F. Hartogensis

THE PURPOSE AND METHOD OF DETERMINING THE DUST CONTENT OF THE AIR IN FACTORIES

Many different methods of determining the dust content are described in the literature. The choice of a method will be influenced by various considerations, which are mentioned shortly. Dust determination will be carried out to give information for a special purpose, for instance to get an idea of the risk of silicosis. A wide range of experience has been obtained in Holland in dust determinations carried out in factories with the purpose to get an idea of the risk of certain occupational diseases, especially silicosis, lead poisoning and asbestosis. The methods chosen for these determinations are described in details, especially the use of the thermal precipitator for determining the number and the sizes of dust particles. Some results concerning the divergency of the results, obtained by these methods and the correlation between the dust content and the occurence of silicosis are discussed.

The influence of the method used for the determination and for counting the particles on the number of particles obtained is mentioned. The results obtained by different authors are for this reason not comparable. Some standardization will be necessary to prevent a chaos of figures that would be a handicap for international discussion.

1 *Introduction*

Before anything can be said about the method of determining the dust content of the air, the purpose of such determination must be clearly defined. The method of determination will vary to a great extent according to whether we wish to obtain an idea of the risk for silicosis or to ascertain the amount of dust entering a conduit pipe, to measure the dispersion of fly–ash or to determine the risk for lead poisoning. For each case concerned it will be necessary to select a method that will afford the best possible insight into the problem propounded. There are also various other considerations that may influence the choice of method. One may aim, for instance, at a form of research that will yield as much data as possible, whilst in other cases simplicity of determination will be considered of major importance. It is improbable that any one method of dust determination will give the best results in all cases, and experience has shown that a number of different methods are employed side by side.

A wide range of experience has been obtained in Holland in the course of dust determinations carried out in factories of the most diverse character with a view to forming an opinion as to the risk of certain occupational diseases, especially silicosis, lead poisoning and asbestosis. Efforts have been made to give a good all-round survey of the position in regard to dust dispersion for which purpose the difficulties attaching to lengthy and intricate research were felt to be of minor importance. As the contributory factors in the development of the diseases mentioned are not so well known, it being well-nigh impossible in many cases to state with certainty what part these factors play in causing such diseases, it would not seem warranted at the moment to make any attempt at simplification of this research or limitation of its scope. It is of the utmost importance that the results of research on the presence of dust in the atmosphere should as far as possible be compared with the results of medical examination of the workers. Such a comparison is the best means of throwing light on the external causes of the development of occupational diseases, and the data obtained in this way will lead to the right measures being taken to guard against these diseases.

2 *Factors Governing the Development of Occupational Diseases*

2.1 There is now a fair consensus of opinion that silicosis may be caused by the inhalation of dust particles smaller than about 3 microns which contain free silica (quartz or possibly tridymite or cristobalite). Under otherwise identical conditions, the risk becomes greater the larger the number of dangerous-sized particles inhaled and the higher the quartz content of these particles. Although it is fairly certain that particles larger than 3 microns cause much less danger than small particles, it cannot be said for certain what particles below this limit are the most dangerous and whether very small, sub-microscopic particles smaller than 0.1 micron may possibly be less dangerous than particles of, say, 1 micron diameter. Certain it is that old statements according to which no particles of less than 0.1 μ have ever been found in the lungs of silicosis patients, are based on insufficient data or, at all events to a large extent, on insufficient realization of the limited possibilities of the optical methods employed. Furthermore, no certain knowledge is as yet available as to the effect of other categories of dust inhaled together with the quartz, and as to the difference between »stale« and »fresh« dust (i. e., dust with recently formed surfaces of fracture). Regarding the influence of such factors as temperature and humidity of the environment, strenuousness of the work performed and, in this connection, respiration (expressed as minute volume) upon the development of silicosis, hardly any definite information is available.

As far as is known at present, the probabilities are that every quartz particle of dangerous size which enters the lungs may give rise to fibrose. It would therefore seem likely that the number of particles inhaled is a better criterion for the danger of silicosis than the weight of inhaled dust or the surface of the particles inhaled.

2.2 Regarding asbestosis the available information is even less than in the case of silicosis. It is probable that asbestos needles of relatively great length, 10 microns and more, are still a source of great danger; there is no ground whatsoever for the assumption that needles of a greater length than 5 microns are just as harmless as quartz particles of more than 5 microns diameter. There are different kinds of asbestos, and there is no unanimity of opinion either as to the classification or as to the degree of danger of the various categories.

2.3 As a rule any plumbiferous dust that finds its way into the body will result in lead poisoning, no matter where and in what way it has entered the body. Particles larger than 5 microns cannot reach the alveoli any more than quartz particles of this size, but they nevertheless cause risk of lead poisoning. It should therefore be noted that, where plumbiferous dust is concerned, the weight of dust inhaled is a better criterion for the risk of poisoning than the number of particles. According to American data, which we can fully confirm, there will as rule be no risk of lead poisoning if the air does not contain more than 0.15 milligrams (mg) per cub. metre (m^3).

3 *Methods of Determination in Holland*

3.1 One of the simplest methods of determining the dust content of air, viz., by sucking the air through a filter paper, is regularly employed by us in our experiments. As a rule about 2 m^3 of air are sucked through a filter paper (diameter 9 cm, for quantitative analysis of fine precipitates) in about 30 min. by means of a pump. The dust can be directly weighed if the dust content is fairly high. On being heated to redness practically all the filter paper is burnt away, whereupon the weight of the heatproof dust residue can be accurately determined without difficulty. It is now possible to carry out a chemical analysis of the dust segregated by the filter, but one cannot determine the number of particles nor the size of the particles.

3.2 In the Netherlands a thermal precipitator is used for carrying out the determinations referred to above. The principle applied in this instrument, which is of English make, is presumably known. Dust particles from a small volume of air are sucked through the instrument and made to pass through a narrow slot between a heated wire and two cold glass cover slips fitted on either side of the wire. As a result of the fall in temperature between the wire and the cover slips, the dust particles are precipitated on to the slips. As a rule some 50 cm^3 of air are passed through the instrument during a period of from 7 to 10 minutes. Further requisites are a water aspirator and a source of electric current; the wire is heated by means of D. C. or A. C. at 6 volts potential, the strength of the current being from 1.2 to 1.5 amperes. For the purpose of transport each of these instruments is housed in a metal case of our design which also contains the water aspirator and the necessary electrical apparatus (transformer, battery, rheostat and ammeter).

By means of a system of movable rods, the head of the instrument can be brought close to the workman's face. In order to obviate the necessity of changing the cover slips in the factory we have also designed a multi-thermal precipitator by means of which 7 determinations in succession can be made without opening the instrument.

The dust lines produced on the cover slips are examined in the laboratory under a microscope in a dark field and with 450-fold magnification; the number of particles is counted and a determination made of the distribution of sizes, i. e. the percentages of particles observed that are smaller than 0.5 μ, between 0.5 and 1 μ, between 1 and 2 μ, and so on. Practically no particles larger than 3 μ are to be found in the dust deposits. After this the cover slips with their dust content are heated for some 10 minutes at a temperature of 400–450° C, after which the examination under the microscope is repeated. In many cases the cover slips are subsequently treated with hot, concentrated hydrochloric acid, then re-heated and examined a third time.

The heating removes organic material, which as a rule is not so dangerous. At the same time it also removes most of the dust that occurs in the outside air as well, which is no inconsiderable amount. By the employment of this same method in The Hague, a city with comparatively little industry, we found in the open air average monthly dust contents of from 300 to 700 particles per cm^3 of air (in winter the number was larger than in summer) and, in some cases, as many as 2000 particles per cm^3 of air, 80% of which are removed during heating.

Treatment with acid has been adopted mainly in connection with research on dust dispersion in foundries. In these works it is desirable to be able to differentiate between iron oxide and quartz particles. This treatment to some extent takes the place of more minute chemical examination of the dust particles obtained, such examination not being practicable on account of the extremely small quantity of dust on the cover slips (in the case of a dust content of 50 mg per m^3 of air each slip contains only slightly more than 0.001 mg of dust).

When the particles are viewed in a bright field with a magnification of 100–200, particles smaller than 0.2 μ are not visible; when they are viewed in a dark field with high magnification it is possible to distinguish particles of diameters down to, say, 0.01 or 0.005 μ. As these tiny particles are usually present in large numbers, the result of counting and determining the distribution of sizes depends to a great extent upon the method of observation, so much so that the mention of a certain number of dust particles per cm^3 of air is of no use unless the method of observation is also mentioned. The effect of the method of observation selected is usually greater than the effect of the instrument used for segregating the particles. If we count the same dust line in a bright and in a dark field of vision, the ratio between the results is often as 1 : 2 or 1 : 3, this ratio depending entirely upon the distribution of sizes of the particles.

4 *Some Results of Determinations Made*

4.1 If under (approximately) the same conditions more than one determination is made by filtering, the results as a rule differ comparatively little from each other – not more than, say, 10 to 25%. If, however, more than one determination is made with the thermal precipitator, the results often differ considerably. Determinations in series of, say, 10 in succession were carried out in different factory workshops under apparently the same conditions in each instance. The standard deviation that could be calculated* on the strength of the results was in many cases of the order of 50% of the mean dust content. This means that one or two determinations by the filtration method will usually be sufficient, but that a large number of determinations with the thermal precipitator will be necessary. To enable these determinations to be made in a short time, we have now 8 thermal precipitators at our disposal.

The great divergency in the results may be due to various circumstances: unsatisfactory functioning of the instrument, errors in counting or irregular distribution of the dust particles in space and time. The latter is the more probable. The volume of air taken as sample in the case of the thermal precipitator is usually 50 cm^3, and in the case of the filtration instrument about 2 m^3 or roughly 40,000 times as much; with the latter instrument the effect of fluctuations will for the most part be eliminated in the result. We are at present endeavouring to obtain certainty in this

* If, when making n determinations, we indicate the results by a_i and the mean result by $\bar{a}$, the standard deviation will be determined by:

$$s = \sqrt{\frac{\Sigma (a_i - \bar{a})^2}{n - 1}}.$$

matter by carrying out measurements in a dust chamber in which the dust content is kept practically constant.

4.2 In many cases dust determinations have been carried out in order to test the operation of dust exhaust system and this may lead to unexpected results. For instance, on several occasions it was found that a dust exhaust system which seemed on superficial observation to be functioning properly did certainly restrict the dispersion of coarse particles but not that of fine particles of dust. Without seeking to account for this, it is obvious that cases of this kind afford clear evidence of the great utility of dust determinations as they enable technical improvements to be critically scrutinized.

In this connection we would again point out that no unequivocal relationship exists between the weight and the number of particles per unit volume of air. Even if such a relationship were found to exist for a specific case, it would alter as a result of any change in the conditions.

As a rule the technical difficulties encountered in any efforts to combat the dust nuisance are found to be greater than had at first been supposed. In particular, the dispersion of dust through a variety of causes not always amenable to control – as for instance the transport of material and the dispersion of dust deposited on the ground – is a constant source of difficulty.

5 *Connection between Dust Contents and the Occurrence of Silicosis*

5.1 We are now confronted with the question: Is there a clear correlation between the occurrence of silicosis and the dust contents found in terms of the number of particles per cm^3 of air, if the size of particles and the quartz content are taken into consideration in the assessment? Although this question must generally be answered in the affirmative – otherwise dust determinations would be of little use for this purpose – the connection is not so simple as might be supposed.

5.2 In the ceramic industry, for instance, silicosis usually develops only after some 20 to 30 years work. The cases of silicosis at present found may therefore have been caused by dust inhaled twenty or more years ago. There is no reason to assume that the amount of dust and the composition of the dust then inhaled were the same as at present. Whilst in some cases the dust content has been diminished as a result of technical hygienic measures such as dust exhaustion, damp processing, better ventilation and more spacious workshops, on the other hand the output per worker has in many instances been increased by the introduction of more efficient working methods and further mechanization, which usually results in higher dust contents. The composition of the basic materials processed may have altered; powdered quartz, for instance, is at present ground finer than it used to be 10 to 20 years ago. As no measurements are available from these former times, we are unable to tell whether the risk of silicosis has increased or diminished. Similar considerations apply to other industries. In these cases, therefore, it is not possible to answer the question propounded unless data as to dust determinations are available over a period of 20 years or more.

5.3 Quartz dust will find its way into the atmosphere both in ceramic works and in iron foundries. Silicosis occurs in both these industries but is relatively far more prevalent in the former than in the latter. Nevertheless, the quartz content in foundries is higher rather than lower than in the ceramic industry, if in the case of foundries we consider the particles remaining after treatment of the dust with acid no consist of quartz. Although nothing can as yet be stated for certain on this matter, it would seem likely that the permissible content of quartz particles in the ceramic industry should be set at a lower value than in foundries. It may be that in foundries the ferriferous material that is inhaled together with the quartz material has a protective effect analogous to that described in the case of aluminium.

Our experience indicates that in general there certainly is a clear correlation between the occurrence of silicosis and the dust contents expressed in terms of the number of particles per cm^3 of air. On the other hand, we have not been able to find any correlation between the occurrence of silicosis and the dust contents expressed in mg of dust per m^3 of air.

6 *Standardization of Dust Determinatios*

Although it would seem unnecessary and undesirable to prescribe one particular method of dust determination for each purpose, the multiplicity of methods described in relevant literature does in some respects give rise to an undesirable situation. Whilst dust contents expressed in mg of dust per m^3 of air will be in fairly good agreement with each other whatever method of determination is used, it being of little consequence for the assessment of these contents whether they were determined with an electrostatic precipitator, with a paper filter or with a soluble filter, this does not apply to dust contents expressed in terms of the number of particles per cm^3 of air. As the finest particles are the most difficult to segregate, the difference between the results found when using different instruments is sometimes very great. A still greater influence is probably exerted by the method of observation, i. e., by the optical system employed. For determinations of this nature I would consider it desirable to select and standardize one particular method (perhaps together with one or two alternative methods). The standard method should be used at the various research centres and serve as a basis for comparison in cases where preference is given locally to some other method.

As far as can be surveyed, the instruments commonly used at present in America are: the impinger, the electrostatic precipitator and also the thermal precipitator; in England the latter instrument is mainly used, in Germany this same instrument and the conimeter, in France the soluble filter of naphthalene tetrachloride, in Holland the thermal precipitator. It seems to me that for a standard instrument the thermal precipitator offers the most possibilities. This would mean in practice that at every research centre where dust determinations are carried out there should be a thermal precipitator regularly in use for comparing the results obtained with other instruments. The method of counting and the optical system used for this purpose should also be laid down. As the best yield of data is obtained by observation in a dark field – particles smaller than 0.2 micron can only be counted under these conditions – and as counting in a dark field is more agreeable than counting in a bright one, we are of opinion that this method is preferable. As an alternative one could perhaps standardize another method of counting whereby the particles are projected on to a screen in a bright field of vision.

In the present state of affairs it is usually impossible to compare a dust content mentioned in literature with one's own observations, as no sufficient particulars have been established as to the method of determination, nor is sufficient information available as to the properties of the instrument used. In the American list of maximum permissible concentrations the maximum dust content of quartz material is fixed at 175 particles per cm^3 of air as determined with the impinger and with the counting system in vogue in America; in our own method of determination we have fixed this content at about 350 particles of heatproof dust. Although it may be assumed that these limiting values agree with each other as well as is reasonably possible, the fact is, that in this way a limit is set to the number of heatproof particles counted by the method we are using in the Netherlands, whilst in America a limit is set to the total number of particles having a diameter of about 0.2 micron or more. The establishment of one accurately defined method would prevent a chaos of figures that would indeed be a great handicap to international discussion in this field of research. International deliberation on this matter, now an urgent necessity, has already commenced.

Research Institute for Public Health Engineering T. N. O. Hague

Received for publication 20. VIII. 1953

Selected bibliography

1. *Gardner:* Inhaled silica and its effects on normal and tuberculous lungs. J. Amer. med. Ass. *103*/–/743 (1934).
2. *Green and Watson:* Estimation of dust hazard in industry. Med. Res. Council, Spec. Rep. Ser. no 199, London (1935).
3. *Policard:* Sur la nature tuberculeuse du nodule pneumoconiotique. Ann. Med. lég. *15*/–/126 (1935).
4. *Drinker and Hatch:* Industrial Dust. New York – London (1936).
5. *Faber:* Nachweis und Grössenbestimmung ultramikroskopischer Quarzteilchen im Lungengewebe. Staub Heft 3, 372 (1936).
6. *King, E. J.:* The solubility theory of silicosis. Occ. Med. *4*/1/26 (1947).
7. *Hatch and Kindsvatter:* Lung retention of quartz dust smaller than one-half micron. J. Ind. Hyg. Tox. *29*/5/342 (1947).
8. *Reichmann:* Stand der Silikoseforschung. Beiträge zu Silikoseforschung Heft 1 (1949).
9. *Gessner, H.:* Zur Bestimmung des Korngrössenbereiches von Silikogenen Staub. Schweiz. Med. Wschr. 79/51–52/1241 (1949).
10. *Bedford, Th.:* The size and nature of dust particles found in lung tissue. Brit. J. Ind. Med. *7*/–/187 (1950).
11. *Holzapfel:* Zur Silikosewirksamkeit von soggenanntem aktiven Quarz. Z. Unfallmed. Berufskrankh. p. 341. (1950).
12. *Jötten, Gärtner:* Die Staublungenerkrankungen. Darmstadt (1950).
13. *Zrenner:* Gedanken zur Silikoseentstehung. Beiträge zur Silikoseforschung Heft 9 (1950).
14. *Forbes a. o.:* Review of literature on dusts. United States Dept. of the Interior, Bur. of Mines, Bull. 478 (1950).
15. *Davies:* Dust sampling and lung disease. Brit. J. Ind. Med. *9*/–/120 (1952).
16. *Holzapfel:* Eine kritische Betrachtung zur chemischen Theorie der Silikose. Beiträge zur Silikoseforschung, Heft 15 (1952).
17. Institut d'Hygiène des Mines: Conimetrie. Communication no 94; Hasselt (1952).
18. *Meldau:* Handbuch der Staubtechnik I. Düsseldorf (1952).
19. *Thomas, R. W.:* Silikosis in the ball-clay and china-clay industries. Arch. Ind. Hyg. A. M. A. *6*/3/280 (1952).
20. International Labour Organisation: Third international Conference of Experts on Pneumoconiosis. Record of Proceedings, Geneva (1953).

Sadržaj

SVRHE I METODE ODREĐIVANJA PRAŠINE U ATMOSFERI TVORNICE

U literaturi su opisane različite metode za određivanje sadržaja prašine. Ovdje se ukratko spominju razlozi, koji utječu na izbor neke metode. Određivanje se prašine provodi s određenim ciljem, da se na pr. uvidi opasnost od silikoze. U Holandiji su stekli mnogo iskustva pri određivanju prašine u tvornicama, i to sa svrhom da upoznaju opasnost od profesionalnih bolesti, naročito opasnost od silikoze, azbestoze i otrovanja

olovom. Metode za ta određivanja opisane su potanko. Naročito se prikazuje upotreba termalnog precipitatora, kojim se određuje broj i veličina čestica prašine pojedinim rezultatima, koji su dobiveni tim metodama.

Obrađuje se korelacija između sadržaja prašine i pojave silikoze. Spominje se, kako sama metoda za određivanje i brojanje čestica utječe na dobiveni broj čestica. Zbog toga se ne mogu usporediti rezultati različitih autora. Potrebna je neka standardizacija, jer će inače zbrke brojki smetati kod svake internacionalne diskusije.

Istraživački institut za zdravstvenu tehniku Hag

Radnja primljena 20. VIII. 1953.