger than about 1 μm. having no smaller particles apparently adhering to them are rarely observed but the number of particles per unit area of the larger particle is very variable, even for particles in the same sample.

Following the definition of a particle applied in microscopy these apparent agglomerates must be regarded as individual particles. Clearly if these agglomerates were to be dispersed the size distribution which would be observed would be quite different. The question arises as to whether it is more correct to regard such agglomerates as one particle or as many. This is a question which in the present state of knowledge cannot be fully answered. I think that it is safe to assume that for the purpose of determining the proportion of these agglomerates retained in the alveoli it is correct to regard them as single particles. However, once they are lodged in the alveoli, it is conceivable that the particles may become dispersed, or partly dispersed, in the lung fluids and in their biological effects they may behave as many particles. Even if the particles do not become dispersed in the lung I think one might expect that the action of the agglomerate would be different from that of the large particle alone.

If the agglomerates are regarded as single particles then the presence of " satellites " greatly increases their surface area and this must be taken into consideration in calculating the area from some other dimension such as the projected area diameter. This could be done by considering the satellite particles to constitute a *surface roughness* which may conceivably be taken care of by a surface roughness factor. Determination of this factor would involve finding some mean surface roughness for the dust sample. It seems likely that this factor would vary widely from one sample to another, depending on the degree of agglomeration, which one would expect to increase with time.

If it is desired to determine the size distribution of a bulk sample such as that collected with an electrostatic precipitator then it is first necessary to disperse the dust particles. Now it is usually very difficult to achieve a complete dispersion of the particles. In general, therefore, the size distribution which one obtains is a function of the method of dispersion. I have discussed this point in detail elsewhere [1, 2].

DEPENDENCE OF THE SIZE DISTRIBUTION ON THE DEFINITIONS OF A PARTICLE AND OF PARTICLE SIZE

It is clear that the size distribution of a dust sample as determined by any method will depend on the definition of a particle and of particle size. If the determinations are made by sedimentation then the distribution of Stokes diameters is obtained. If

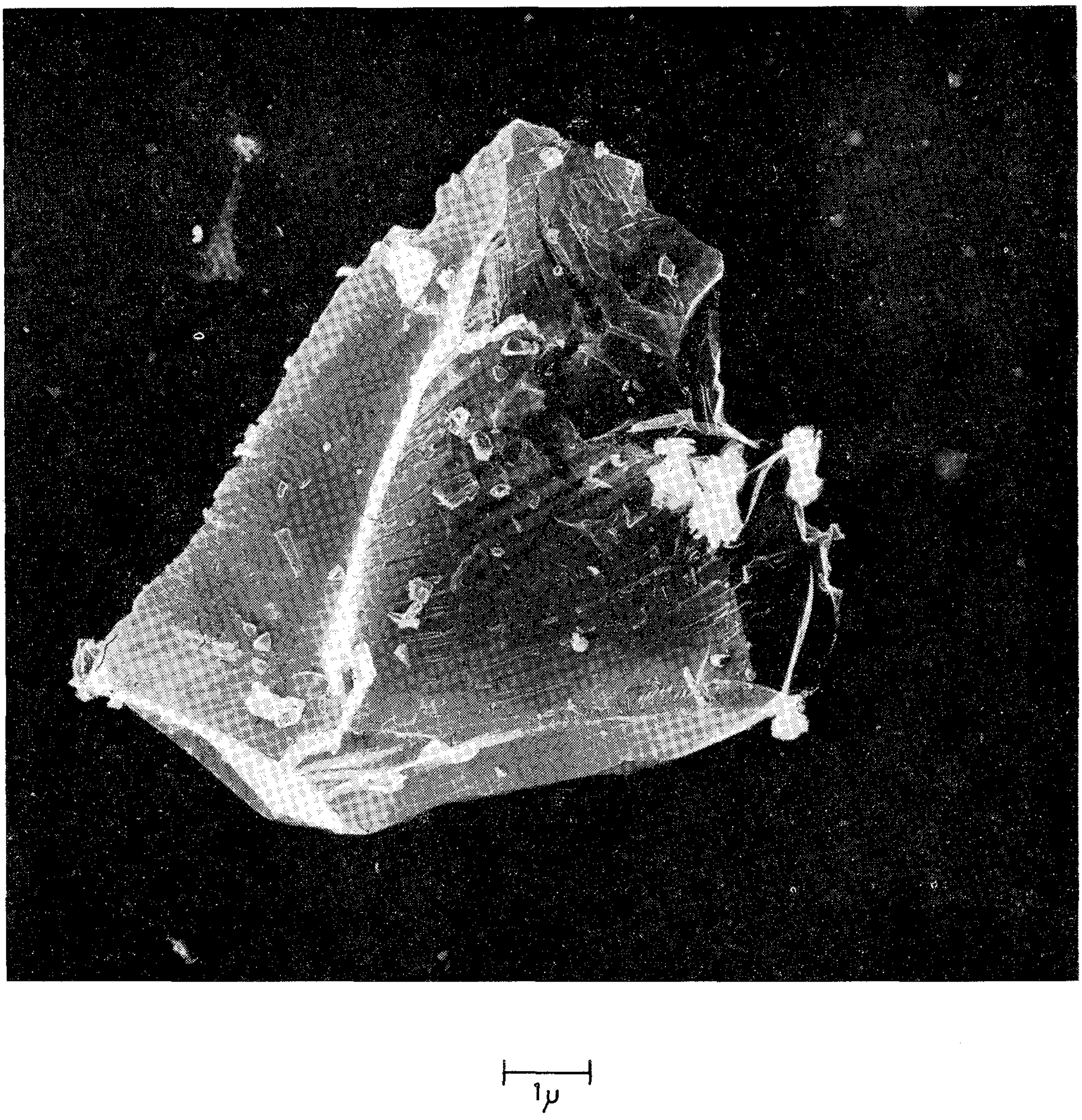

Fig. 2. Electron micrograph of another particle in the same sample of tipping dust. Note that the number of particles adhering to the large particle is smaller than in Fig. 1, illustrating the variability of the degree of agglomeration of particles in the same sample.

a microscope is used then the distribution of projected area diameters, Martin diameters, longest chord or some other dimension is obtained. Other methods such as sieving or turbidimetry lead to distributions of yet other size parameters. The definitions of a particle and of particle size are often so different that in most cases one would not expect the size distributions obtained by different methods to agree and, in fact, they rarely do.* The only criterion for deciding which result is more correct than another is the purpose for which the results are to be used.

The dependence of size distributions on the definition of a particle and of particle size is a point which has been neglected by the formulators of size distribution "laws". A number of these laws have been derived either from observations or theoretically, starting from certain premises. Attempts have been made to describe the observed size distributions of dust samples by mathematical expressions of these "laws". In doing so no account has been taken of the possibility of agglomeration. This was pointed out in the literature six years ago [2] but the point has received scant attention. Sichel[3] considered that changes in size distribution due to agglomeration and sedimentation would produce concomitant changes in the parameters of the Sichel distribution but that this distribution would still be capable of describing the observed distributions. This view I believe to be mistaken. Extrapolation of observed size distributions in accordance with the Sichel Law indicates the existence of very large numbers of small particles. It is clear that the rate of agglomeration of these particles would be high and that this would eventually lead to a mode in the number size distribution, something which the Sichel Law does not allow.

It has been claimed that one of the advantages of knowing the size distribution law of mine dust is that more accurate information concerning the number, area and volume distributions of the population can be obtained. If the sample is small then, owing to statistical fluctuations, the observed frequencies may not be representative of the population as a whole. By fitting a size distribution corresponding to this law these fluctuations can be smoothed out. The argument is that this fitted distribution is more representative of the population as a whole than the observed distribution and that number, area and mass frequencies obtained from it will be more accurate estimates than values obtained from the observed frequencies. This is similar to the procedure used in studying the distribution of intelligence quotients or of heights. Observations are made on a sample of the population and a Gaussian curve is fitted to these. The mean, standard deviation and any other indices required are calculated from the Gaussian rather than from the observations themselves. In this way the effects of statistical fluctuations caused by taking a small sample are minimized.

The above procedure would be acceptable provided one was certain that the correct type of curve was being fitted. This can be decided by performing a goodness-of-fit (X^2) test. If such a test indicated a very good fit then the procedure would be vindicated. However, if the test indicated a poor fit then it would be foolish to base any calculations on the fitted curve, rather than on the observations themselves. At this stage I feel I should sound a note of warning about the practice of making deductions from fitted curves without performing goodness-of-fit tests.

A number of size distribution laws have been proposed for South African gold mine dusts. Experiments have been carried out at the Physical Sciences Laboratory in which large numbers of dust samples have been examined. Size distribution laws have been fitted and goodness-of-fit tests have been carried out. The results indicate a poor fit for all of the proposed laws in nearly all cases. It is clear that if a mathematical expression exists which is capable of describing most of the dust samples to a high degree of accuracy then it has certainly not yet been discovered.

Different samples vary so widely in size distribution that it seems to me that any mathematical expression which was capable of describing most of them would need to

*The discrepancies are often concealed by representing the data by cumulative mass size-frequency distributions.

have a large number of parameters. The labour in fitting curves, and in performing goodness-of-fit tests, increases rapidly with the number of parameters, so that if the number of parameters is large the value of knowing the mathematical form of the size distribution may be partly negated. The solution would seem to lie in taking bigger samples and in making all calculations from the observed distributions.

This is not to say that the existing size distribution laws are of no value. It can be seen from plots that there is a rough correspondence between these and most of the observed distributions. Often in the design of dust sampling or evaluating equipment, and probably for many other purposes as well, it is useful to have a simple mathematical model of the size distribution even if this does not accurately represent most observed distributions. This was so in the development of the diffraction size-frequency analyser[4] where these mathematical models enabled us to predict the approximate form of the diffraction patterns to be expected from dust samples.

DETERMINATION OF SIZE DISTRIBUTIONS

At the beginning of this paper it was mentioned that for our purposes there are two reasons for wanting to know the size distribution of mine dust. The first is that we wish to apply the alveolar dust retention curve to estimate what dust is retained in the alveoli. There is some doubt as to exactly what information is required for this but it seems that the important parameter may be the Stokes diameter. This is not a dimension which is easily measured in routine sampling. Large samples are required and the measurements are time consuming. There would appear to be little point in attempting to make extremely accurate measurements as the alveolar retention curve depends on such factors as respiratory frequency and tidal volume and therefore cannot be regarded as something which can be determined with great precision. If subsequent investigations confirm that the Stokes diameter is the appropriate dimension then it may be better to find a way of obtaining this from some more convenient measurement.

The second reason for wanting to know the size distribution is to form an estimate of the harmfulness of the dust once it is lodged in the alveoli. The current belief is that for quartz this depends mainly on the surface area. Measurement of this quantity presents difficulties. Projected area can be measured very easily but variations in the ratio of surface area to projected area make it difficult to calculate the former from the latter. The difficulty arises from variations in the mean ratio of particle thickness to projected area diameter and from variations in the surface roughness.

Particle thickness can be measured by visual microscopy using a low angle shadowing technique, but surface roughness cannot conveniently be measured by microscopy. The diffraction size-frequency analyser[4] in its present form provides a rapid and accurate means of measuring the distribution of projected area diameters. Using the low angle shadowing technique it would appear that the distribution of particle thicknesses could also be determined by this technique. This information, together with the surface roughness, may not be sufficient for determining the surface area since it is not clear how the particle thicknesses are to be distributed among the diameters. It is possible that the investigation of a large number of samples may result in this point being cleared up.

As mentioned earlier the linear dimensions and the shape of a particle are interrelated concepts. The diffraction pattern of a dust sample depends on both the sizes and shapes of the particles. If a dust sample is shadowed with aluminium at 90° to the slide and if the particles are subsequently removed then the aperatures in the aluminium film are of the same sizes and shapes as the projection of the particles onto the slide. Any irregularities at the edges of the particles are reproduced in the outlines of the apertures. These irregularities have a pronounced effect on the diffraction pattern of the aluminium film. However, if the dust sample is shadowed at an angle of about 10° using a slightly extended source of aluminium then the tip of the shadow becomes diffused and the information concerning the edge irregularities is lost. The diffraction pattern is similar to that which would be obtained if all the particles had smooth surfaces. This provides a method of measuring the surface roughness. One half of the dust sample could be shadowed at 90° and the other half at 10° and the diffraction pattern of each half recorded separately. This would increase the amount of work but the speed of the diffraction technique is such that it would still be many times faster than any other method.

The traditional method of obtaining the distribution of projected area diameters in the South African gold mining industry is by visual microscopy. Apart from the inherent inaccuracy and relatively poor reproducibility of the results, the method is slow and laborious and usually results in small particle counts subject to large statistical fluctuations. The accuracy and reproducibility can be improved by using the Hamilton-Phelps technique of imaging each particle as an aperture in an aluminium film[5] but the method is still too laborious. Several automatic types of microscope have been devised for the purposes of determining size distributions. These are very expensive, are usually slow and so far none has proved successful for our gold mine dust. Basically the trouble with microscopy is the limited depth of field, calling for automatic focusing to compensate for slides that are not sufficiently plane and stages which cannot be made to move with sufficient accuracy. Added to this is the fact that particles have to be observed individually.

In the diffraction technique all of these troubles have been obviated. The instrument is very simple and requires no precision work and no focusing. A certain amount of electronic equipment is necessary, but this is small compared with that required for an automatic microscope. The total projected area can be readily obtained from the diffraction pattern, but at present the size distribution is obtained by means of a digital computer. The cost of computing is about R3·00 per sample. This is too high for routine use but with the improvements at present taking place in digital computers it seems likely that the cost will be considerably reduced in the next few years. However, there appears to be a much better way of solving this problem. This is to equip the instrument with an electronic analogue computer which will result in the size distribution being drawn on the recorder chart in place of the diffraction pattern. Preliminary estimates indicate that even with such an analogue computer the instrument will still be considerably cheaper and less elaborate than an automatic microscope type of instrument. In addition the diffraction method is so much faster that one instrument would be able to do the work of at least ten automatic microscopes.

Since the diffraction method makes use of the entire dust sample the statistical uncertainty due to observing a limited number of particles is minimized. Reliable estimates of number, surface area and volume frequencies can therefore be obtained without the need to fit any type of curve.

There is of course another approach to the problem which may make it unnecessary to determine size distributions. This is to use an elutriator ahead of the dust sampling instrument, so designed as to allow only those particles which would be retained in the alveoli to reach the dust sampling instrument. It would then only be necessary to measure the surface area. The projected area could be obtained most conveniently using the simpler diffraction method. This approach will probably appeal to many of you. It has, however, several serious disadvantages. One is that our knowledge of alveolar dust retention is incomplete. It may well happen that at some future time it will be found that the alveolar dust retention curve is not quite as had been supposed but has a slightly different form. For the purposes of dust control this would not be very serious, as this has to be based on current knowledge, but for experiments taking place over long periods of time, or for estimating the average dust exposure over the years the consequences could be serious. Another minor problem is how to simulate the alveolar retention curve accurately. By far the most serious objection is that elutriators are notoriously prone to the influences of air currents. An elutriator can be designed to work very well in the absence of extraneous air currents but the presence of such currents can completely alter their characteristics.

It may be possible to design an elutriator which will not be appreciably affected by air currents and I believe that this matter is at present receiving some attention at the Physical Sciences Laboratory. If successful this will remove one of the principal objections to the use of elutriators. There will, however, still be the problem of relating projected area to surface area, and in view of our incomplete knowledge of the action of the dust in the lung, there is always the possibility that it may be discovered that factors other than surface area are relevant.

CONCLUSION

It seems that there is a need to try and obtain a clearer picture of the objectives of dust sampling and to relate sampling techniques more closely to these objectives. In particular there is a need for more information concerning the alveolar retention and the biological effects of dust. Until this information is available no dust control programme can be soundly based. It must be recognized that while the alveolar retention curve cannot be regarded as something absolute which can be determined with arbitrary accuracy it is important to know what factors influence it and how they influence it. This knowledge may not enable us to predict what will happen to the individual but it may enable us to predict the average behaviour of a large population. The same may perhaps be said of the biological effect of the dust. Clearly there is a case for more intensive and more carefully controlled research on the biological side.

The influence of the size distribution and the importance of being able to determine it have been discussed at some length. This is only one aspect of the problem. To a large extent the discussion has been based on the widely held belief that the surface area of the dust retained in the alveoli determines its toxicity. Clearly there is more to it than this. The different minerals found in mine dust are known to have different effects. The two most common constituents are quartz and mica, the latter being less toxic than the former. The mica particles

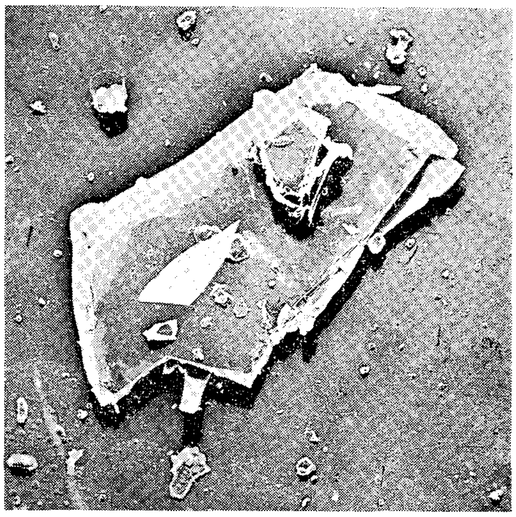

Fig. 3. Illustrating the use of shadowing to minimize the contribution of mica particles to total projected area. Mica particles, because of their platy shape cast smaller shadows in relation to their size. (Compare the shadow cast by the large mica particle with that cast by the small particle above left).

are usually flake-like and rest with their flat surfaces parallel to the slide. Using projected area as a measure of the dust hazard greatly exaggerates the importance of the mica constituent. This can be largely corrected in the diffraction method by using shadowing, thus shifting the emphasis onto the particle height rather than the projected area diameter (Fig. 3).

Other aspects which require consideration are the condition of the surface of the particles and the perfection of the crystal lattice. It seems reasonable to suppose that the presence of slip lines or of substances adsorbed onto the particle may influence its toxicity. Some workers [6, 7] believe that defects in the crystal lattice of quartz particles have a profund influence on their toxicity. If this is the case the problem of estimating the toxicity of airborne dust must indeed be complicated.

In conclusion it appears that there are still many important problems to be solved if those responsible for dust assessment and control are to play an effective role as the impact of the second industrial revolution introduces a new era in mining. Not the least of these is the varying mineralogical composition of mine dust. What we really need is to be able to determine the size distribution of each important mineralogical constituent separately. It is not sufficient to determine the proportions by volume of each constitutent when it is believed that retained surface area is the appropriate quantity to measure. The possibility of determining the size distributions of each constituent separately by X-ray diffraction has been under investigation at the Physical Sciences Laboratory for some time. In principle there is no problem. In practice the problem is to obtain sufficiently intense X-ray sources. In the light of present day physical theory maser action at X-ray frequencies appears to be impossible. No doubt our descendants will get round this problem but it certainly looks like a problem for a later generation.

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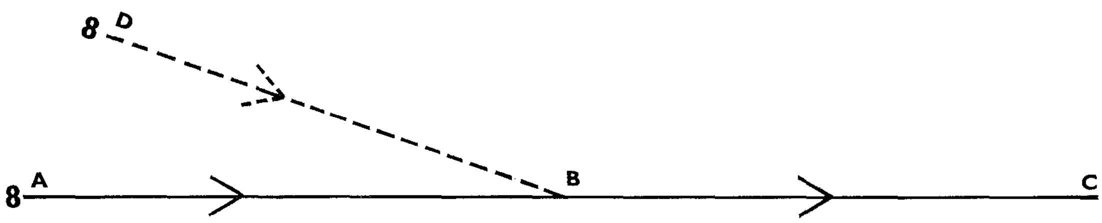
SEMI-PARALLEL AIRWAYS

by A. W. T. Barenbrug*



In the suggested solution to question 4, Part 1, October, 1963, of the Transvaal and Orange Free State Chamber of Mines advanced examination in ventilation and dust prevention, use was made of the so-called " residual fan curve." This concept is probably not well understood.

In the following notes an alternative method is described using the same question 4 as example.

Question 4 reads as follows:

Fan " A " in ventilation column A, B, C is delivering 10,000 c.f.m. at a presssure of

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