

TBF 50 and Tyndallometer TM digital — Two Instruments Supplementing each other for the Occupational Hygienic and Technical Assessment of Dust Conditions

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SYNOPSIS

For the occupational-hygienic assessment of the exposure of underground personnel to respirable dust as well as for the assessment and control of dust suppression measures, the Mining Research Establishment of the Steinkohlenbergbauverein of Essen developed two different sampling instruments:

- (a) The TBF 50 with an air throughput of 50 l/min used to determine the concentration and composition of respirable dust in mass units for the assessment of respirable dust exposure. The instrument can be operated by a compressed air ejector, a battery with a fan, or by a pump.
- (b) The 'Tyndallometer TM digital' for digital recording as well as for recording and possible transmission of short-time values to a control station with arbitrary integration of the measured values and determination of the average value. The electrical energy can be supplied from either a battery or from the grid power supply.

The airborne dust is sized in the TBF instrument by means of two successive cyclones into three fractions: coarse, fine, and ultra-fine dust. The new Tyndallometer is used to determine only that proportion of fine (respirable) dust as a fraction of the total airborne dust without pre-selection of the coarser particles by measurement of the angle of the light scattered by the dust at a selected wave length. The instruments, being different, assess the dust in different ways, but account has been taken of the probability of the deposition of dust particles in the alveoli of the lung.

The paper contains the results of comparative investigations in the laboratory with the two instruments with dust of various origins and size distributions as well as an account of the experience gained underground with these instruments.

INTRODUCTION

A dust-sampling method should fulfil two separate basic functions:

- (a) The primary function is the assessment of the exposure of workers to respirable dust at their working places. In the case of mixed dusts, the composition of the respirable dust is also determined. Usually, however, only the quartz content is determined and included in the assessment. A concentration of respirable dust which exists for only a short while does not constitute a direct hazard to men, as dust affects the human lung only if it persists for long periods. Consequently only mean values of measurements taken over a long period of time can be used to assess pneumoconiosis risks. According to the list of MAC-values 1974 of 'Deutsche Forschungsgemeinschaft',¹ the value for quartz-containing dust in coal mines is 4,0 mg/m³ for an exposure period of five years.
- (b) The second function is the investigation of the amount of dust produced in mining operations in practice or in the laboratory, the efficiency of dust suppression methods, the generation of dust by a mining machine under various conditions, or the stirring-up of dust by air currents of different velocities. In the latter case, a relation must be sought between the production of respirable dust often within very short periods of time, due to the often rapidly changing working processes and the behaviour of the dust in the air current.

In recent years, there has been a demand for further methods of dust sampling, namely, for monitoring continuously the dust contents of air currents, by means of recording devices at specific points. This applies particularly to workings in which the large amount of dust produced can be kept within permissible limits only by the use of continually effective dust-suppression methods.

A number of dust-sampling methods and devices are available which are more or less suitable for one or other of these tasks, depending on the principle of sampling used, the possibility of analyzing the samples and the results obtained.

For the occupational-hygienic assessment of working places, gravimetric samplers in which there is pre-selection of the coarse dust are being used increasingly, such as the British MRE gravimetric dust sampler, the TBF 50, which will be described later, or different types of personal dust sampler. The development work leading to the design of these gravimetric samplers has been much influenced by the recommendations issued by the First Pneumoconiosis Conference in Johannesburg (1959) regarding the sampling of respirable dust. According to Breuer,² these samplers are replacing increasingly the previous short-time samplers, such as the thermal precipitator, the konimeter and the Tyndalloscope, in West Germany. The latter samplers have, without doubt, rendered valuable service in the past in the intensification of dust suppression measures. They are easily handled and permit measurements during short-time processes, and the dust concentration can be determined directly at the sampling point, as with the Tyndalloscope. Some of these advantages are lost in long-period gravimetric sampling, because the collection of an analyzable sample often requires several hours. It therefore became necessary to develop samplers capable of indicating and recording short-time values of respirable concentrations directly at the sampling point. It is essential that these samplers should need as little attention as possible at the measuring point. The values obtained should be recorded as mass concentrations of the

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respirable dust or be convertible into mass values, although this would apply only to specific types of dust produced in a particular branch of an industry. The use of such samplers at fixed points with remote transmission of the values measured is a requirement which can be easily met by existing techniques in electronics and data processing.

The Mining Research Establishment of the Steinkohlenbergbauverein in Essen has developed, in co-operation with other research institutes and manufacturers, two flame-proof samplers which meet the special conditions in West German coal mines. These samplers are:

- (i) the TBF 50 for the occupational-hygienic assessment of dust conditions in terms of mass concentrations of the respirable dust, and
- (ii) the Tyndallometer TM digital for use in testing stations and in practice, especially for the investigation of dust problems as well as for the continuous monitoring of respirable dust concentrations.

DEVELOPMENTS LEADING TO THE TBF 50 AND TO THE TYNDALLOMETER TM DIGITAL

Demands on the samplers

According to the recommendation of the World Health Organization (WHO) in Katowice 1967, the gravimetric dust sampler TBF 50 was required to separate all airborne dust, which would be deposited in the lungs, into two fractions:

- (a) the respirable dust which would be deposited in the alveoli of the lungs and cause pulmonary diseases, and
- (b) the coarse dust which would be deposited in the upper respiratory tracts and cause bronchitic diseases.

The sampler was to have a high throughput of air in order to take a sufficiently large sample so that the composition of dust at any location could be determined and to have a sampling period covering the entire effective working time (four to six hours). With shorter sampling periods, the sampler was required to be able to determine at least the concentration of the respirable dust. Alternative means for the aspiration of air were a compressed air ejector, a battery-driven blower or an electrically-driven pump, without a manual setting of the air volume.

The Tyndallometer TM digital was to collect, from the total airborne dust sampled, without any mechanical pre-selection and without disturbances by other light sources, only the percentage of the light scattered by the respirable dust and to measure it photometrically. The value obtained was to be recorded digitally for a time interval of 10 seconds. In addition, it was required of this sampler that it should have connection for a recording instrument with integrator and provision for the remote transmission of the values obtained.

Questions arise as to how the percentage of respirable dust contained in the airborne dust is to be defined precisely and how is it to be measured by the two samplers?

According to investigations by Hatch and Gross,³ the percentage of dust which is deposited in the lung depends on the breathing volume and on the number of breathing cycles per minute. On the basis of this and on other investigations, the Task-Group on Lung Dynamics⁴ recommended that the design of preselectors should be based on the deposition curve for a breathing volume of 1 450 cm³ at the rate of 15 breaths/min. This curve shows a maximum of deposition (≈ 35 per cent) at a particle diameter of 2 μm , with deposition increasing again with decrease in particle size beyond the minimum (≈ 20 per cent) at 0,5 μm . This is

not of particular importance as regards airborne dust produced in mines, because the mass percentage of such fine dusts in mines is very low. Further investigations are being carried out at present into the relationship between the dust particle size, the breathing process and the deposition of particles in the various zones of the lung, *inter alia*, by the 'Institut der Gesellschaft für Strahlen-Forschung GmbH.' (Institute of the Society for Radiation Research) of Frankfurt am Main in co-operation with Bergbau-Forschung GmbH (Mining Research Establishment of the Steinkohlenbergbauverein) in Essen. During these investigations, different instruments will be checked by the same test methods which were used to measure the percentage of dust which can be deposited in the lung. These investigations will be the subject of a report to be published later.

In the TBF 50, the separation of the airborne dust takes place by means of two successive cyclones (Fig. 1). The separation curves for cyclones 1 and 2 (Fig. 2) were determined

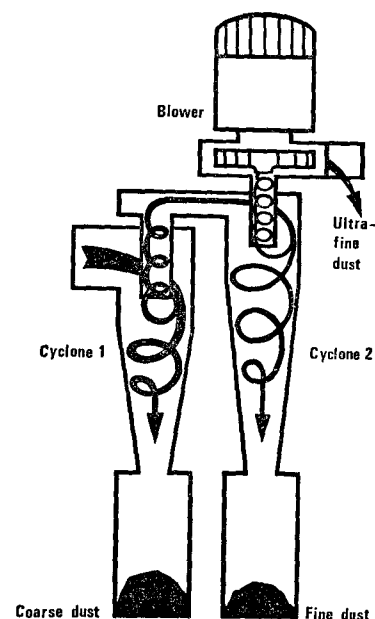


Fig. 1. Separation of airborne dust by two successive cyclones in the TBF 50 with radial blower.

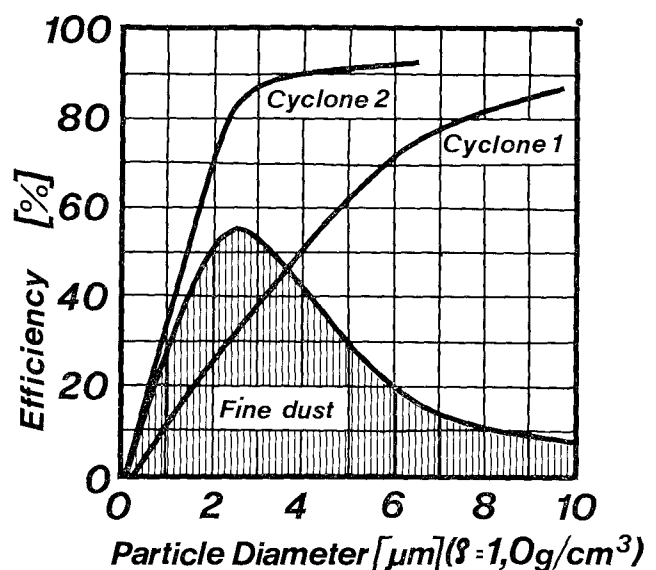


Fig. 2. Separation curves of the cyclones 1 and 2 in the TBF 50 for separation of the respirable dust.

by tests in a wind tunnel, into which coal dust and rock dust as free from aggregates as possible were introduced. The values found by sedimentation analysis were converted to unit density ($\rho = 1,0 \text{ g/cm}^3$) equivalents. The maximum size of the respirable dust separated in the second cyclone is between 2 and 3 μm if it is a dust with the same frequency of the particle diameter d as assumed (Fig. 2).

At the start of the development work less was known about the optical 'separation' of respirable dust by measuring the scatter of light than about mechanical separation of dust in cyclones. Theoretical and experimental investigations were carried out in co-operation with the Battelle Institute⁵ of Frankfort am Main in order to obtain the necessary fundamental knowledge. As a result of this research work, a different angle of radiation and different measuring arrangements were chosen (Fig. 3). The angle at which scattered light is measured is now about 70° instead of 30° with the Tyndalloscope. Primary light of wavelength $0,94 \mu\text{m}$ is used instead of the white light used with the Tyndalloscope. By these means the over-assessment of the respirable dust $< 1 \mu\text{m}$ by the Tyndalloscope, has been reduced significantly as is shown by the hatched area in Fig. 4 and the maximum intensity which occurs at about $0,6 \mu\text{m}$ is reduced in a ratio of 4 : 1. With a primary light source of about 2 000 nm which it is hoped will be available very soon, the maximum intensity could be shifted into the particle size range between 1 and 2 μm . This will enable a better approximation of the scattered light curve to the deposition curve to be obtained. The specific light scatter intensity given in Fig. 4 in volts (Tyndallometer) and in intensity values I (Tyndalloscope) per mm^3 of dust in 1 m^3 of air have been measured in monodispersed aerosols.

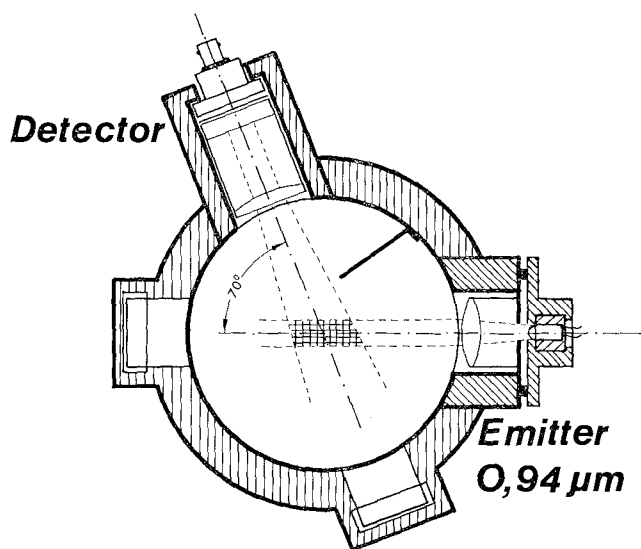


Fig. 3. Optical elements in the open dust chamber of the Tyndallometer TM digital.

A comparison of the curves for the assessment of dust given in Figs. 2 and 4 shows that the maxima are still clearly different with the two instruments. It must be borne in mind, however, that the methods of investigations were also quite different; one was direct measurement of the intensity of light scattered by monodispersed aerosols with the Tyndallometer and the other the assessment of the dust from the degree of efficiency of the cyclones with real coal mine dusts by sedimentation analysis with the TBF 50. It is still doubtful whether the values obtained for liquid and spherical particles without correction factors apply also to solid and irregularly shaped particles and *vice versa*. In any event, the discrepancies

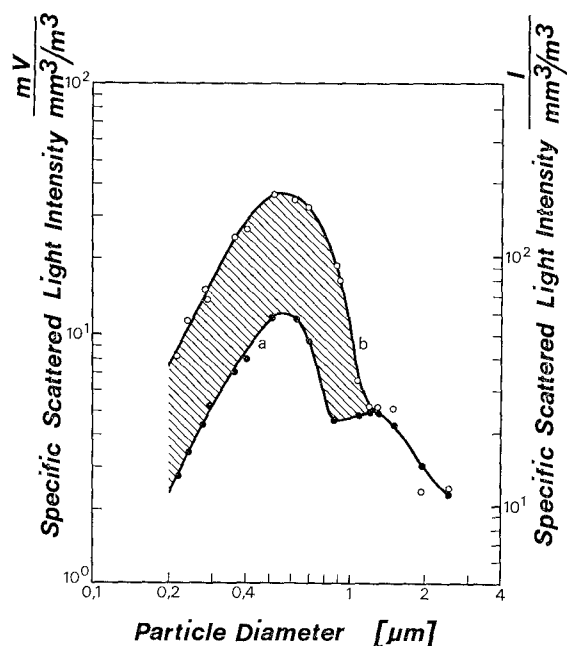


Fig. 4. Specific light scatter intensity according to values measured by the Tyndallometer (a) and of the Tyndalloscope (b), (measured from monodispersed aerosols in the 'Institute of the Society for Radiation Research' (Institut für Strahlenforschung mbH) Frankfurt/Main).

between the assessment curves show that the possible influence of the particle size, as well as of the shape and density of the dust particles on the conversion of the values obtained by the Tyndallometer into mass values will have to be investigated.

Description of the samplers

The TBF 50 (Fig. 5) was designed in a piecemeal fashion. Technical data for the instrument and its accessories are given in Appendix I. The sampler consists of a basic device with two cyclones for the separation of the coarse dust from fine particles, and additional equipment for the aspiration of air ($Q = 50 \text{ l/min}$ at a velocity of $u = 2,5 \text{ m/s}$). In addition, a filter can be included behind the first or second cyclones. A filter behind the first cyclone collects the fine and the ultra-fine dust particles. This combination is used to measure air pollutants which usually have the highest percentage of particles $< 1 \mu\text{m}$.

By installing the filter behind the second cyclone, the ultra-fine dust can be collected together with the coarse dust and the normally respirable dust. These three fractions serve to characterize the size distribution of an airborne dust. Such a filter should be used in conjunction with a vacuum pump or an ejector, because of the very large pressure drop across the sampler, namely, $P > 20 \text{ kPa}$ compared with only $0,7 \text{ kPa}$ for the two cyclones alone.

The aspiration rate is kept constant by means of an electronic regulator when the instrument is operated by blower and battery, and by an air-limiting orifice when the sampler is operated by an ejector or a pump. The dust samples collected must be washed out of the cyclones by means of a syringe so that their masses and compositions can be determined. The syringe ($\gamma = 9 \text{ cm}^3$) (50 per cent by volume of distilled water and 50 per cent methanol) should contain sufficient liquid to ensure that the containers in the pots of the cyclones contain a small amount of liquid after two cleanings. The closed containers can be dispatched by ordinary mail to the place where they are analyzed. Correct cleaning is always necessary prior to analysis of the samples in order to dissolve



Fig. 5. TBF 50 with radial blower.

salts which may possibly be present in the dusts and which increase the dust concentration and possibly affect the determination of minerals such as quartz.

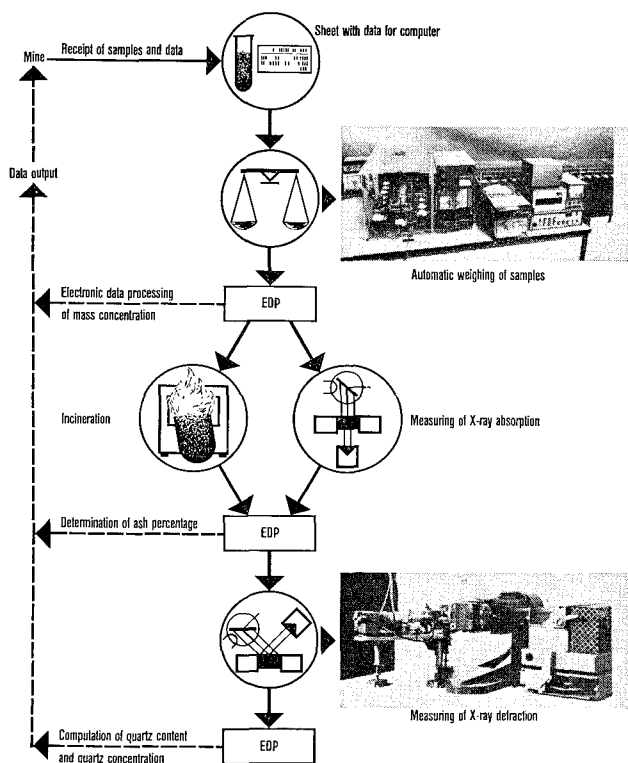


Fig. 6. Central evaluation by Bergbau-Forschung GmbH, Essen-Kray, of respirable dust samples collected at mines (designed for an annual throughput of 70 000 mass and ash-determinations, 20 000 quartz-determinations).

When this or similar samplers are used for routine dust sampling, a large number of samples is obtained. Special instruments for analyses were, therefore, developed in Bergbau-Forschung GmbH of Essen which ensure a high throughput of samples and precise analyses by a small number of personnel. The sequence of the various processes during the analysis is given in Fig. 6. First of all, the dust is separated from the liquid and collected on a membrane filter. The masses of the samples are determined by an automatic balance which can weigh up to 1 000 samples within eight hours. The ash content of the samples is then determined either by incineration or by X-ray absorption. The mass attenuation coefficient of the dust sample found by the latter method serves initially as a correction factor in the determining of the quartz content by X-ray diffraction. The automatic apparatus used for the purpose has a throughput of 72 samples/day. The values obtained from the analyses are analyzed electronically during the individual stages and are processed, together with the data of the measuring report, in an EDP-plant. Values of the ash content of the respirable dust are available after one day and values of the quartz content two days later.

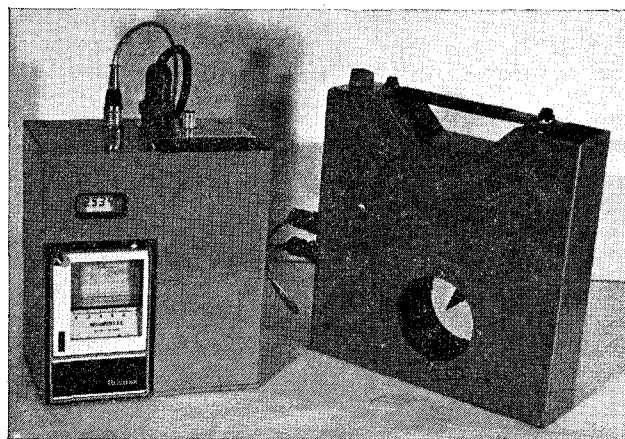
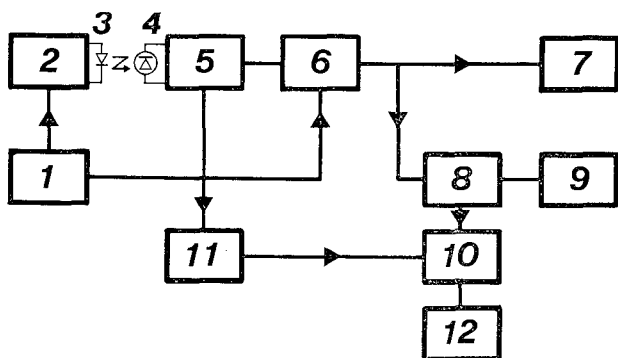


Fig. 7. Tyndallometer with connected recorder, integrator and battery for use in coal mines (flame-proof).

The Tyndallometer was also designed in a piecemeal fashion. Figure 7 shows the basic instrument with the recently completed flame-proof part for use in coal mines. This part accommodates the battery, the recorder and the integrator, digital indication being given of the cumulative value for the respirable dust concentration over any time interval. When the Tyndallometer is used outside coal mines, additional commercial components can be connected, provided they conform to the fundamental characteristics of the basic instrument, which are listed in Appendix II together with other technical data. The basic instrument, described in detail by Breuer *et al.*,⁶ includes the following essential components:

- (i) The measuring chamber ($d = 80$ mm) with transmitter (a GaAs-luminescence diode),
- (ii) a receiver (a silicon photodiode), a trap for the primary light,
- (iii) a plate to screen-off undesirable scattered light (Fig. 3),
- (iv) the electrical section, the components of which are shown in the block switch diagram (Fig. 8), and
- (v) the dust-proof housing.

The instrument is put into operation by a key and 13 seconds later the measured value appears as an integral value for the first 10 seconds on a three-figure digital indicator. The indicator can be set in two ranges, from 0 to 9.99 and from



- | | |
|---------------------------------|--------------------|
| 1 Cadence tapper | 7 Analogous output |
| 2 Emitter supply | 8 Digitalvoltmeter |
| 3 Emitter diode | 9 Data output |
| 4 Detector diode | 10 LED-indication |
| 5 Amplifier | 11 Troubletone |
| 6 Phase-sensitive Rectification | 12 Voltage control |

Fig. 8. Electrical elements of the Tyndallometer.

0 to 99,9. This range corresponds to respirable dust concentration ranging from 0 to 99,9 mg/m^3 , provided the properties of the dust measured correspond to those of the test dust used for the calibration of the instrument (maximum at $d = 1 \mu\text{m}$, $\rho = 1,0 \text{ g/cm}^3$). For such a dust, the lower limit of detection is 0,03 mg/m^3 .

The measuring range can be extended beyond 99,9 by modifying the electrical section or by including an attenuation glass with a known extinction (10 : 1) in the path of the rays. The measuring signal can be supplied either by means of the analogue output to a recorder or, by means of a digital output to a puncher, a printer or a magnetic tape with which, the pre-requisites are provided for transmission of the results and for regulation of certain processes according to the respirable dust concentration. The component for this purpose and a device for the aspiration of the air as well as for keeping the optics and the measuring chamber clean is still under development at present.

Disturbances of the measuring process by extraneous light, excessive measuring sensitivity or electrical faults, are being checked. The precision of indication by the instrument can be checked in practice by a standard beam of scattered light, and the scattered light intensity of this standard can again be checked in a calibrating Tyndallometer in which is used a reproducible standard aerosol ($d \approx 1 \mu\text{m}$).

The important components of the instrument, particularly the electronic components, can be readily interchanged. The individual parts of the basic instrument may also be accommodated in a different housing and, if this is done, data outputs, which are not required, can be omitted as with the basic instrument.

Figure 9 shows a special type of the instrument, with analogue output of the measured values to a recorder. In this case, the instrument is used in a wind tunnel to determine rapid changes in the concentration of respirable dust during the investigation of a new dust-suppression method, supplementing the task of gravimetric long-time samplers.

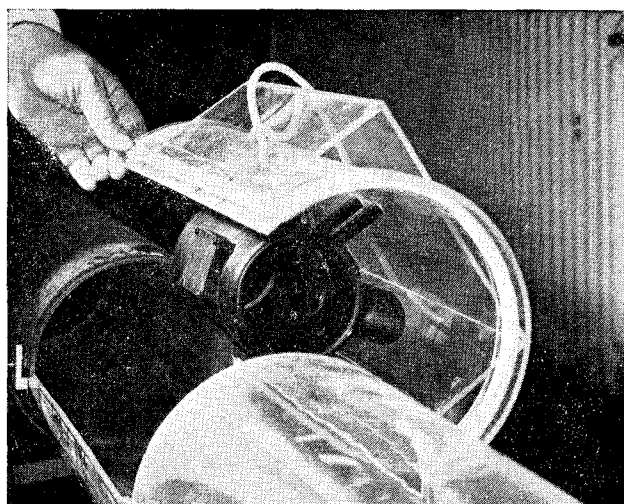


Fig. 9. Special type of Tyndallometer for measurements in a wind tunnel.

COMPARATIVE MEASUREMENTS WITH THE TYNDALLOMETER TM DIGITAL AND THE TBF 50

After introduction of the flameproof Tyndallometer, comparative investigations with the TBF 50 were begun in mid-1974 first in a wind tunnel and later underground. Robock, Breuer *et al*⁷ reported results obtained with the prototype of the Tyndallometer TM digital and on the first results of these studies. The purpose of these comparisons was to investigate the possibility of converting the results obtained with the Tyndallometer (in volt) to mass concentrations of respirable dust of different size distributions of rock dust and coal dust in the laboratory and underground. In workings underground, water mist and oil droplets occur in addition to dust which can disturb the readings of an optical device. According to Breuer² sufficient experience and comparison values have been obtained with the Tyndalloscope.

Comparative measurements in the wind tunnel

The result of the previous comparative investigations in the wind tunnel are shown in Fig. 10 and data on the type and the size distribution of the test dust in Table I. The percentages (by mass) < 2 and $> 7 \mu\text{m}$, converted to unit

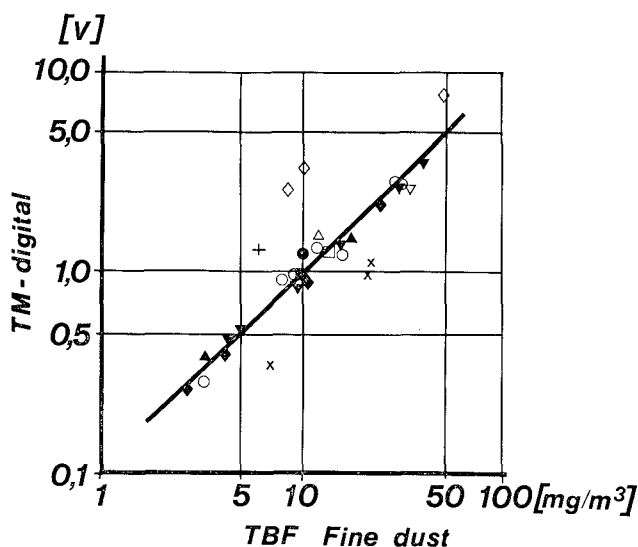


Fig. 10. Results of comparison measurements with the Tyndallometer and the TBF 50 in a wind tunnel.

TABLE I

DATA ON TYPE AND SIZE DISTRIBUTION OF THE TEST DUST, ACCORDING TO FIG. 10

Ser. No.	Sym- bol	No. of measure- ments	Data on the size distribution of the dust				
			According to sedimentation analysis ($\rho = 1 \text{ g/cm}^3$)		According to TBF 50 (proportionate figures)		
			< 2 μm	> 7 μm	Coarse	Fine	Ultra-fine
(a) <i>Coal dust</i>							
1	×	3	2,5	90,5	6,74	1	0,178
2	▼	4	3,9	86,0	3,68	1	0,208
3	●	1	7,0	64,0	5,2	1	0,361
4	■	1	12,7	22,0	1,32	1	0,231
5	▲	3	14,5	9,7	0,468	1	0,305
6	+	1	16,0	1,0	0,82	1	0,820
7	◆	3	19,0	44,0	2,20	1	0,186
(b) <i>Rock dust</i>							
8	□	1	6,3	72,6	5,98	1	0,415
9	○	8	14,0	72,0	3,64	1	0,429
10	▽	1	30,0	19,0	1,15	1	0,281
11	△	2	45,0	1,8	0,590	1	0,885
12	◇	3	74,0	4,0	0,120	1	2,070

density $1,0 \text{ g/cm}^3$, are given to characterize the size distribution of the dust. These two percentages should have a decisive effect on the scatter of the comparative values, corresponding to the different 'cut-off curves' of the dust in the Tyndallometer and the TBF 50 (see Figs. 2 and 4). In addition, Table I shows the proportion of the amount of fine dust ($= 1,0$) to the amounts of coarse and the ultra-fine dust, calculated from the mass of the samples taken with the TBF 50. These relative figures have been shown to be suitable in practice for characterization of the size distribution of the airborne dust, for example where sedimentation analysis gives wrong results because of the many aggregates in the airborne dust. Figure 10 shows that the results obtained by the Tyndallometer can be converted, for a wide range of size distributions of the coal dust and of the rock dust, into mg/m^3 of respirable dust according to the TBF 50 (measuring series Nos. 2 to 5 and 7 for coal dust and Nos. 8 to 11 for rock dust). Deviations from the plotted centre line were greater mainly only for the fine dust (Nos. 6 and 12) and for coarse dust (No. 1) because of the different 'cut-off' curves for the dust in the two instruments in the size ranges < 2 and $> 7 \mu\text{m}$. Similarly, the influence of the different densities of the dusts (coal : $1,41$ and shale dust $2,78 \text{ g/cm}^3$) on the position of the comparative values should be apparent from Fig. 10, because of the different measuring principles of the two instruments; the differing densities do not affect the scattering of light by the dust, but do affect the separation of dust in the cyclones and the determination of the mass of the dust samples.

These influences could not be recognized during the measurements. Obviously, the differences caused by the density and the size distribution of the dust, balance each other out over a wide range of size distribution. The centre

line plotted in Fig. 10 is a 45° straight line. In other words the value given by the Tyndallometer is proportional to the concentration of fine dust for the range of the size distribution of both test dusts in the measured range of concentration from about 1 to 100 mg/m^3 fine dust. According to Breuer, Gebhart *et al.*,⁶ this statement holds down to the lower limit at which fine dust ($< 0,03 \text{ mg/m}^3$) can be detected.

Comparative measurements in coal mines

Comparative measurements have been started underground with the two instruments. The results obtained up to the time of writing, are plotted in Fig. 11 and data on the source, the ash contents and the size distribution of the dusts are shown in Table II. The line of best fit of Fig. 10 has been transferred to Fig. 11. Most of the comparative values obtained so far lie below this line. The majority of these results are for dust from workings where most of the airborne dust was produced during the transport of coal. This type of dust usually contains many aggregates and only very little fine dust (measurements Nos. 3 and 5). Dust as fine as that produced in the wind tunnel (Table I, No. 5 and 12) has not yet been found underground.

For comparison and assessment of the scatter of the values in Figs. 10 and 11, it should be borne in mind that the first measurements were made with the Tyndallometer and that the test conditions underground are much worse than those in the wind tunnel. In underground workings the dust concentration is usually not uniform over the duration of measurement and usually particle size distribution and dust concentrations at the point of measurement are very erratic. There are also errors of measurement and in analysis which may amount to about 10 per cent for each instrument.

Experience shows that the deposition of dust in the measuring chamber of the Tyndallometer, so far found to be unavoidable, can cause an increase of the reading of up to $\approx 0,1 \text{ mg/m}^3$ because of reflection of the light on this dust. This occurs when this instrument is used for several hours in high dust concentrations, without cleaning of the chamber. The deposition of very large individual and light-reflecting particles in the measuring chamber should be avoided at all costs as this could possibly have a drastic effect on the concentrations being measured. Any disturbances of the reading by deposition of dust in the measuring chamber can be detected easily by checking the zero-point of the instrument.

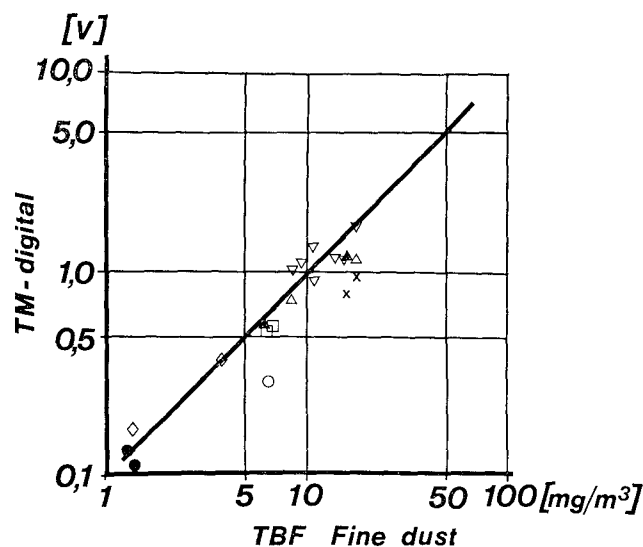


Fig. 11. Results of comparison measurements with the Tyndallometer and the TBF 50 in coal mine workings underground.

TABLE II
DATA ON COAL MINE DUST ACCORDING TO FIG. 11

Ser. No.	Symbol	No. of measurements	Source of dust	Ash contents of fine dust (in %) (by mass)	Proportional figures of the dust according to the TBF 50		
					Coarse	Fine	Ultra-fine
1	△	2	Stripping coal; getting	31	3,9	1	0,066
2	▲	2	Stripping coal; getting	37	10,4	1	0,041
3	○	1	Coal transport	15	6,6	1	0,085
4	□	2	Cutting coal; getting with pneumatic stowing	36	6,7	1	0,163
5	×	2	Cutting coal; getting	10,5	8,4	1	0,052
6	●	2	Stripping coal; getting, wet coal face, salt aerosols	19	2,03	1	0,113
7	▽	8	Cutting coal; getting with shield support	29,4	7,20	1	0,150
8	◇	1	Coal crushers	49	4,73	1	0,230
9	◇	1	Coal crushers	67	22,7	1	0,233

The expected influence of liquid aerosols on the reading shown by the Tyndallometer could be evaluated because the percentage of aerosol in the airborne dust was rather low, except in the case of measurement No. 6, and because these aerosol particles which, according to Fig. 4, have a diameter $< 1 \mu\text{m}$, affect the reading shown by the Tyndallometer to a much less extent than that of the Tyndalloscope. This is confirmed by measurement No. 6.

The studies in the wind tunnel and those underground will be continued on coal and other dusts in order to obtain further data for conversion of the Tyndallometer readings to mass values, and to acquire more experience in the application and suitability of this instrument in the mining and in other industries. These studies will be the subject of a report to be presented to supplement this paper at the Mine Ventilation Congress 1975 in Johannesburg.

ACKNOWLEDGEMENTS

The TBF 50 was developed by Bergbau-Forschung GmbH of Essen-Kray, the Engineering Bureau van Tongeren of Heemstede (Netherlands) and the manufacturer, Messrs. Mollidor and Müller, of Rodenkirchen, near Cologne.

The theoretical and experimental bases for the optical measurements of respirable dust in coal mines were compiled by the Bergbau-Forschung GmbH of Essen-Kray together with the Battelle-Institute of Frankfurt/Main. The manufacturing firm, Messrs. Ernst Leitz GmbH of Wetzlar participated in the development of the Tyndallometer TM digital.

This research and development work was carried out with the financial aid of the Land Nordrhein-Westfalen within the Federal Republic of Germany and of the Commission of European Communities.

TECHNICAL DATA OF THE TYNDALLOMETER TM DIGITAL

Principle of measurement: Tyndallometrically, 70° to the forward direction, monochromatic primary light of $0,94 \mu\text{m}$ wave length.

Method of Measurement: Principle of single light beam.

Indication: Digitally, with three figures after 13 seconds:

I 0 – 0,999 V

II 0 – 9,99 V

Data outputs: Analogue and digital.

Precision: Measuring range I better than ± 10 per cent ± 1 digit.

Measuring range II better than ± 5 per cent ± 1 digit.

Lower size limit for detection: $< 0,03 \text{ mg/m}^3$ (for dusts with a density 1 g/cm^3 with a maximum size distribution at about $1 \mu\text{m}$).

Dependence on temperature: < 5 per cent in the range from 0 to 40°C .

Possible applications:

I Hand measuring device with digital indication.

II Stationary measuring device with data recorded at the analogous and the digital output.

III Stationary measuring device with data recorded only at the analogous output.

Voltage in practice: D.C. voltage, 12 V.

Current consumption:

With possibility of application I 280 mA

With possibility of application II 270 mA

With possibility of application III 200 mA

Flame-proof protection: According to VDE 0170/171.

Dimensions and mass: $23 \text{ cm} \times 23 \text{ cm} \times 6 \text{ cm}$; about 2,5 kg.

Manufacturer: Messrs. Ernst Leitz GmbH, 6330 Wetzlar (Federal German Republic).

Battery: Intrinsically safe according to VDE 170 (VDE = Verein Deutscher Elektroingenieure (Association of German Electrical Engineers)).

Charging voltage: 21,5 V.

Charge rate: constant 180 mA.

Operating time: About 8 hours according to possibility of application III.

Dimensions and mass: $22 \text{ cm} \times 10 \text{ cm} \times 7 \text{ cm}$; 3,5 kg.

Manufacturer: Bergbau-Forschung GmbH (Mining Research Establishment), 43 Essen, Frillendorfer Strasse 351.

TECHNICAL DATA OF THE DUST SAMPLER TBF 50

Principle of measurement: Gravimetric dust sampling.

Method of measurement: Separation of the dust by two cyclones into coarse, fine and ultra-fine dust.

Assessment: By weighing of the samples.

Specific volume of aspiration Q : About 50 litres/min.

Possible applications:

- I. Battery operation (two-stage sampling).
- II. Operation with compressed air (two- or three-stage sampling).
- III. Operation with vacuum pump (two- or three-stage sampling).

Pressure loss p :

- ad I: 0,70 kPa.
- ad II: 20 resp. > 30 kPa.
- ad III: 20 resp. > 30 kPa.

Data for operation with battery:

- Voltage E: About 12 V.
- Current consumption I: About 220 mA.
- Charging voltage: 21,5 V.
- Charge rate: constant 200 mA.
- Operating time: Max. 9 hours.
- Flame-proof protection: Intrinsically safe according to VDE 0170/171.

Dimensions (including battery): About $33 \times 22 \times 7$ cm.

Mass (including battery): About 5,5 kg.

Mass of battery: About 3,4 kg.

Manufacturer: Messrs. Mollidor & Müller, 5038 Rodenkirchen (Federal German Republic), Weisser Strasse 161.

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