COMMISSION OF THE EUROPEAN COMMUNITIES

Technical measures of dust prevention and suppression in mines

Synthesis Report
on Research carried out
within the framework
of the Second Programme
1964 - 1970

LUXEMBURG 1972

SYNTHESIS REPORT

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1. DUST SUPPRESSION

Research in the field of technical measures of dust prevention and suppression in mining have gained increasing importance over the past years+). This resulted from the increase in the concentration of workings and output in mining and also from the introduction of new methods and machines generating extensive dust. In order to be able to suppress the anticipated dust generation in the future and, going beyond this, to reduce the incidence of dust in workings, the known methods of combating dust must be made more effective and be adapted to changing mining techniques. In addition, new methods of combating dust have to be developed especially in relation to such machines and methods for which the traditional methods do not suffice so as to ensure permissible dust conditions in workings. This applies for example to road-heading machines.

1.1 General research

This heading covers those research projects whose results have a general application and may therefore be used with almost all underground techniques.

Some of this research was concerned with further improving the effectiveness of water to precipitate suspended dust using finely diffused water drops and by increasing the water content of dust in loosened or conveyed product to facilitate its binding. The purpose of this was to ensure a minimal amount of suspended dust being generated during winning and conveying the product and thus entering the airstream or being stirred up by it.

+) BREUER H.: Measures against dust and silicosis related to concentration of workings and increased output. Glückauf 107 (1971) 14, pp. 514/19.

The effect of water in dust suppression is to be improved by wetting agents or other additives. Should it prove impossible to achieve satisfactory improvements even with these additional methods, the suspended dust will have to be aspirated and precipitated in dedusters. This applies particularly to roadheading machines. It is with this object in view that extensive research and development was undertaken.

1.1.1 Effectiveness of water in dust suppression

A certain quantity of water, with adequate time to become effective, is needed for a satisfactory wetting of the product in order to prevent the generation and stirring of dust. Both these factors depend on the properties of the water and the type and size distribution of the product. Earlier research of the Steinkohlenbergbauverein, Essen,+) into dust generation with pneumatic stowing has shown that water contents of between 4 and 6% of weight of the stowed product suffice to largely prevent the stirring up of dust, even given high relative velocities as between particles of product and blown air, such as occur in the stowing pipe. Pre-condition for this, however, is the thorough wetting of the product.

A good deal less promising was the precipitation of suspended dust in the air stream, judging by the results of theoretical and practical research into water drops. The effectiveness of the flat-jet sprays often used for this purpose has been investigated by the Steinkohlenbergbauverein, Essen, in a series of tests by the HOAG Bergbau (now Bergbau AG Oberhausen), (Research project 6251-13/1/002); this was done for relatively fine stone dust (40% weight $< 3 \mu m$) which can occur in shotfiring, pneumatic stowing and occasionally with cutting winning operations.

+) See Section 1.2.4.2

Figure 1 shows the test procedure in diagrammatic form. The cross-section of the dust tunnel is 7.5 m^2. Shale-dust - according to DIN 70 (German Standard) - was blown out in front of the fan through a dust feeder pipe, creating an average air stream velocity of up to 0.6 m/s in the tunnel. Sets of 2, 3 or 4 flat-jet sprays of the Lechler Company, Stuttgart, were inset into the road in such a way that the water drops reached every part of the tunnels' cross-section, but without acting against one another. Measuring devices were placed 12 m in front of and 24 m behind the jet area; these were tyndalloscopes and BAT 1 fine dust filters. The tests provided the following results of value to practical methods:

- The degree of effectiveness of dust precipiation decreases sharply with the reduction in the diameter of dust particles. It is, for example, reduced with an average air stream velocity of 0.6 m/s from 85% for particles of 5 μm to 20% for particles of 1 μm diameter size with a water flow pressure of 18.5 kp/cm^2 in 2 flat-jet sprays with drill hole diameters of 4 mm.
- In order to obtain a satisfactory effect in dust precipitation it is necessary to ensure a flow pressure of at least 10 kp/cm^2, but preferably of 20 kp/cm^2.
- Increasing air stream velocity means a lowering of the jet effectiveness despite a constant water feed, roughly in inverse proportion to the air stream velocity. This means that the degree of effectiveness depends primarily on the specific water throughput in litres of water per 3m^3 air. For example, a degree of effectiveness of 50% was achieved with a specific water consumption of 0.5 l/m^3 and a flow pressure of 10 Kp/cm^2. The degree of effectiveness rose with this specific water quantity to 65% with a flow pressure of 40 Kp/cm^2.

- By adding wetting agents to the jet water the effectiveness in bringing down the fine suspended dust is improved by very little. Wetting agents therefore, appear to be of little practical value in these conditions.
- Due to the very high specific water consumption needed to obtain a satisfactory degree of effectiveness this spraying method should only be used in very limited spaces, viz: at the point where suspended dust enters the air stream with shearer drums.
- The effectiveness of water drops to bring down suspended dust can only be increased by a very large increase in the relative velocities between water drops and dust particles. This occurs, for example, with dedusters working on the Venturi principle. With these, relative velocities of about 100 m/s are encountered.

1.1.2 Use of additives to water to improve wet dust suppression

A large number of agents may be added to water with the object of possible improvement in the dust conditions.

These agents can be classified into 4 groups depending on their physical properties and modus operandi:

- Wetting agents achieving quicker and more effective wetting of the dust by reducing the surface tension as compared with normal water. Important fields of application are, for example, the spraying of loosened product with drum shearers, drilling with water flushing and coalface infusion.
- Flocculating agents which achieve a faster and firmer adhesion of dust particles. These effects are, for example, important with pneumatic stowing where the binding forces of the dust particles in the stowed product can be easily overcome by the high relative velocities as between the blown air and product being stowed.

- Agents which reduce the evaporation rate of the water. Water used in dust suppression evaporates easily when the sprayed product is markedly warmer that the surrounding air. The consequent increase in moisture of the ventilation air can lead to adverse climatic conditions in warm pits.
- Agents which markedly increase the viscosity of the water. These can be used with coalface infusion in order to facilitate winning in seams which are firm and not much loosened by fissures. This also means that less dust is produced.

There is a large number of wetting agents and flocculants which are largely used in the soap and detergents industry. They can be subdivided into anion-active, cation-active and non-ionic substances.

Many of these substances have been tested by the Clinica del Lavoro, Milan, and the Turin Polytechnic for their suitability for use in drilling with water flushing and for pneumatic stowing (Research project 6251-25/4/021). For this purpose two models were used, a flotation cell and an abrasion chamber (Fig. 2), in which it was possible to reproduce the dust binding processes for the above mentioned fields of application. If one compares the results of the laboratory tests with the operating tests mentioned below,+) no satisfactory agreement among the results can be found. The differences are probably due in part to the measuring conditions in an operating test being a good deal less clear than with a laboratory test, while on the other hand, the influence of important factors cannot be adequately allowed for in a laboratory test. These include the type of surface of the product

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+) These and other tests with additives to water are reported in greater detail in the appropriate sections on dust suppression.

being treated, the properties of the water used, the accuracy of dosage of the wetting agents and finally the time the water takes to become effective when treating the product.

Nevertheless, the laboratory tests did enable those of the many available substances which held out any prospect of success to be identified. They also helped to establish the optimal percentages in which to add these substances for the operating test. For most substances this lies between 0.01 and 0.1%, occasionally very slightly above this. This information is important in establishing the likely cost of the use of wetting agents.

From the results of the tests known to date with additives, including those whose results were negative - and these have often not been published - the following conclusions can be drawn for future work:

- In investigating the interaction between the surface properties of solids and the specific properties of the additives in watery solution it should be noted that water often has natural additives. These are either in the water in the natural way or they are separated out of the treated product during use. This applies, for example, to salts from coal and the surrounding rock in seams in the Ruhr coalfield.
- From the results of this basic research a number of models may be developed for the experimental establishment of the suitability of additives for certain methods of dust suppression.
- The development of simple and reliable feed regulators for the additives is needed for carrying out operating tests in underground workings.
- The effects of these substances on the human body, especially on the functioning of the human lung, will

have to be investigated. They may be directly inhaled with the sprayed water and suspended dust or they may reach the lungs from the suspended dust generated by winning as is the case, for example, after coalface infusion where wetting agents have been used. These substances may have neutral, impairing or helpful effects in view of the changes in the dust-affected lung when combining with the inhaled dust.

1.1.3 Development and use of dedusters

In many underground workings it is becoming more and more important to aspirate the dusty air stream and to precipitate the dust so as to ensure acceptable dust conditions in the workings. Requirements for such dedusters are, in addition to satisfactory dedusting, primarily: appropriate size, low maintenance and unquestionably safe operation.

The known types of dedusters are divided according to their separating principle into four groups, electrically separating dedusters, gravity dedusters, filtering dedusters and wet dedusters; of these the electrically separating dedusters of standard design and operation have only a limited scope of application in mining operations. The method described in Section 1.1.4, as yet only examined in the laboratory, does offer the prospect of such electrical dedusters being used underground as well. The most usual form of gravity-operated dedusters is the cyclone, although its dedusting effect within the range of fine dusts is very limited. It is, therefore, limited in its use to precipitating coarse dust, by being used as preliminary deduster for filter dedusters. One application of this kind is the removal of sedimented dust +). On account

+) BAUER H.D.: Development and use of equipment to aspirate sedimented dust in underground working. Staub-Reinhaltung der Luft, 29 (1969) 3, pp. 118-23.

of the low effectiveness in the fine dust range the rotary current deduster, a high-performance gravity deduster, has also not so far found wider application in underground workings.

At fixed dust sources, such as in the shaft area, at loading points and crushers, where there is usually sufficient space, filter dedusters are used successfully. These dedusters have high degrees of effectiveness in the fine dust range, are reliable and need little maintenance. However, the loading out of dry dust is sometimes a problem.

The designed size follow from the small specific filter surface involved, which should not exceed 2 m^3 per m^2 of filter surface per minute with fine dust, and from the cleansing operation of the filters, which requires an enlargement of the filter surface.

When using filter dedusters to precipitate dusts liable to fire and explosion, such as coal dust, extensive safety precuations are necessary. These apply to measures to monitor the temperature and to extinguish in the event of fire.

For dedusting in cramped space conditions and with fine dust concentrations wet-operating dedusters have come into general use. In these the dust particles are brought into contact with water drops at air stream velocities of between 50 and 100 m/s. The resultant suspension medium is separated in an installed drip or medium separator using gravity forces.

Operating conditions underground require working with as small a quantity of water as possible. Testing trials showed that when using a specific quantity of water from 0.3 to 0.51 per m^3 of aspirated primary air, good contact between the dust particles and the water drops is achieved. The drop spectrum and the location and type of water feed into the crude gas stream are of great importance; sometimes the use of air-water jets can be of advantage.

Test rig trials at the Steinkohlenbergbauverein, Essen, (Research project 6251-24/1/004) have shown that, as seen in Figure 3, there is a clear interdependence between the separating performance and the energy expended with this type of wet dedusters +). In this way it is possible, by increasing the stream velocity, to reduce the designed size of the deduster.

The amount of air that has to be aspirated underground is usually between 100 and 400 m^3/min. The amount of water needed for this is between 30 and 200 l/min and can in most cases not simply be fed from the deduster at the point of use. For this reason extensive research has been done to create a recirculation system at the deduster. In the present state of this work the water produced in the medium separator is caught in container and pumped either directly to the jets or to a main water tank. In the latter case the medium is drained off by another pump and sprayed into the contact zone. To avoid the sedimentation of solids in the main water tank, continuous strong turbulence has to be produced in the liquid. This is achieved by the appropriate laying of the recirculation pipes.

+) Becker H., Breuer H. and Engels L.H.: Wet dedusters. Development, test rig trials, operating experience. In: Results of investigations in the field of dust suppression and combatting silicosis in coalmining. (Silicosis Report: North Rhine-Westphalia). Vol.7., Detmold, Bösmann 1969, pp. 107-114.

The solid matter in the medium, which has been separated in the deduster, is drained out of the system either by pumping away a certain quantity of the medium or through a "hydro-cyclone". The feed-in of fresh water is done by automatic float valves. This completes the water recirculation system; but as various underground operations have shown, it still requires a lot of maintenance and is too costly. Simpler methods should be sought. Instead of the water recirculation system a water throughput method is used and the medium drained directly out of the system through pipelines.

1.1.4 Development of suspended-particle filters

The Silicosis Research Institute, Bochum (Research project 6251-24/1/075), has developed a fine dust filter in which the dust is separated in an electrical field which is inhomogeneous. +) It is built up between layers of wire mesh which are covered with a synthetic material as an insulator. The direction of the field is changed by reversing the polarity at 30 second intervals.

With a laboratory filter a separation of 92% was achieved with an initial flow velocity of 10 cm/s for coal dust particles of 1 μm size diameter. The degree of separation depends on the electric charge of the dust particles. According to Figure 4 even particles with small charges are still separated up to 70% under the above-mentioned conditions.

+) Walkenhorst, W.: Considerations and investigations regarding the filtration of dusty gases with special reference to electrical forces.
Staub-Reinhaltung der Luft 29 (1969) 12, pp. 483-93.

The use of this method in workings liable to firedamp requires special safety precautions. According to the regulations on intrinsically safe electrical installations in the Federal Republic, the electrical energy stored in a condenser may not be greater than $2.8 \cdot 10^{-4}$ Wz. The proposed arrangement is a condenser of 600 V, which therefore has a maximum capacity of $1.56 \cdot 10^{-9}$ F; its resistance at the above voltage has to be at least $4 \cdot 10^{5}\ \Omega$.

The intention is to use this type of de-dusting in dust masks, for clearing spaces by filtration and certain tasks underground.

1.2 Dust suppression in the face

Research to improve dust suppression measures in the face have included the further development of coal face infusion, improvement in the effectiveness of pulsed-infusion shotfiring, methods of dust suppression with winning equipment and machines in workings using stripping and cutting coal winning and dust suppression when stowing.

1.2.1 Coal face infusion

In seam infusion the objective was to perfect existing methods +) and to develop new techniques and to carry forward the development of equipment for coal face infusion which would be better suited to new requirements. Research involved infusion from the face or from roadways or from roadways parallel to the working (advance remote infusion).

In particular, research was done to determine the differing effectiveness and techniques as between continuous and discontinuous infusion.

+) A schematic picture of coalface infusion methods according to the definition and classification adopted in the German Federal Republic is shown in Figure 5.

Laboratory and subsequent practical tests in mines have improved the knowledge of the effectiveness of certain additives to the infusion water such as wetting agents and salts. Similar tests were carried out using "tracers" to determine the waters flow direction and distribution in the seam.

Basic questions relating to the behaviour of water in the coalface during discontinuous infusion were resolved with the aid of a mathematical model which embodied all the findings of practical tests. Since the results of infusion depend on the operating parameters and given geological conditions, research was carried out into the effects of compressive stress on the coalface and into the suitability of infusion of seams with water-bearing surrounding rock and high gas emission.

1.2.1.1 General investigations

Investigations of the Faculté Polytechnique, Mons, (Research project 6251-/11-2-026)+), have made a valuable contribution to the study of the swelling of surrounding rock. The research programme included petrographic investigations of thin sections of rock, of the phyllitic matrix (ground matrix consisting of silicas) by means of differential thermal analysis and X-ray diffraction analysis.

The different physical properties of rocks were studied: moisture absorption with the aid of angle of contact measurement, the specific internal surface according to the nitrogen adsorption method (B.E.T. method) and microporosity and fissuration by mercury porosimetry. The per-

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+) F. Robaszinski: (Recherches sur la protection des épontes des couches de houille contre les effets de l'injection d'eau en veine) - Revue de l'Institut d'Hygiène des Mines, 1972.

meability of samples, in the form of drill cores of 22 mm in diameter and at least 20 mm in length, was measured by a specially constructed "permeameter" designed for pressures up to 200 Kg/cm^2. Lastly, the compressive strength of rocks was determined on the Schreiner method (Amsler apparatus) based on the breaking load obtained on penetration by a rod of 5 mm^2 area.

To establish the chemical properties of rock, the exchange capacity of cations was measured using the ammonium acetate saturation method, the amount of retained ammonium being determined by the Kjelldal micro-distiller. Certain shales were also examined by infra-red rays.

These studies have shown that the swelling of rocks under water impact is at its maximum when the quartz content is minimal and when the rock consists of open illite or is interstratified with layers of high china-clay content (20 to 50%). Swelling also occurs when the exchange between cations and the internal surface is high (8 to $10m^2/g$). Swelling and lift can also be expected when pores admitting water have a diameter of several microns.

The use of water-repellant additives, and those derived from the amino group, to infusion water has been considered as a possible way of reducing the swelling of surrounding rock. Phenomena superficially resembling lift are, however, produced by pressures caused by winning. These can largely be reduced by improving infusion and by judicious technical measures in winning and support.

A Steinkohlenbergbauverein research project (6251-11-1-007) was devoted to infusion methods in very gassy coal. It showed that the effect of infusion on normal methane emission is hardly measurable, bearing in mind that 90% of methane is linked to the coal by adsorption.

Fluctuations in the CH_4 content of the mine air depend not only on the different methane concentrations in coals but also on the types of winning; they can be markedly greater than the quantity of methane expelled from the coal pores following infusion.

According to certain findings of the Institut d'Hygiène des Mines de Hasselt (Research project 6251-11-2-032), there may be a relation between the chloride content of coal and its permeability, the latter controlling the emission of methane from the free pore area or its "trapping" in the seam.

The Institut d'Hygiène des Mines, in collaboration with the Institut National des Industries Extractives of Liège, is engaged in a study on this subject: "advance remote infusion in the seam and its effect on the behaviour of methane".

In the first experimental working the methane desorption indices (V_1 indices), measured over two months prior to the treatment of the panel and during six months following the start of advance remote infusion, have changed from 0.50 to 0.25 cm^3 /10g on average. Advance remote infusion, therefore, slows down methane desorption during winning operations.

When water is injected into very gassy seams it is found that infusion pressure is constant most of the time, occasionally increasing. Since methane expansion is possible after infusion is completed, special safety measures should be taken to prevent accidents and the flow back of water from the seam.

A sphere of research important for successful infusion is the distribution of water in the seam, as is also the study of binding between water and coal. Here, both laboratory and underground tests have been carried out in all the coal-producing countries of the Community.

The distribution of water in the seam was investigated by means of moisture tests on coal samples taken from the seam (drillings or channel samples) or on conveyors in the face. In the latter case the size consist is usually 0-10 mm. Results derived from drillings in the seam are often not significant, because the amount of water which enters the borehole is disproportionately high due to the methane pressure variations in the borehole. This feature has frequently been noted during the study of other problems, particularly in measurement of methane contents in coal.

In a study of the Silikose-Forschungsinstitut at Bochum (Research project 6251-11-1-074) it was found that there is a relation between pressures in the overlying strata and the coals susceptibility to drilling and infusion.

The slow-down in drilling speed resulting from the depth of the borehole does not only depend on "increasing coal resistance". To an important extent it is caused by the increasing weight of the drill-rods and the increasing distance the drillings have to travel.

In the trials done from the face, using a carriage-mounted drilling machine, a considerably greater reduction in drilling speed was noted in the middle part of the face than in the top or bottom third. This is probably due to the fact that here roof pressure and abutment pressure induce greater fissuration of the coal.

Recorded drilling times in the same borehole are maximum ones; Figure 6 shows two maximum times at depths of 10.5 m and 19.5 m.

This feature of seam stress during drilling is not always found so clearly when infusion pressure is measured. Certain findings of the Institut d'Hygiène des Mines (Research project 6251-11-2-030) have given maximum infusion pressures with depths of 10, 17 and over 20 m, i.e. in fissuration zones corresponding approximately to those in research projet 6251-11-1-074.

In all infusion tests special attention was focussed on damage to surrounding rock. It was found that high infusion pressures - which sometimes prove necessary when infusion with high water throughput has to be done due to lack of time - are a disadvantage, and for this reason alone further work should be done on continuous infusion methods.

1.2.1.2 Infusion methods from the face

Infusion techniques from the face are grouped in the Federal German Republic into shallow infusion, deep-hole infusion and remote infusion. In both France and Belgium they are defined as infusion in the zone of macro-fissuration or infusion in the zone of micro-fissuration.

With infusion at small or medium depths (zone of macro-fissuration) water is injected under pressure through boreholes perpendicular to the face and regularly spaced along the entire length of the face. With remote infusion (beyond the zone of macro-fissuration) two boreholes a day at the most are infused, whose length is at least that of a weeks' rate of advance in winning. The main difficulty lies in drilling in coal, across zones of considerable stress, creating great and sometimes insurmountable difficulties in faces with rapid advance.

Research carried out in Belgium (Research Project 6251-11-2-030) and in the Federal German Republic (Research projects 6251-11-1-45 and 6251-11-1-007) have shown the effectiveness of this technique and led to an improvement in drilling and remote infusion equipment.

In infusion from the face it was usual until recently to infuse the requisite quantity of water only during the infusion shift (generally at night) and not during winning shifts. A study carried out in France by CERCHAR (Research project 6251-11-3-066) aimed at replacing this discontinuous method by a low pressure infusion method. To this end two different techniques were used: one called the "multi-probe", the other, permanent infusion.

Multi-probe infusion has been used since 1966 in the Nord and Pas-ce-Calais coalfield; several probes are connected at one time to the same infusion pump and infusion takes place during several consecutive **shifts**. Water flow as between all the holes is kept approximately equal by inserting a flow-reducer into each probe (this may be a membrane); infused waterflow is generally between 5 and 10 l/min.

With permanent infusion, a method being studied since 1967, the infusion holes, from 12 to 15m deep, are connected to the face water supply. Infusion is under low pressure - 1 l/m approximately for each hole. Applied initially to faces being worked by pneumatic picks, this technique is equally suited to plough faces if the holes can be drilled high to clear the ploughs action. It is, however, scarcely applicable to drum shearer faces.

Further development in infusion equipment has concentrated on the improvement of electric pumps (Research project 6251-11-1-007), essential to effective infusion from the face in mechanised faces. For remote infusion new drilling equipment (Research project 6251-11-1-074) and feed regulators for infusion with additives (Research project 6251-11-1-077) have been improved.

1.2.1.3 Infusion parallel to the face

Depending on the type of winning adopted, winning faces are either advancing or retreating faces or a combination of both (Z pattern). Retreating faces give an opportunity of infusing as from the two gate roads; the Z-face, with at least one road driven before the exploitation of the panel begins, is also suitable for infusion by holes drilled parallel to the face+). Infusion from gateroads presents an enormous advantage compared with conventional infusion from the face: it in no ways impedes work in the face and can be carried out during winning shifts.

Studies into its suitability and effectiveness have been carried out in different geological conditions and differing types of exploitation by the following bodies: Stofinstituut van de Gezamenlijke Steenkolenmijnen, Limburg (Research Project 6251-11-6-058); l'Institut d'Hygiène des Mines de Hasselt (Research Project 6251-11-2-030); CERCHAR (Research projects 6251-11-3-062 and 6251-11-3-066); Steinkohlenbergbauverein (Research project 6251-11-1-007).

The dust-binding effect provided by this method is particularly good and consistent. The infused water is introduced into the coalface at a continuous rate and is usually only halted at weekends. Since the flow of infused water is considerably less (2 to 8 l/min per hole) than in discontinuous infusion from the face, the stresses created in the seam and surrounding rock are considerably reduced.

The drilling of infusion holes - at intervals of 15 to 60 m, 15 to 80 m deep, is generally effected by carriage - mounted drilling machines equipped with banded bits ensuring good flushing of fine drillings by water or compressed air. The sealing of the probe - sometimes a simple plastice hose - is effected by cementing the hole.

+) Becker H.: Silicosis Report - North Rhine-Westphalia Publishers: Detmold, Bösman, 1969, 7, 97/100.

Depending on the inclination of the hole or the methane content of the seam, special cement mixtures and cementing devices have to be used.

Infusion by a hole parallel to the face may continue for several weeks with interruptions during weekends. This is why the sealing of the probe is very important, all the more so because stoppages may also result from winning requirements. Tests have shown that in such conditions inflatable probes (which have become general for infusion at right angles to the face) are not recommended and are virtually impossible to re-use several times since their recovery is very difficult.

During a first stage infusion is effected by compressed air pumps; the flow is regulated by simple, hand-operated valves. Since a large quantity of water (up to 200 m^3) is injected, the operation has to be closely monitored by regular measurements of pressure and flow. In France infusion is also practised with low pressures by connecting the probes to the mine water supply. Pressure is about 10 to 20 bars which produces a throughput of about 1 l/min. To achieve the best results with this method infusion must be started long before the passage of the face (one to three months), but the water is better distributed in the coal if infusion is carried out under high pressure over a short period.

1.2.1.4 Advance remote infusion

Very extensive study and research into the factors governing the prevention method of advance remote infusion has been carried out in Belgium+) (Research project 6251-11-2-032). This method has also been tested in the German Federal Republic by the Steinkohlenbergbauverein (Research project 6251-11-1-007) and in the Netherlands by the Stofinstituut at Heerlen (Research project 6251-11-6-057). Compared with all other techniques advance remote infusion has the advantage of being completely independent of winning cycles, enabling a panel to be treated before winning is begun and all benches making it up to be reached, provided it is correctly carried out. Its application does presuppose a regular stratification without serious geological faults (at least in the panel to be treated). The studies have also shown that in certain circumstances this method of dust suppression is very effective and that the opportunity of applying it depends largely on good drilling and keeping the holes well sealed, as should also be done with infusion parallel to the face. Monitoring of the pumping installations is vital since they may be located in rarely visited sites. For this reason it is essential to use infusion pumps requiring little maintenance and equipped with special lubricating devices. In the Belgian tests, in addition to infusion holes (or adduction holes) outlet holes (or relaxation holes) were frequently drilled to ensure one flow direction for the water and to protect the roadway running above the seam.

+) Lavallée, H.: Assessment of certain features of deep deposits using advance remote infusion in seams of water absorbent coal. Annales des Mines de Belgique, 1969, 11, pp. 1173-1263.

Degueldre G. and Lavallée H.: Deep infusion in zones of microfissuration. Advance remote infusion or infusion of a panel prior to winning.
Rev. Inst. Hyg. Mines, 1965, 20, pp. 199-232.

Interesting variants of the normal advance remote infusion have been tried, particularly where, for reasons imposed by winning requirements, the roadways from which the holes were executed had to be dismantled or equipment withdrawn, which involved the moving back of the pumping station to another site. Another procedure consisted of drilling "ballistic holes" from the gateroads, i.e. drilling holes in the roof of the seam which would intentionaly be diverted to reach the seam at certain fixed points (this latter variant, it has to be admitted, is not compatible with the rapid advances of mechanised faces).

1.2.1.5 Investigations with additives to the infusion water

Due to more rapid daily advances (winning and loading out ever larger tonnages and the consequent introduction of ever more powerful machines) it has become necessary to try to increase the effectiveness of infusion by adding to the water certain substances to form a solution which would have better wetting and poorer evaporation properties.+)

The basic characteristics of these additives have already been examined (Section 1.1.2). The "quality" of the water therefore has a special importance particularly since mine water often contains salts in solution (for example, chlorides), the proportion of which modifies the wetting properties and the tendency of the water to evaporate. For this reason, when the effectiveness of additives is being studied, it is essential to control the composition of the solutions used. Bearing in mind the difficulties already mentioned in Section 1.1.2 of feed of additives, it is also necessary to maintain systematic

+) Bauer H. D.: Infusion with calcium chloride additives. Bergfreiheit 35 (197o) 2 , pp. 26-33.
Cartigny S. : Le comportement des inhibiteurs d'évaporation en présence de produits houillers. Rev. Inst. Hyg. Mines, 1968 , 23 , p. 79-124.

and regular dust measurements to recognise properly the fluctuations due to infusion conditions.

Two long series of measurements have been carried out in the German Federal Republic with a view to comparing exactly the dust conditions with or without addition of Ca Cl_2 with infusion parallel to the face (Research project 6251-11-1-077).

The use of evaporation-inhibitors - in the form of Ca Cl_2 solutions - tends to improve the air and assist dust suppression in faces with large outputs where the deterioration of climatic conditions and dust production are mainly due to the transport of the product won. In order to achieve a noticeable improvement in the climate, solutions of over 10% Ca Cl_2 have to be used.

The Institut d'Hygiène des Mines (Research project 6251-22-2-034/001) found that by infusing solutions of about 10% Ca Cl_2 from the face and achieving "humidification" of the coal between 5 to 20% lower than that obtained with water alone, dust suppression improved by 10% at least. In the same face with an output of 80 tonnes per hour, increases in absolute humidity and air enthalpy were reduced to such an extent that the practical effect achieved was comparable to that of a refrigeration plan operating at 125,000 units per hour in a 100 m long face.

In the German Federal Republic, "Relatin" and the experimental product L 9001 of the firm Henkel were used as highly viscous and structurally strong infusion liquids in order to build up higher infusion pressures. It was possible to demonstrate the basic suitability of infusion with highly viscous liquids; the development of equipment, particularly the blender, is not yet completed (Research project 6251-11-1-007).

1.2.2 Infusion shotfiring

Infusion shotfiring is a special technique for shotfiring in coal and rock+). When a shot is fired the detonation pressure is normally propagated directly through the wall of the borehole and the gas pressure used to loosen the material. In infusion shotfiring the pressure can be better transmitted by the infused water. To keep the empty spaces in the coal in the vicinity of the borehole constantly filled, the coalface is infused and the shot fired during infusion. The technique is thus a combination of infusion at low pressure with shotfiring.

In difficult working conditions effectiveness needs to be increased by prior high-pressure infusion to create the wide water distribution required for shotfiring. This was demonstrated in tests of the Steinkohlenbergbauverein, Essen (Research project 6251/13/1/009) in seams of high-volatile coal and a gas coal seam.

Compared with standard shotfiring infusion shotfiring has a number of advantages:

- dust production in shotfiring is effectively reduced;
- resulting from the different course of the gas pressure phase due to cooling of the explosion gases, the coal remains loosened and standing or it falls only into the conveyor track;
- the reduced shotfiring fumes produced make the method usable even while coal winning is in progress.

With infusion shotfiring a special explosive has to be used which is waterproof and can be detonated under water pressure. For example, the explosive permitted for this method in the German Federal Republic must be detonated when completly immersed in water, since otherwise

+) Prestar, F. and Becker H.: Infusion shotfiring in coal mines of the Ruhr. Nobel-Hefte 31 (1965) 1/2, pp.45/64.

ignition of CH_4 mixtures might occur. To check on this immersion in water at the moment of firing the Stein kohlenbergbauverein, Essen (Research project 6251-13/1/009) tested various methods. First, the fact that a measurable water pressure exists in the zone of the bore-hole to be charged suggested that water immersion could be checked by means of a pressure gauge, but the water pressure in the borehole proved to be so variable that this method is not satisfactory. Other developments used float switches. This system failed where borehole incli-nations and water pressures varied. Then the difference in electrical resistance between air and water were used to monitor the water content of the borehole. This system itself proved suitable but due to basic objections the Mining Inspectorate's permission was not given.

At present the water pressure in front of the bore-hole and the water flow in the feed to each borehole are established during and after firing the shot using a flow indicator. In a new technique water immersion of the explosive is ensured by sheathing it in a type water-containing ampoule. This technique has not yet been applied in the ECSC.

Studies by the Steinkohlenbergbauverein, Essen (Research project 6251-13/1/009) have shown that infusion shotfiring can be successfully employed to overcome starting up in mechanised faces and in plough faces with hard coal or not easily ploughable rock inclusions, in cutting coal in stable holes of faces and in rise headings. In some cases it was also used tobreak up roof coal in faces with drum shearer-loaders to prevent hold-ups in conveying caused by unduly large pieces of coal.

In an experimental working the area face advance could be raised from 0,55 to 0.91 m^2/min. To achieve a rate of advance of 2.2 m per day the number of winning shifts, before using infusion shotfiring, was 2.5 and after,1.6. Dust concentration in this trial was reduced by some 50%. It proved to be more economic and safer to fire shots singly rather than several simultaneously.

Application in steep and semi-steep formations requires a special technique involving detonator chords to make the method practicable. Such detonators are not allowed for these purposes in coalmining in the Federal Republic.

In rock the method can only be used if there is adequate water distribution when infusing. Since this rarely occurs the method is of little value to blasting in rock.

Infusion shotfiring has been widely employed in Belgium and France. In Belgium the Institut d'Hygiène des Mines, Hasselt, went on to investigate the use of this method in seams liable to sudden gas outbursts (Research 6251-11/2/031). In the German coal industry it is used far less frequently and is now scarcely employed due to the high outlay in men and materials.

In the Research projects 6251-11/1/007 of the Steinkohlenbergbauverein, Essen, and 6251-11/1/045 of the Silikoseforschungsinstitut, Bochum, the possibility of using tracers in the infusion water was studied in order to clarify the processes involved in coal wetting. In the investigation of radioactive substances, inorganic and organic dyes, salts and wetting agents in the coalface and in laboratories it was found that apparently only salts, wetting agents and the organic dye "uranin" lend themselves to this purpose because with all other substances adsorption to coal is too great. Even with these three it has as yet proved impossible to provide quantitative indication about water distribution in the coalface.

It is known that coalface infusion by its loosening of the coal can provide a measurable easement in winning. Therefore coal treated in this way should produce less dust. CERCHAR, Paris (Research projects 6251-11/3/066 and 6251-11/3/062) has investigated pulsed infusion+) - a method aiming to loosen the coal - with room and pillar working and developed it to the point of practical application.

+) Labus, K.: Advances in coalface infusion due to the high-pressure pulsed infusion method. Glückauf 105 (1969) 17, pp. 814/19.

Documents techniques des Charbonnages de France: Infusion shotfiring or water-assisted shotfiring, N° 7, 1968, pp. 377-95.

Bigourd, J.: Safety of water infusion shotfiring, Documents Techniques des Charbonnages de France, 1966, N°12

Cocu J., Bigourd J., Giltaire M.: Shotfiring in Water. Revue de l'Industrie Minérale, 47(1965) No 9 (Sept.) Explosives for shotfiring under water pressure. Paper presented at the 36th International Congress of Industrial chemistry (Brussels, September 1966).

Cochet B.: Shotfiring under water pressure and with rams. Doc. Techn. des Charbonnages de France (1965), N° 8, pp. 405-7.

Ioss and Verne: New methods of shotfiring under water pressure. Revue de l'Industrie Minérale, July 1964, pp. 593-612.

Brassac Group: Shotfiring tests under water pressure in steep workings. Doc. Techn. des Charbonnages de France, N° 12 (1963), pp. 743-7.

Nord and Pas-de-Calais Coalfield: Shotfiring under water pressure in the Valenciennes group. Documents Techniques, N° 4, 1962, pp. 129-48. Explosifs, N° 1, 1963, pp. 18-34.

1.2.3 Dust suppression on winning equipment and machines

1.2.3.1 Dust suppression in plough workings

Spraying of the plough track will be increasingly important in the future, being an auxiliary method where-ever coalface infusion cannot be employed. In winning faces producing much dust it is sometimes used as an additional dust suppression method.

Research into plough faces with different spraying systems, with the focus on automated spraying, has been carried out in the German Federal Republic (Research project 6251-12/1/043, Silikose-Forschungsinstitut, Bochum), the Netherlands (Research project 6251-21/6/051, Stof-instituut, Limburg) and in France (Research project 6251-12/3/064, CERCHAR, Paris).

Activation of the valves in plough track spraying was first based on the conveyors' movement to allow the plough to pass. This principle was chosen because it could be used with all plough installations except the "Gleithobel".

Some problems were created by dirty and corrosive underground water. It was also found that this type of plough track spraying could hardly be used with soft, easily ploughable coal as the movement of the conveyor did not suffice to trip the spraying system.

In France, a continuous spraying method has been widely adopted using jets spaced the length of the armoured flexible conveyor (CERCHAR publication n° 1734). A valve which the plough operator can operate, or an electric valve linked to the plough drive, enables spraying to take place only while the coal is being won.

The Bochum Silikose-Forschungsinstitut investigated pressure-operated valves, based on the idea that the higher pressure occuring in the pusher ram during passage of the plough could be used to trip the sprays. This was discontinued because the pressure in the pusher ram is already so high that the 10 Kp/cm^2 increase in pressure required to trip the sprays is not available.

High-pressure pumps operated by compressed air are often used to activate the pusher rams. Switches on the pumps cause strong pressure variations in the hydraulics system so that the pressure change in the pusher ram cannot be definitely attributed to the passage of the plough.

Then a spray tripping device was developed, which was independent of the pressures in the pusher ram, in which tripping was mechanical. This device was also unreliable in operation because the lever tripping arrangementment became clogged, mainly by dirt.

The lever arrangement is replaced in a new development by magnetic force transmission, producing a considerable improvement in tripping and consequently greater reliability in the spraying system.

Some basic consideration of the effectiveness of plough track spraying is indicated to direct further development. This should establish whether the effect of spraying is due to the wetting of the loosened coal on the conveyor or to cleansing of the air stream by diffused water drops. Solution of this problem will no doubt also influence the design of spraying systems and finally resolve the suitability of automated plough track spraying.

Particularly noteworthy is the research carried out in the United Kingdom to spray the plough from the plough body itself, thereby opening up a different prospect of automation.

1.2.3.2 Dust suppression with drum shearers

Research into dust suppression in winning operations with drum cutter loaders had three tasks:

- improving the winning and loading process of coal to reduce dust production,
- improving the effectiveness of spraying systems,
- installation of dedusters on the winning machine.

In an experimental working the Steinkohlenbergbauverein, Essen (Research project 6251-12/1/008) investigated the speed of the machine, cutting width and rotation speed of the drum, nature of the coal cut and quantity of ventilation air as factors affecting the production of fine dust at the drum cutter loader+). It was found that with constant machine speed but increased drum rotation speed the production of fine dust increases considerably (see Figure 7a). Reason for this is reduced depth of web and consequent greater degradation of the coal. Dust production increases when the loosened amount of coalis so large that it cannot be rapidly discharged by the drum, leading to further serious degradation.

Like increasing machine speed and depth of web, increased cutting depth also leads to reduced fine dust production, as can be seen in Figure 7b.

Particularly difficult dust conditions occur when the surrounding rock is cut, especially in the roof. The resulting rock dust is usually very fine.

The ventilation stream in this experimental working lay between 600 and 1100 m^3/min. With increases in ventilation and consequent greater ventilation velocity in the face, the fine dust concentration rose from 100

+) Heiermann, H.:Investigations into dust production and size distribution with drum cutter loaders using statistical methods. Thesis, Clausthal, 1967.

at 600 m^3/min to 175 at 1100 m^3/min, as can be seen in Figure 8a, curve 4. No water was, however, being used for dust suppression in the face. As the ventilation velocity increased, more and more dust was raised from the loosened product.

Other investigations in workings with ploughs and drum cutter loaders have shown that wet dust suppression (coalface infusion, spraying), reflected in the moisture content of the transported product, is of extreme importance to the formation of fine dust+) (figure 8b).

With coarse dust an even better effect was obtained with a reduction in concentration of up to 95%, if the use of internal spraying had increased the initial moisture from between 2 to 3% weight to 6% with cut product of $<$10 mm.

CERCHAR, Paris (research project 6251-12/3/064) developed a new external spraying device which can be directed towards points of dust production during operations.

Underground tests of the Steinkohlenbergbauverein, Essen (Research project 6251-12/1/008) with this device, together with other systems of internal and external spraying, have shown that an adequate water pressure in the jets is an essential condition for effective dust suppression with drum cutter loaders.

These tests achieved a water pressure of between 15 and 20 Kp/cm^2 in the jets by the use of pumps in the machines' water supply system.

Comparative tests with internal spraying with water emission through perforated picks from the body of the machine showed no significant differences in effectiveness.

+) See footnote on page 5

In a fat coal working of the Saarbergwerke AG, Saarbrücken, the Silikose-Forschungsinstitut, Bochum (Research project 6251-12/1/071), the effectiveness of wetting agents as additives to the sprayed water was tested on an EW 170 L drum cutter loader of Eickhoff, Bochum. Using 100 l/min water throughput containing about 0,1% wetting agents the tyndallometric fine dust concentration could be reduced by roughly 30%. This compared with spraying with a water throughput of 200 l/min but without wetting additives+).

Special investigations were aimed at developing devices to dedust drum cutter loaders.

At the start of this programme CERCHAR, Paris (Research project 6251-12/3/064) developed a dust filter for a drum cutter loader, type S16, using oil-soaked metal shavings as filtering material.

The Silikose-Forschungsinstitut, Bochum (Research project 6251-12/1/044) first tried aspiration without deduster on such a machine in iron ore mines. These showed that an aspirated partial ventilation stream of 100 m^3/min was sufficient to trap most of the dust, the ventilation velocity being below 1 m/s in the face. Dedusting was effected by a rotating current device, made up of several components, of the Rüskamp firm, Bayreuth; this however captured too small an airstream - at 60 m^3/min - and its performance was reduced by intake of coarse dust. It could be established that the "insulation" of the drum is particularly important so as to limit the quantity aspirated. In order to clarify aspiration conditions with drum cutter loaders the Steinkohlenbergbauverein, Essen (Research project 6251-12/1/008) built a 1:10 scale model of a face.

+) Bauer, H.D. and Klinker H.G.: The effectiveness of surface-active substances in wet dust suppression with drum cutter loaders. Glückauf 107 (1971) 5, pp. 161/69.

In addition, a drum cutter loader, EW 170 L of Eickhoff, was provided with an aspiration device consisting of an intake duct and a fan. This was to determine the required amount to be aspirated and the number and positioning of the aspirating points (Research projects of the Silikose-Forschungsinstitut, Bochum (6251-12/1/073) and the Steinkohlenbergbauverein, Essen (6251-12/1/008).

As part of this research extensive testing investigations were made of the "Rotovent" deduster of the firm Hölter & Co., Gladbeck, various modifications giving improved performance. Details are given in section 1.3.2.3. At the end of the research period an aspiration device equipped with a "rotovent" deduster for a double-drum cuter loader, EDW 170 L of Eickhoff, was completed and submitted to testing trials.

The design of dedusting devices involved the solution of special problems. The length of the device had to be kept as short as possible and any structural changes in the winning machine had to be kept to a minimum. Use of the deduster requires a following "trailer"+) which entails a greater length of stable hole in the face. Power supply for a dedusting system is difficult in workings with a voltage of 500, because the power required lies between 50 and 70 Kw and can thus curtail the winning capacity of the machine. Generally speaking the employment of wet dedusters with drum cutter loaders requires special measures to ensure water supply and remove the resultant slurry. The release of clean air should not stir up the dust; a reduction in fan noise is also important.

Underground trials will begin at the end of 1971.

+) The "trailer" consists of deduster, fan and motor with an approximate length of 12 m.

1.2.4 Additional dust suppression measures in the face

One of the results of the need for concentrated workings and increased output has been multi-shift coal winning. This means a build-up in dust production in winning and filling the worked out area+). The latter operation means high ash contents and usually also relatively high quartz contents in the fine dust.

In caving attention should be paid that the stirring up of dust is avoided when the roof coal comes down. An important measure here is the spraying of the caving area. In pneumatic stowing it is important to avoid degradation and abrasion of the product in the pneumatic pipe as also stirring up dust from the stowed material in its impact on the slope. Reduced dust production is achieved chiefly by choice of suitable stowing material, wetting of stowing material and stowing area before pneumatic stowing begins and by improvements in the layout and operation of pneumatic stowing installations.

1.2.4.1 Caving

The possible great influence of caving on dust levels in the face was shown in the Netherlands coal industry (Research project 6251-21/6/051, Stofinstituut, Limburg) with the aid of dust measurements in 15 faces with pneumatic pick exploitation, winning and withdrawal occuring at different times. Although the concentration during withdrawal was on average only 50% of the values during winning, the weight ratio for particles $< 5\,\mu m$ in the total dust was higher by about a factor of 1.4, the ash content by about 2 and the quartz content by a factor of > 3 higher than with dust produced during winning.

+) See footnote on page 5

Measurements showed the need to reduce considerably the dust levels in the caving area during withdrawal by effective measures.

Development of an automatic spraying system, dependent for its operation on the counter-pressure of the conveyor on the pneumatic pusher rams during plough passage, was abandoned once hydraulically operated pusher rams came into general use. With those the low compressibility of the hydraulic liquid produces no displacement or one too slight to trip the spraying system+).

Since 1968, therefore, a new spraying system has been developed in which the caving area is automatically and intensively sprayed during forward movement of the frames, i.e. at a point in time and in a zone representing the major dust source. This automatic process avoids the spraying installations not being started, the system being stopped prematurely and excess water being sprayed.

The spraying installation is firmly linked to the hydraulic powered supports. The operating valve is connected to the high-pressure emulsion system of the supports and to the water supply. The jets are attached to its outlet.

Details of the operating valve can be seen in Fig. 9. The emulsion for the support is fed through piping (1) to the valve, the water supply is connected at (2), the feed to the jets is shown at (3). While the support is under pressure the emulsion presses upwards against the lever (4) which presses a ball (5) into the duct for the water supply. When the support unit is moved the emulsion pressure drops causing the water pressure to press the ball downward thereby feeding the jets.

+) Similar features have already been noted in connection with plough track spraying (Section 1.2.3.1)

If necessary a time-lag mechanism can be built in so that spraying can continue for a time after the support unit has been moved.

Since this system of spraying has clearly proved successful, its employment in other coalfields is recommended.

In future special attention should be given to the dust created when operating powered supports by rock falling on to the lowered roof bars during advance and being crushed small when these are pressed against the roof, the resultant dust being exposed to the ventilation stream during the next lowering.

1.2.4.2 Pneumatic stowing

Dust suppression during pneumatic stowing was already the subject of extensive research in the 1st Research Programme+) on a test rig of the Steinkohlenbergbauverein, Essen, and in underground workings which yielded useful indications how to reduce dust formation, during pneumatic stowing++). These helped to improve dust conditions considerably. The most important measures of dust suppression with pneumatic stowing may be recapitulated here in view of the fact that some of the new research is based on these results.

+) ECSC - High Authority. Technical Measures of Dust Prevention and Dust Suppression in Mines, Vol. I. Series on Occupational Hygiene and Medicine, Luxembourg. Publications Department of the European Communities 3890/1/66/1 (I), 1966, pp. 34-36.

++) Breuer H.: Investigating the causes of dust formation in pneumatic stowing. Glückauf - Forschungshefte 26 (1962) 4, pp. 177-85.

- The specific consumption of stowing air in Nm^3 per m^3 stowing material is to be kept as low as possible. This prevents the formation of suspended dust through further degradation during transport of the product in the stowing line and when making impact on the slope of the stowing material.
- The stowing material must not be too coarse. As the upper size of the particles in the stowing material increases, stowing air consumption, dust formation and wear on the stowing line increases.
- The stowing material such as sandstone, which is strongly dust-forming, should either not be used or only with less dust-forming material.
- The stowing material must be sufficiently moist during transport to the stower and prior to pneumatic stowing. With an upper particle size of 60 mm a water content of between 4 and 6% weight is sufficient.

The three latter requirements can be met by sound organisation in preparing the stowing material. The most important measure is to keep the stowing air consumption as low as possible and this is difficult since it depends on frequently changing factors such as quantity and nature of the stowing material, length and condition of the pneumatic stowing line. To ensure this, fully automatic devices to control the stowing air consumption should be used.

Part of the new research is devoted to the question whether the results obtained for stowing material in coalmining can be applied to other material, for example, in iron ore mining. To this end tests were carried out by the Turin Polytechnic+) on a laboratory scale with a narrow

+) Occella E., Pelizza S. and Vaiani G.: Technical measures against dust during pneumatic stowing. Paper read at the International Dust Suppression in Mines Conference, Gottwaldov (Czechoslovakia, 1970).

size range of stowing material from the Toscana pyrites mines (granite, shale, marly limestone, limestone) (Research project 6251-21/4/019) with the following findings:

- Dust formation during transport of material resulting from abrasion increases as the average particle size of the stowing material decreases.
- The quartz content of the fine dust produced by abrasion is very different from that of the initial material, the size consist of the material used having an apparent effect on this as well. This is particularly true of shale whose quartz content in the dust is markedly higher than in the original material.
- The addition of a little water to the dry material increases dust formation to a peak figure, but reduces sharply with increased watering until it reaches a value which is below that of dry material.
- The addition of tension-altering substances to the water in concentrations of 0.01 to 0.1% reduces dust formation by approximately 15 to 25%. Such a reduction has also been demonstrated in an operational test in a pyrites mine using the wetting agent "Flokal".
- Wetting agents have differing degrees of selective effects on the dust binding of minerals contained in dust. It is, therefore, quite possible that a reduction of the overall fine dust concentration is linked to a rise in quartz content.
- The surrounding rock of Ruhr coals (argillaceous shales) used for comparison showed considerably higher dust formation than the stowing material from the Italian pyrites mines.

The above mentioned influence of the stowing materials' size consist on dust formation appears to contradict the results obtained in coalmining. The latter had shown that preferably small sized stowing material, whose diameter is suited to the diameter of the pneumatic stowing line, should be used. Small sized material clearly often contains a high percentage of dust-like material, which must be well wetted to prevent it entering into suspension. If this is not done, dust formation is increased to a level where the degradation effect of the material during pneumatic stowing no longer affects dust formation. On the other hand the well wetted, dust-like part of the stowing material makes an important contribution to levelling out the speed of movement of the different sized material on the pneumatic stowing pipe. The lower the relative velocity of individual particles of material is compared with the stowing air, the rarer will the collision of these particles be in the pneumatic stowing pipe, a collision which otherwise leads to degradation and dust formation.

It is worth noting here that in the Saar+) coalfield fine dust formation during pneumatic stowing has been reduced by about the same percentage as in the above-mentioned test in the Toscana pyrites mines by the addition of wetting agents to the spraying water.

A different approach to improving dust conditions during pneumatic stowing to complement the above-mentioned measures was made by the Silikose-Forschungsinstitut, Bochum (Research project 6251-21/1/038). The assumption was that the addition of a paste - trade name "Tratex" -

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+) Klinkner, H.G. and Bauer, H.D.: Tests to improve dust suppression during pneumatic stowing, with particular reference to the use of surface-active substances. Bergfreiheit 34 (1969) 8, pp. 198-202.

could completely bind the dust contained in the stowing material and reduce abrasion. Operational tests+) with this paste showed that, in optimum conditions, a 30% improvement in effectiveness is obtained compared with untreated water. Essential for this is an adequate quantity of paste (at least 20 kg paste per cubic meter of stowing material) and thorough maxing of paste and stowing material. Special apparatus is required to manufacture and mix paste and stowing material. The stowing material must not be too wet before adding the paste and should not be sprayed afterwards to prevent the paste being washed out. The addition of the paste needs constant supervision and has to be adapted to the composition of the stowing material in each case.

Another starting point for improving dust conditions during pneumatic stowing is the practice of precipitating the fine suspended dust issuing from the stowing line with the stowing air by spraying. Since the expelled stowing air often has an air velocity of over 100 m/s, the prospect of precipitating the usually very fine suspended dust in the stowing air stream with water drops is very small. This assumption was confirmed by several tests in different faces in the Netherlands mines by the Stofinstituut, Limburg (Research project 6251-21/6/056).

1.3 Dust suppression other than at the face

Dust suppression other than at the face was primarily concerned with road heading. In conventional road heading with shotfiring, investigations included those into drilling with water flushing, into factors affecting dust formation during shotfiring, into stemming materials

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+) Landwehr, M. and Bauer, H.D.: Improving dust suppression during pneumatic stowing by addition of paste to the stowing material. Bergfreiheit 31 (1966) 7, pp.181-192.

and the composition of shotfiring fumes. Special weight was attached to dust suppression on roadway heading machines, partial or full-facers. For these, wet mechanical dedusters were developed, ventilation being given special consideration.

Importance was also given to dust suppression in transport, particularly at transfer and loading points. In this connection the use of evaporation-retardants was tested in some instances. Possible solutions for removing sedimented dust in gate-roads were put forward.

1.3.1. Dust suppression during road heading

1.3.1.1. Road heading using shotfiring

Measures to reduce dust formation during conventional road heading have been the subject of a series of investigations dealing with drilling with water flushing, ventilation of stone-drifts, the shotfiring process itself and with measures to combat the dusts and gases occuring after the shots have been fired.

When drilling with flushing the dust formed at the cutting edge of the bit is normally bound by a water outlet at that point. Improvements in this dust binding can be achieved by creating a number of water-barrier rings as investigations in the iron ore mines of Italy of the Clinica del Lavoro, Milan, have shown (Research project 6251-25/4/024). Technically there is a limit to the number of water outlets that can be made due to the durability of the cutting edge. Two outlets at the cutting edge proved still feasible, set diammetrically. Their distance should be 5 cm and the diameter of the second aperture 10% greater than the first. In these optimum conditions an increase in effectiveness of 25 to 35% was found compared with a bit with only one aperture.

In suction ventilation of roadways, fine dust concentrations near the heading face can reach high levels despite effective wet drilling if the released dust is not aspirated quickly enough or if a ventilation circuit is formed. Suspended dust of this kind can only be aspirated effectively if the air duct opening is at a distance from the heading face. As shown by tests of the Clinica del Lavoro, Milan (Research project 6251-25/4/023) in an experimental roadway, fine dust concentrations in the vicinity of the drilling machine decrease with reduced distance within 10 m between the heading face and the aspiratory mouth of the air duct: relative values of dust concentration reduce from 100 at 10 m to 50 at 4.2 m, to 10 at 0.5 m distance between heading face and air duct. For practical purposes it is therefore important to avoid the creation of a so-called "dead zone" in working areas near the heading face in roadways with suction ventilation; this occurs if the distance between the air duct opening and the heading face is too great. The proposal is to extend the air ducting by an additional section so far forward that its opening is at most 2 m from the heading face. When shots are fired the extension is removed.

A number of technical factors affecting dust formation during shotfiring have been investigated by the Steinkohlenbergbauverein, Essen (Research project 6251-13/1/002) in gate roads: type of explosive, number of shots, type of sumping, depth of pull. To determine the effect of these factors others - such as ventilation, dust suppression using dust binding stemming and spraying the deposited dust - have to be kept constant.

Results of these investigations are as follows:

- Fine dust formation increased in a ratio of 100 to 180 as the use of safety explosives moved from weak explosives (Class III) to powerful (Class I). The choice of explosive - its blasting power adapted to rock and coal -

can in itself reduce dust formation considerably.

- As the number of rounds needed to achieve a pull increases so does the total amount of dust formed. For example, the specific fine dust formation per m^3 of pull rose from 100 with one round to 135 with two and 175 with three rounds. Unless there are other important considerations against this, one pull should be obtained with a single round.
- Dust formation with different types of sumping depends largely on the amount of explosive required. Large amounts of explosive for sumping produce intensive fragmentation and high dust levels (Figure 10). Staggered wedge cuts and shotfiring with one large borehole yielded relatively low fine dust formation.
- Sumping should be as long as possible, increased length resulting in much reduced fine dust formation (Fig. 11).

The routine measurements carried out in a number of gate roads in special experimental workings following these tests showed that dust formation during shotfiring and winning is much greater in fat coal than in high-volatile coal. Even within one group of seams marked differences can occur,caused by differing seam and surrounding rock properties.

During shotfiring in roadway headings increasing use is being made of dust-binding stemming in the form of water or paste ampoules. In the mines of the German Federal Republic the use of this type of stemming need no longer be accompanied by the traditional mist screen zones, since investigations by the Silikose-Forschungsinstitut, Bochum (Research project 6251-23/1/040) demonstrated that the effectiveness of these dust-binding stemmings are roughly equal to that of the mist screens. The latter also have an unfavourable effect on the surrounding rock, if this is liable to swelling, and on climatic conditions.

CERCHAR, Paris (Research project 6251-23/3/065) has made extensive tests in French mines using different stemming materials in widely differing conditions. Due to the great disparity of individual results these tests did not give a clear indication of the effect of the type of stemming (normal stemming, water ampoules or paste ampoules) on dust formation during shotfiring. At least some 40 tests capable of proper evaluation would have had to be carried out to obtain reliable results.

As part of these tests a new type of spraying system was also tried out, which enables a very finely diffused mist screen to be produced in the vicinity of the heading face. This spraying system normally operates for half an hour and has a water consumption of approximately 300 l min. Average effectiveness was about 30%. It is noteworthy that the nitrous gas content ($NO + NO_2$) was reduced by roughly the same percentage.

Extensive research into the formation of nitrous gases and possibly hydrochloric acid during combustion of explosives has been carried out by the Institut National des Industries Extractives, Liège, Division Pâturages (Research project 6251-23/2/036). The original assumption was that, by altering the basic constituents of safety explosives ($KNO_3/NH_4\,Cl$ and $NH_4\,NO_3/NH4\,Cl$) the formation of nitrous gases could largely be obviated. To study this relationship an experimental apparatus was constructed, consisting of a stainless steel "bomb" equipped with a valve to draw off combustion gases and a measuring device to establish the power of the explosion and speed of reaction by measuring variations in pressures (created during combustion of the mixtures under review). The resultant gases and vapours were trapped in two glass containers containing either distilled water or hydrogen peroxide to dissolve the harmful constituents of combustion gases. The nitrite and chloride ions formed in this solution were analysed by colorimeter or complexometer.

Subsequently, a more exact analysis of the nitric oxide and hydrochloric acid was carried out using infrared absorption spectometry. To implement these processes numerous tests and trials had to be undertaken.

Tests made with different explosives mixtures yielded the following conclusions:

- The best results were obtained with a mixture ratio of 1,5 parts NH_4Cl and 1 part KNO_3.
- With this ammonia-rich mixture a marked reduction of nitric oxide in the shotfiring fumes can be anticipated as compared with an equi-molecular mixture and no traces of hydrochloric acid are found in the combustion gases.
- The combustion rate increases by about 20% with a mixture rich in ammonia.

1.3.1.2 Dust suppression with mechanised roadheading

In the last few years especially, roadheading machines have increasingly come into use and their importance will grow in the future. As the trials of dust suppression methods with heading machines - partial or full-facers - have shown conventional methods such as spraying, wetting and ventilation when cutting through rock in these heading do not suffice to contain dust within permissible limits and it is necessary to aspirate the dust forming at the heading face and precipitate it in a deduster+). Since the dust produced

+) Becker, H.: Development and testing of dedusters for machines with high dust formation. Contained in: Results of investigations into measures against dust and silicosis in coalmining. (Silicosis Report North Rhine - Westphalia). Vol. 8 Essen: Verlag Glückauf 1971, pp. 23-29.

when cutting rock is very fine, the dedusting devices used in such seams must have a high separation performance. The research carried out by the Steinkohlenbergbauverein, Essen (Research project 6251-24/1/004) and by CERCHAR, Paris (Research project 6251-12/3/064) was aimed at developing dedusting installations which would meet the above requirements when driving roadways with heading machines.

This also involved devising aspirating systems, usable both with partial and full-facer heading machines, adapted to ventilation currents of between 100 and 400 m^3/min. The suspended dust produced in cutting must be completely trapped in the immediate vicinity of the heading face and within range of the cutting tools of the heading machine. To achieve this it is necessary - in addition to an effective placing of the aspirating ducts - to adapt the aspirating and dedusting system to the roadway drivage ventilation system in an appropriate way. As a general rule road headings have either suction or forcing ventilation. With suction auxilliary ventilation, normally only used in short drivages, the dust-bearing air is purified in a deduster which is either stationary or built in to the suction air duct close to the heading face (Research project 6251-12/3/064 of CERCHAR, Paris)+).

In the German Federal Republic mechanised road headings are almost exclusively ventilated by the forcing ventilation method. The dust aspirated at the heading face is precipitated in a deduster accompanying the roadway heading machine. The purified air is released into the roadway immediately behind the deduster and mixes there with the remainder of the fresh-air current whose volume exceeds that of aspirated air at the heading face (Figure 12). The dust concentration resulting from mixing is a product of the dust content and the relative quantities of the two partial air streams.

+) CERCHAR publication N° 2200

With a forcing fresh-air supply the aspirating systems for partial and full-facer machines exhibit basic differences. As can be seen in Figure 12 the cutting area of the full-facer machine is screened by a shield from the remainder of the roadway. The suspended dust present in the cutting area can thus be aspirated fairly easily. With the current partial roadheaders (Figure 12 a) such a shield cannot be used because the machine operator determines type and speed of cutting and has to observe the cutting tools to do so. With these machines so-called open aspiration has to be employed, where fresh-air currents are discharged radially from a special section of air duct at an adequate distance from the heading face. This prevents the dust in the zone of the cutting tools being stirred up by the fresh-air current.

The air discharge point of the fresh-air duct is situated between the heading face and the clean air outlet of the deduster. This ensures that the clean air discharged from the deduster does not re-enter via the suction ducts. A further precuation against creating a ventilation circuit in the dedusting zone is always to feed a greater amount of fresh air to the roadway heading than the purified air released by the deduster. The fresh air stream must also be large enough to dilute the dust concentration in the dedusters' output to an extent which provides permissable dust conditions. The open aspiration system was successfully used in roadways of between 10 and 20 m^2 excavated section and aspirated quantities of 150 to 400 m^3/min.

Machines cutting complete cross-sections (full facers) can be operated with considerably smaller aspirated quantities due to the presence of the shield. Given a properly installed aspiration point at the dust shield and adequate sealing of the shield against the roadway wall, an aspirated quantity of 100 m^3/min was sufficient for driving a roadway cross-section of 18 m^2. This closed aspiration system was already shown to be practicable in operation some years ago with the Wohlmeyer machine of Krupp, Essen, and recently with the Robbins machine of Robbins, Seattle, U.S.A.

Investigations with the latter, however, also showed that, in addition to aspiration, it is necessary to provide adequate wetting of the broken material starting from the cutting area so as to maintain a dust concentration which fully meets occupational hygiene requirements. Wetting the broken material in the cutting area considerably reduces the amount of suspended dust to be trapped by the deduster. The use of water jets at the conveyor transfer points of the roadheader effectively prevents dust being stirred up when the cut material is being transported away. Nevertheless, it is planned that in future operations dedusting at the conveyor transfer points will replace spraying, above all to avoid climatic problems which arise from the use of large quantities of water up to 250 l/min.

On the Steinkohlenbergbauverein test rig for dedusters numerous investigations were carried out in the course of developing dedusters for roadway heading machines (Research project 6251-24/1/004). The main object of these was to design dedusters which were both effective and of small physical dimensions (see also Section 1.1.3). In designing wet dedusters, one of the aims was to develop a fully automatic water recirculation system, comprising sequence control of pumps, flow-through monitoring devices and safety devices. The discharge of solids separated out in wet dedusters is effected by pumping out a certain quantity of the slurry medium from the circulation system, either immediately or after pre-thickening in a hydrocyclone. The aim is to develop equipment which will remove well-thickened slurry.

The following deduster models were tested both on test rigs and underground in conjunction with roadway heading machines:

- Wet filters with filter mats made from anti-static synthetic material. The filter material was tested with a high specific surface load of up to 25 m^3 primary air per m^2 of filter area per minute, with a pressure loss of up to a maximum 140 mm water column. The prototype of this deduster was subjected to trials underground with the partial heading machine EV 100 of Eickhoff, Bochum, providing successful results. Due to the relatively high maintenance effort and design problems in further development, no further model of this type has been built.
- Compressed air radial aspirating dedusters, from which the "Rotovent" deduster with electric fan was developed. This deduster resembles the Venturi dedusters which operate at velocities of up to 90 m/s in the Venturi pipe. The first operational test of the radial aspiration deduster was carried out on a Dosco Roadway Cutter-Loader. The high compressed air consumption and the unreliable slurry separation of the pilot model led to a number of modifications and the development of the "Rotovent" system which was employed at a number of points underground.
- Cyclonette dedusters. This deduster's key dedusting feature is a centrifugal separator with an input of 50 m/s at a tangential angle, the separator being 10 mm in diameter and 25 mm in length. Depending on the volume of the incoming stream, a number of these separators are used in parallel arrangement. The underpressure needed for the separator is approximately 350 mm water column, sufficient to achieve the above-mentioned velocity. A prototype of this deduster was tested with the Greenside machine and a later version with a "Nashorn" machine, VS 2E, of DEMAG, Duisburg. The cyclonette deduster shown in Figure 13 was successfully used to dedust the Robbins road header.

Operational experience has shown that improvements have to be made mainly in the design of the water circulation system, including the drawing off of the dust and slurry separation behind the contact zone.

The required high separation performance of dedusters calls for high-performance fans of special design with noise suppressors and a relatively high power consumption (for example, 60 kW with 350 m^3/min). Experience has shown that the provision of such a power supply with the smaller partial roadheaders, and noise-suppression, can create considerable difficulties whenever the machines are employed.

Tests carried out by the Institut National des Industries Extractives and the Institut d'Hygiène des Mines with the mechanical drivage of roadways have shown that, especially with a Joy MK II machine, it is necessary to use spraying water at a rate sometimes in excess of 80 litres/minute. It was also found that a deduster with an overall capacity of 95% might still be inadequate.

When a machine - say a Dosco machine - cuts into a psammatic and sandstone roof band, it is not uncommon to find measurements of between 1500 and 1600 mg/m^3 of all types of dust despite an auxilliary ventilation of from 2,3 to 3 m^3/s.

Using a mixed ventilation system and a Microydyne 8 JM deduster (4 to 4.4 m^3/s), adapted by the addition of a second-stage spraying system, an overall effectiveness of over 99% was achieved, dust suppression being 78% for particles between 5 and 1 μm and 69% for particles between 5 and 0,5 μm.

In one particular instance it was also found that dust conditions were markedly improved by employing a different type of support; roof bolting on certain occasions (drivage which was limited to that in coal and in shale floors produced dust levels which were 4 to 5 times lower).

1.3.2 Dust suppression during transport

1.3.2.1 Dedusting at face-roadway junctions and loading points

In tests carried out by the Silikose-Forschungsinstitut, Bochum (Research project 6251-22/1/072) at a face-roadway transfer point, which was sealed off for a length of 7 m, the dust in the area of the plough stable hole was thoroughly captured and the continuous forward movement of the entire deduster unit avoided. In use was a Rotovent deduster with electric drive and water circulating system of Hölter and Co., Gladbeck, which was hauled forward on a monorail.

The first measurements taken gave improved dust conditions in the area of the transfer point and in the road-head.

At another site a movable face-roadway transfer point was also successfully dedusted, in this with downcast ventilation; an initial dust level of III was reduced to dust level I through dedusting (Research project 6251-24/1/641 of the Silikose-Forschungsinstitut, Bochum).

This research showed again that traditional dust suppression methods often do not suffice at such transfer points and that further development of dedusting systems is needed.

1.3.2.2 Use of evaporation-retardants in winning and other operations

Laboratory tests of the effectiveness of evaporation-retardants added to sprayed water for dust suppression purposes and to reduce the evaporation rate should assist in selecting suitable products for each type of coal (Research project 6251-22/2/034 of the Institut d'Hygiène des Mines, Hasselt).

The evaporation-retardant effects of NaCl, Ca Cl_2 and Mg Cl_2 solutions and lubricating oil emulsion and soluble oil+) have been studied in the laboratory and have been classified according to instant and total evaporation coefficients++). The retarding action of these additives depends not only on their properties and initial concentration but also on the ventilation currents velocity, on the temperature and the humidity of the air and the rock to be treated.

From the dust suppression point of view, salt solutions gave good results in reducing stirred up dust in lean coal; in fat coal it is necessary to add a small amount of wetting agent. Oil emulsions and soluble oils, on the other hand, are more suitable for fat coals with low ash contents.

From the viewpoint of climatic improvement, the above-mentioned chlorides, particularly $CaCl_2$, are the most appropriate evaporation-retardants and their action has been found to be largely independent from the type of coal and its size consist. The effectiveness of oils decreases as the product becomes finer. (Evaporation losses were recorded

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+) With salts the retarding of evaporation is achieved by a reduction in the water vapour tension; the use of oils involves an intermediary water layer between air and water which acts as a screen and should largely prevent evaporations. See: Cartigny, S.: The action of evaporation-inhibitors with coal. Rev. Inst. Hyg. Mines, 1968 23, pp. 79-124.

++) Instant evaporation: Ratio of quantities of evaporated water in relation to time, with or without inhibiting agents. Total evaporation : Ratio of total quantities evaporated after a fixed period.

with the aid of an "oven" equipped with thermostat and remote measuring of temperatures). The salt concentrations used do not entail significant increases in corrosion risks.

In underground tests measurements showed that chloride solutions (of 15-2o% Ca Cl_2) in spraying alone above the roadway conveyor ensure a more lasting "humidification" of products transported in the opposite direction to the air intake. The total quantities of evaporated water and heat loss to the surrounding air in the loader gate-road and the working are reduced even if spraying in the face is carried out without additives. On the other hand, if spraying takes place in the face and above the roadway conveyor it may be possible to reduce by 1.75°C or 1,05° the air humidity in the roadhead in certain workings (given comparable liquid quantities: either a 15% solution or unadulterated water) with outputs of 30 or 80 tonnes per hour.

In all such instances dust conditions are improved as a result of reduced drying out of the transported product.

1.3.2.3 Removal of dust sediments in roadways

In the research submitted by the Silikose-Forschungsinstitut, Bochum (6251-2/1/048) and the Institut National des Industries Extractices, Liège (6251-22/2/037), Division Pâturages, the object was to aspirate dust deposits from an uneven, non-encumbered levels (i.e. gate roads with or without rails).

Solutions of a technical kind already existed for aspirating dust from a level and an uneven, non-encumbered floor+). Nevertheless, certain minor improvements were put forward such as a lower designed height and easier negotiation of curves by the machines.

+) ECSC-High Authority: Technical Measures of Dust Prevention and Suppression in Mines. Vol.I. From the series: Occupational Hygiene and Medicine, Luxembourg, Publications of the European Communities 3890/1/11/1 (I),1966, pp.39-41.

By combining two sets of features: that of a pneumatically driven, mobile and small-sized transporter equipped with a ring-type ejector and of a stationary deduster (cyclone and radial suction deduster) capable of both continuous and discontinuous intake of aspirated dust from the mobile unit, an improved version of the Hölter & Co., Gladbeck, Rotovent deduster was evolved. Specification and methods of operation of this apparatus have been given elsewhere.+)

The extensive research carried out included in particular the study of the effect of the amount of water fed on the removal of shale dust (DIN 70), depending on whether the apparatus worked with compressed air only, with a fan or with compressed air and a fan (mixed system). Results showed that by changing from fan operation to the mixed system, the increase in throughput of 100 to 125 m^3/min and that of the specific water quantity from 0,1 to 0,3 l/m^3 and the use of an air-water jet in the ring slit of the deduster, there is a marked reduction in throughput rates (Figures 14 and 15). Figure 15 shows that the throughput rates are also low, when using compressed air, even with modest specific water consumptions.

To be able to dedust long gate roads with a stationary installation, it is necessary to separate out the coarser particles at the time of trapping. Fine dust sucked in by the fan was then removed in a cyclone deduster and a bank of ultra-fine dust filters. A main duct, 200 mm in diameter and 500 m long in both directions from the installation, was equipped with 50 m long secondary ducts 100 mm in diameter, to which hoses for aspirating all the dust were connected. A cyclone interposed between main and secondary ducts trapped the coarsest dust. Amounts of 1 to 1,65 m^3 dust per

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+) Bauer, H.D.: Possibilities of improving dust suppression methods. Glückauf 106 (1970) 7, pp. 309-21.

hour were successfully aspirated at points approximately 450 and 210 m from the stationary fan. Improvements are, however, needed in the suction apparatus and in the connectors to the suction ducts.

For cleaning the base of conveyors and the walls of return air roadways the Institut National des Industries Extractives, Liège, has proposed a wet, mobile deduster working on the Venturi principle+). The tests covered the study of the most effective spraying system, the most advantageous positioning of the inlet duct and the efficiency of the recovery device for water drops carried in the air-stream. Deduster, fan and recuperator form an assembly 0,5 m in width and 3,6 m in length, adequate water recovery being assured by a vertical, screw-type device. With an air throughput of 270 m^3/min and a pressure loss Δp in the fan of 235 mm water column, the device has a separating capacity of 98.7% weight with dust consisting of 97% $< 5 \mu m$, the specific water consumption being 0.25 l/m^3 air.

Once a deduster is installed underground, the sedimented dust is placed into suspension ready for subsequent aspiration.

This is achieved by a specially designed apparatus consisting of four "arms" revolving round a horizontal axis. Each of those arms is a pipe emitting compressed air which cleanses the side walls. The distance between the ends of the arms and the side wall can go up to 0,4o m.

In these conditions an "advance" is obtained which corresponds with the cleaning of 1m of roadway per minute.

+) Bracke, J: Research work on a deduster for cleaning mine roadway walls. Bulletin Technique Sécurit9 et Salubrité, N° 2, November 1970, Institut National des Industries Extractives, Liège, p. 11

Further studies will be needed to reach a satisfactory outcome in the main roadways and in winning workings.

A proper understanding of the size consists influence on the effectiveness of salts is still lacking.

Evaporation-retardant saline solutions of various chemical composition were used in an iron-ore mine of the Salzgitter Erzbergbau AG to assess wet dust suppression methods in hot workings at great depths. Among all additives tried, Mg Cl_2 solutions were the most satisfactory even though the overall results were disappointing.

These investigations were carried forward by the Silikose-Forschungsinstitut, Bochum (Research project 6251-22/1/046) in a roadway drivage (fat coal) using calcium chloride with a view to possible improvement in climatic and dust conditions after shotfiring or during slushing:

- spraying of the debris,
- installation of 400 to 500 Kg Ca Cl_2 in bags in front of the heading face prior to shotfiring, spraying of debris as above,
- stemming every borehole with Ca Cl_2 cartridges (250 g), spraying debris as before,
- shotfiring, using one Ca Cl_2 bag (1000 g) in front of each borehole, spraying debris as before,
- shotfiring, using one Ca Cl_2 bag (1000 g) in front of the boreholes, placing of 100 Kg Ca Cl_2 bags in front of the heading face; stemming some or all boreholes with one Ca Cl_2 cartridge each; spraying of debris in a manner adapted to these conditions.

Differences in relative moisture contents before and immediately after shotfiring were relatively small at a maximum figure of some 8%. In some tests relative moisture contents rose during slushing, pointing to the evaporation of part of the sprayed water before it interacted with Ca

Cl_2. Spraying prior to slushing seemed more appropriate than during slushing having regard to climatic conditions.

Very fine dust in particular was mostly bound by the calcium chloride used in blasting in the shotfiring fumes.

In the slushing of the sprayed debris permeated by $CaCl_2$ there was also a partial but significant improvement in dust conditions: the peak improvement values as compared with the first series of measurements were 29.7% for gravimetric measurement of total dust, the very fine dust values were 44.6% the reduction of the dust index being at maximum 58.3%. It should be pointed out that spraying of debris was not uniform throughout.

1.3.2.4 Other aspects of dust suppression during transport

Foam has been used in shafts (tubbing) and transfer points to aid dust suppression (Research project 6251-14/3/060 of CERCHAR, Paris): Two types of foam-producing devices were tried with "Teepol" and "Saframi"foam. The foam itself was fairly quickly demolished by pieces of coal and dust; stirring up of dust was not observed.

The research centre intends to engage in further tests of these foam-producing devices and jets. At other centres, too, the effectiveness of foam in dust suppression is being investigated.

The research carried out by the Silikose-Forschungsinstitut, Bochum (6251-25/1/039) on dust suppression in workings in thick iron ore veins underground, especially extraction and transport, has been extensively described elsewhere+). The good results obtained have been largely due to improvements in ventilation techniques and modifications in winning and transport methods.

+) Landwehr, M. and Bauer, H.D.:Dust suppression in extracting and transport operations in thick iron ore veins. Bergbauwissenschaften 13 (1966) 7, pp. 281-86.

The Chambre syndicale des Mines de fer de France (Research project 6251-25/3/079) has studied methods of reducing dust levels in workings where rotary drilling machines mounted on "jumbo" carriages are used.

One method, in which the dust is aspirated at the outlet of the drilled hole and then filtered through cloth, was first developed; in practice, however, the apparatus required proved too bulky to be used commercially in underground mining.

Another method was adopted after development: a mixture of air and water is infused into the central hole of the drill bit; the mist this forms wets the dust as it is produced at the extremity of the hole. Numerous dust measurements have proved the efficacy of this method. The equipment needed is simple and practical. It has been adopted with "jumbo" drilling machines which drill over 3 m/min.

Research project 6251-25/3/080 +) of the Chambre syndicale des Mines de Fer de France has examined the possible elimination of nitrous gases produced by diesel engines.

This work was divided into the following four stages:

- Bibliographical study of methods of measuring the nitrous product content of gas mixtures.
- Development of a measuring method which is continuous and adapted to the gases produced by diesel engines: the method is based on the Saltzmann discontinuous colorimetric method. The nitrous vapours produced consist of NO and NO_2; NO is first oxidised into NO_2; the NO_2 is absorbed by reactive agent in solution which colours it; the concentration is determined by the colorimeter and recorded. Calibrating problems were solved using sodium nitrate solutions.

+) Deniau R. and M. Netzer : Nitrous vapour emission by diesel engines. Bulletin technique No. 1o1 of the Chambre syndicale des Mines de fer de France.

- Establishment of the effect of two parameters on the production of nitreous vapours; this was done on a test stand with a 140hp. motor of a type in current use in mines. The angle of lead at injection has a significant effect; it is important to adjust this angle to a value below that which gives the best performance. With the engine tested a reduction of the angle from 24° to 14° made it possible to reduce the emission of NO_x significantly, but this reduction is smaller when the engine is working than while idling.

  Recirculation in the air intake of some 20% of escaping gases is more important since it always reduces the emission of NO_x in high proportions (which may go up to 60% during full load operation). This method increases the CO content but keeps it within tolerable limits.

  Combining the two methods is regarded as undesirable: it reduces engine power too greatly.

- Study of gas bubbling in water

  The most effective cleansing of escaped gases was achieved with a tank equipped with numerous deflector plates; it is important that the gases are expanded before entering the tank and that they cover as long a distance as possible in the tank; in any event the resistance of the turbulence tank to the passage of gases must be low. NO_x retained by the tank never exceeded 20% of the volume emitted. The addition of various basic additives to the water made no appreciable improvement.

Research should continue in several directions:

- determining the effect of the nitrites content in the turbulance water;
- study of the solubility of gaseous mixtures containing NO_x;
- test stand trials of recirculation of gases and reduction with other types of diesel engines;

- tests with catalysers in the exhausts;
- industrial-scale underground tests of the various methods developed in laboratories.

2. INVESTIGATIONS TO ASSESS DUSTINESS

To assess the effect of technical dust suppression measures and the attendant risk of dust-induced lung diseases in coal mining, a thorough understanding of the properties of the dust to be measured is needed together with the development of methods and apparatus to measure dust conditions. Results to date of statistical surveys of the incidence of silicosis, and of animal and cell-tissue experiments, have shown that occupational hygiene considerations require the establishment of the mass concentrations of respirable fine dust and its specific harmful effect which depends on its physical composition. Respirable fine dust in this context means that proportion of suspended dust which can be deposited in lung alveoli in certain size consist ranges. Since such deposition depends on individual human factors, calculation is based on an average deposition curve such as shown in Figure 16. Exposure to dust in terms of time is also of great importance for the progression of silicosis; its influence can only be assessed by statistical evaluation of medical data and of the dust exposure of a large number of miners (see Section 3).

The research described in Section 2 covers new findings about the physical, mineralogical and chemical properties of fine dust, reassessment of existing methods of measurement and the development of new methods and equipment incorporating new aspects.

A number of questions raised have as yet not been answered.

2.1 Properties of dust

2.1.1 Light scatter measurement of dust particles

In order to determine the scope and limits of optical dust measurement in establishing fine dust concentrations the Steinkohlenbergbauverein, Essen, carried out:

- theoretical calculations of diffused light with spherical dust particles,+) ++)
- comparative studies between tyndalloscope optical measurements and gravimetric measurements of fine dust underground with the BAT I filter +++) ++++)
- experimental investigations of light diffusion with single actual dust particles (Research project 6251-31/1/010 +++++).

+) Olaf, J. and K. Robock: Theory of light diffusion with coal and stone particles. Staub 21 (1962) 11, pp. 495-99.

++) Robock, K.: Basis of optical dust measurements. Staub 22 (1962) 3, pp. 80-84.

+++) Breuer, H.: The importance of particle size distribution for measuring and combating suspended dust in coal mining. Staub-Reinhaltung der Luft 29 (1969) 3, pp. 105-13.

++++) Reisner, M.T.R.: The relationship between diffused light and fine dust mass in the Ruhr coalfield. Contained in: Results of investigations into measures against dust and silicosis in coalmining (Silicosis report, North-Rhine Westphalia) Vol. 8 Essen: Verlag Glückauf, 1971, pp. 85/89.

+++++) Breuer, H., J. Gebhart and K. Robock: Determining dust concentrations in coalmining using light diffusion. Staub-Reinhaltung der Luft 30 (1970) 10, pp. 426-31.

Both theoretical calculation and underground measurements showed that the tyndalloscope records too high values for fine dust in the size range under 1,5 μm as compared with the actual deposition of such small particles in the lung alveoli. Therefore the size consist of respirable fine dust is decisive for the diffused light evaluation per unit volume of dust and consequently for the photometric assessment of its mass concentration. On the other hand, the type of dust particles (coal or stone), designated by the optical constants n (index of refraction) and x absorption index, is of secondary importance with the dusts formed in mining and the mixed dust composition (ratio of coal to stone) need not be taken into account in measuring.

The purpose of the experimental laboratory tests carried out jointly with the Battelle institute, Frankfurt/Main, on dust particles was to verify the results of previous theoretical calculations and underground measurements of single dust and stone particles of different sizes and then to devise a new dust photometer whose measurement values would correspond usefully with those of gravimetric fine dust measuring instruments.

Figure 17 shows a diagrammatic representation of the test pattern for measuring diffused light intensity with single particles as related to the scatter angle.

The key figure of the arrangement is a modified "Millikan" condenser for maintaining the dust particle in suspension. The particle can be illuminated either with a laser within the visible spectral region (630 nm) or an infra-red laser (3390 nm). Photographic recording of intensity distribution of diffused light is effected with film in the visible spectral region; with infra-red measurement the angle of refraction ϑ is scanned by a photo-electric infra-red detector in steps of 2^{o} and the diffused light intensity is read by an electrical measuring device as a photo-electric current.

Figure 18 compares the theoretically calculated value for a glass sphere of 6 μm diameter, with the photographed value and the densitometrically evaluated diffused light intensity as related to the angle of refraction. The two intensity distributions coincide well. As can be seen from the figure, increases in the refraction angle produce considerable reductions in the diffused light intensity. The maximum and minimum values are so definite only with sperical particles and when illuminated by monochromatic light; this does not obtain with irregular actual particles illuminated by white light; curve tracings remain constant.

Both theory and practice led to the conclusion that the diffused light phenomena with stone particles correspond closer to those of coal particles than to those of transparent quartz or glass particles, since the absorption indices are $\varkappa > 0$ for the former and $\varkappa = 0$ for the latter. Absorptionless dust particles (x=0) are not found in underground workings and the diffused light intensity's dependence on the material need to be taken into account. The size consist of dust particles does have considerable influence on diffused light intensity. The functional interelation between diffused light intensity and size consist depends on the wave length of the light used for illumination and the refraction angle. Since only this feature need be considered in designing a photometer, the diffused light yield per article volume can be adjusted to the probable dust deposition in the lung, which depends on the size consist, by selecting appropriate wave lengths and angles of refraction. This is achieved by using monochromatic light within close range of infra-red (800-900 nm) and, not as heretofore a wave length range of primary light in the visible field (350-650 nm), and by going over to a medium refraction angle of 70° instead of 30°. This eliminates the unduly high values for fine dust in the range below 1,5 m shown by existing tyndalloscopes. A photoelectric measuring system dispenses with visual matching; the measurement can either be read off as an instantaneous value from an instrument or be recorded continuously as a time function. A start has already been made on the development of such a dust photometer jointly by the Steinkohlenbergbauverein, Essen, the Battelle institute, Frankfurt/Main, and the Leitz company, Wetzlar.

Work on the development of a photoelectric dust measurer using diffused light was also carried out during 1965 and 1966 at the Stofinstituut, Limburg (Research project 6251-41/6/055). A laboratory device yielded good results on the connection between diffused light intensity and dust concentration. However, in view of the work by the Steinkohlenbergbauverein, Essen, the tests were discontinued.

The Institute of Medical Physics at Münster University has made extensive investigations into the relationship between the diffused light intensity of the tyndalloscope and surface area values of dust (Research project 6251-31/1/049+)). Their purpose was to determine whether relating diffused light intensity to dust surface area values led to better results, at least for a certain range of observation angles and particle sizes, than relating these to mass concentrations. In these investigations the Brico-Phoenix-photometer, Model 2000, of Phoenix Precision Instruments, USA, was used together with the tyndalloscope. The dust was usually studied in watery suspension as it proved difficult to keep the tested dust suspended in air with a constant particle size distribution. Measurements were carried out on spherical latex particles (sizes from 0.557 to 3.490 μm), irregular quartz particles (maximum sizes from 0.33 to 2.0 m)

+) Desler, H.: Investigations into the relationships between diffused light intensity and surface area values of poly- and mono-dispersed latex particles and poly-dispersed quartz particles in hydrosols with a view to changes in tyndalloscope calibration. - Thesis, Münster, 1969.

and particles of different types of coal (sizes from 0.53 to 2.31 μm). With refraction angles between 40° and 50° a better proportionality to the surface was found with latex particles than with the 30° observation angle of the tyndalloscope which was then in industrial use. A particle size range possessing surface area consistency was found for both latex and quartz particles of sizes between 0.5 and 7 μm. The marked dependence of diffused light intensity on the average particle size of the quartz particles can be seen in Figure 19a, in which the relative diffused light intensity is plotted above the mass concentration of quartz particles for a refraction angle of 30°. In figure 19b, on the other hand, the intensity is plotted above the specific surface area, obtained according to the permeability method and a linear correlation is obtained which is largely independant of particle size. Only the quartz dust figure does not conform with a maximum particle size of 0.3 μm. In the particle size range between 0.5 and 7 μm a uniform proportionality exists between diffused light intensity and surface area.

The institute obtained results with the tyndalloscope similar to the above-mentioned ones with the Brice-Phoenix-Photometer. A special small bath was used in which dust suspension tests could be carried out. Coal dust measurements, however, did not offer good correlation opportunities for diffused light intensity and specific surface area, since the latter produced values which could not be correlated due to the porosity of the coal particles and consequent internal surfaces. On the basis of the numerous measurements results it should be possible to calibrate the tyndalloscope to the specific surface area of homogeneous, transparent coal dusts and presumably also of transparent stone dusts thereby reducing the tyndalloscop's error margin to ± 35%. If coal dust predominates in a dust mixture, only a slight improvement in dust assessment may be expected. As calibration curves would also have to be established in each case for the different mine dusts in a mixture, the method appears to be impracticable.

The investigations into diffused light with dust particles have therefore shown up the limits of the tyndallometric method as used until now, yet also pointed to a way in which optical dust measurement can be used to determine the mass concentration of fine dust in relation to probable deposition in the lung.

2.1.2 Semi-conductor properties

Statistical results indicate that the incidence of silicosis in different mining areas cannot be explained merely as a result of fine dust concentrations and their quartz content. Experiments with animals and cell tissues also established that even dusts derived from crystalline and amorphous $Si\ O_2$ modifications (quartz, crystobalite, tridymite, quartz glass) exhibit considerable differences in terms of time and harmful effect. Neither the type of $So\ O_2$ modification nor the degree of crystallinity can be correlated with the harmful effects of these dusts[+]. Consequently physical properties other than the quartz content in the dust must be responsible for their specific harmfulness. Only when this is known is it possible to give a clear assessment of hygienic dust conditions at the place of work in addition to that based on fine dust concentration. For this reason investigations were carried out by the Steinkohlenbergbauverein, Essen (Research project 6251-32/1/013) in collaboration with the Institute for Occupational Hygiene and Medicine of the Essen Klinikum (Ruhr University, Bochum), on the specific harmfulness of dusts[++]. These investiga-

+) Klosterkötter, W. and Robock, K.: New results of basic silicosis research. Arbeitsmedizin Sozialmedizin, Arbeitshygiene, 5 (1970) 11, pp. 284-87.

++) Robock, K.: New theories on the origin of silicosis. Luminescence measurements and biochemical cell tests with $Si\ O_2$ dusts. Staub-Reinhaltung der Luft, 28 (1968), 4, pp. 148-56.

tions are based on the electron theory of catalysis, according to which the mineral and stone dusts belonging to the semi-conductor group (substances whose electrical conductivity places them between metals and non-metals) intervene harmfully as catalysts in the biochemical reactions of the lung, due to their electron structure. This catalyst action is determined by the valence electrons of the atoms forming part of the dust particles' structure. According to the electron theory of catalysis, a catalyst influences chemical reaction by taking on or releasingelectrons. Since every catalyst does not have a catalytic effect on every reaction, the catalyst must be "matched" to the reaction "partner". Only if enough electrons with "matching" energy factors are present in the catalyst, can the latter become effective and release electrons to biochemical reaction partners of certain cells of the lung alveoli. The result is a misdirection of chemical reactions and, ultimately, cell damage which is today regarded as a cause of the onset of silicosis.

Luminescence measurements following X-ray activation of numerous $Si\ O_2$ dusts enabled the energy of the electrons responsible for such a catalytic effect - or the electron structure - to be determined. It could be proved that the cell-damaging effect of dust samples could be correlated with these electron energy factors, i.e. the activating energy of their electron adhesion points (figure 20). This figure shows the metabolic action of cells, measured in terms of their reduction action as against 2, 3, 5 TTC-RA after a dust impact of 120 minutes, as dependant on the activating energy E_H of the electron adhesion points of the dust samples.+) Samples with activation energies in the

+) Klosterkötter, W. and Robock K.: Determination of dehydrogenizing action as a measure of the cyto-pathogenous effect of dusts. Contained in: Results of measures against dust and silicosis in coalmining. (Silicosis report - North Rhine-Westphalia) Vol. 6. Detmold, Bösmann 1967, pp. 51-54.

range of 0,5 to 0,6 eV (electron volts) have confirmed cell damaging effects, recognisable by the lowering of the cell metabolic effect. These electron energy factors are independant of the type of $Si\ O_2$ modification, as is the case with cell damaging effects, but are dependant on the foreign ion content of the samples and so on their sub-molecular structure. Analyses with the X-ray fluorescence method showed up variations in the aluminium content of samples between 50 ppm and 3500 ppm. Aluminium atoms take precedence over silicon atoms in the $Si\ O_2$ lattice thereby exerting considerable influence on the electron structure. It was found that the cell damaging effect of $Si\ O_2$ samples was reduced as the aluminium content increased. This explains why dusts of different derivation can behave in entirely different ways in their biological effect, depending on the origin of their constituents.

It was also found that in the damaging interaction between dust particles and b iological cells a chemical luminescence occurs (figure 21), whose intensity increases with the cell-damaging effect of the dust. Quartz sand DQ 12 and tridymite 2 were equally damaging in the cell experiments, tridymite 1 only to a small degree but tridymite S did not damage the cells after a 120 min. test period. It was also found that prior X-ray radiation of the samples, which excites the electrons, led to a more pronounced cell-damaging behaviour of $Si\ O_2$ samples and to greater intensity of chemical luminescence.

These results indicate that electron transfer reactions are responsible for damaging reactions between dust particles and cells. This means that a definite damaging effect should not be attributed to quartz or any other $Si\ O_2$ modification, or their concentration in heterogeneous dusts, but to the electron structure and the specific physical properties of these dusts which condition it.

The investigations have meanwhile been extended to mine dusts from Ruhr and Saar coals. First results indicate that quartz types of very dissimilar electron structure occur in dusts from different geological horizons and that the combination with other minerals and types of coal has an influence on the cell-damaging behaviour of the dusts+).

These results are to be confirmed by extensive tests on dusts from pits with differing incidence rates of silicosis. It is also intended to use foreign ions to investigate their effect on the basic lattice structure of samples of the different SiO_2 modifications and their electron structure and cell-damaging effect, in order to throw further light on the way the damage is effected. The ultimate object of the research is to devise a routine measuring method to determine the specific harmfulness of dusts using a physical method.

2.1.3 Behaviour of dust in mine ventilation systems

The purpose of investigations into dust distribution in roadway cross-sections, its behaviour along roadways and the influence of the ventilation stream and velocity is to measure the dust accurately in the roadway cross-section. Having done this it is possible to select suitable measures of dust suppression adapted to both type and extent of dust.

Investigations to this end were carried out in an auxilliary ventilation roadway drivage with shotfiring dust and also in return ventilation roadways with continuous dust discharge from the faces (Research project 6251-24/1/003 of

+) Laufhütte, D.W., Robock K. and Klosterkötter W.: Investigations into the cyto-toxic effect of mine dust from Saar coal. Contained in: Results of measures against dust and silicosis in coalmining. (Silicosis report - North Rhine Westphalia) Vol. 8, Essen, Verlag Glückauf 1971, pp. 131-38.

the Steinkohlenbergbauverein, Essen+)).

The distribution of dust concentrations in roadway cross-sections was measured at 5 to 6 levels along the measured distances. As a rule, 9 BAT I fine dust measurers were used simultaneously in one cross-section. This was followed by measurement of decreasing dust concentrations along the roadways at the same 5 or 6 measuring points using only one BAT I measurer at each measuring point, the measured values being corrected in the light of the previous distribution measurements.

The distribution of ventilation velocity and dust concentrations at the measurement levels along the measuring distances was shown diagrammatically in the form of simple lines related to equivalent ventilation velocities ("Isotachen") and equivalent gravimetric fine and coarse dust concentrations ("Isokonien"). Both "Isotachen" and "Isokonien", shown in figure 22 at 2 measuring levels of a face return airway, show, at the first measuring level, the secondary air-stream of type 1++) after deflection of the air-dust mixture by 90° behind the face-roadway junction: the values of maximum ventilation velocity and dust concentration were displaced towards the seam from the face, and there were some "kidney-shaped" bulges, especially of the 1.0 "Isotache".

+) Reinhardt, M.: Experimental research in coalmining roadways into the behaviour of dust in mine ventilation with regard to air stream velocities. Thesis, TU Berlin, 1970. Experimental research into the behaviour of suspended dust in return airways of coal faces. Glückauf-Forschungshefte (in print).

++) A compensating cross current is involved here, such as occurs in an "elbow" turn.

Deviations at any measuring point in the cross-section reach factors of about 0.8 and 1.2 for fine dust and 0,7 to 1.3 for coarse dust formations as compared with the actual average 10 m behind the face. But deviations at one measuring point in the centre of the cross-section from the actual average concentration still made it possible to assess working sites within the zone of the face-roadway junction at about 10 m from the face. Nevertheless, something like 20% of the dust coming from the face, which may have been separated out there, should still be taken into account. A measurement error margin of $\pm$ 20% should be allowed for in respect of non-typical measurements in the roadway cross-section at such a measuring point and any other measuring and evaluation errors.

In roadway drivages with auxilliary ventilation the first measuring level was instituted about 200 m from the face where the shotfiring dust concentration in the roadway cross-section had nearly been compensated.

The range of ventilation velocities (Reynolds indices, "Re") occurring in this type of roadways, and other aerodynamic factors, especially those at the face-roadway junction, had no appreciable influence on the distribution of dust concentration in the roadway cross-section.

This also applied to the disparities between the different possible average values of dust concentration in a roadway cross-section in a part of the roadway with a balanced air current.

Ash and quartz contents in fine and coarse dust provided virtually typical measurements at all points along the measuring distances.

Confirmation of the airborne nature of respirable fine dust was given by the investigations in roadway drivages with auxilliary ventilation and in return airways from the face. In roadway drivage the gravimetric concentration of very fine shotfiring dust was reduced after a transport distance of about 1200 m with ventilation velocities between 0.14 m/s and 0.25 m/s by approximately 50% (dispersal: 35 to 80%); these figures relate to measuring point 1, some 200 m from the face, When assessing values for the dust concentration of a shotfiring dust cloud both the depositing and thinning-out process are taken into consideration. The relevant absolute mass values, including any deposits, were on average no more than about 20%.

In the measuring distances - at most 300 to 350 m - behind faces with continuous dust-forming sources, the fine dust concentration was reduced by about 50% compared with the concentration coming from the face itself.

The progress of fine and coarse dust concentrations in the measurement roadways can be defined by an exponential function. While the inclination of straight lines remained fairly equal for the progress of dust concentrations along the measurement section of the roadway drivage, figure 23 shows that it provided two values (roadway are up to some 10 m and between 10 and 300 to 350 m) in face return airways, three values with coarse dust+), for roadway areas 0-30 m (detour area) some 30 to 100 m (turbulent incoming current) and > 100 m away from the face (full turbulence of the "pipe" current type).

Thereafter the coarse dust concentration within the first 30 m of roadway was reduced by about 40% on average, yet only by 40% in the next 300 m.

+) This only applies to face return airways, since only fine dust was found in roadway drivages with auxilliary ventilation at measuring point 1.

The suggestion was made that, to establish the magnitude of coarse dust deposits, measurements should be carried out with only one measuring device in the centre of the roadway at measuring points approximately 30 and 300 m away from the face. Both measurements were to be entered in the simple logarithmic systems (see figure 23). A straight line connecting the two values gives the anticipated dust deposit per meter of roadway, provided account is also taken of the ventilation stream V̇, the period of dust formation and daily rate of advance in winning. The reduction in fine, coarse and total dust concentration along the measuring sections exhibits no obvious relation to the average air velocity in types of zones which may be expected in such roadways, nor to the aerodynamic conditions at the face-roadway junction and in the roadways themselves. The sameapplies to ash and quartz content in the dust.

A line of research was initiated in which the dust concentration distribution in the working thickness of the face near a drum shearer and at the machine itself is reproduced in model form. The findings should give pointers as to effective aspiration and dedusting on drum shearers.

Since the influence of ventilation speed and air stream V on the formation and stiirring up of dust in the above-mentioned underground tests could not be investigated, model tests in an air current channel are to be carried out, account being taken of the impact of other factors such as dust moisture, type of dust, size distribution, etc.

Gravimetric and tyndallometric dust measurements in 4 faces in the Netherlands coal industry (Research project 6251-24/6/055 of the Stofinstituut, Limburg) with upcast and downcast ventilation for comparison, provided no definite conclusions on the effect of ventilation reversal on dust conditions. It is difficult to maintain the other operating conditions in a face after reversal and the cost is high.

Further investigations on these lines are planned.

2.2 Development of devices and methods for dust measurement

2.2.1 Sampler to determine concentrations

The devices developed by CERCHAR, Paris and the Steinkohlenbergbauverein, Essen, in recent years possess a pre-separator designed according to the mean deposition curve (see paragraph 2). Both types can determine total and fine dust concentrations. The devices had to be portable and self-powered.

The first device developed by CERCHAR, P 66 A (Research project 6251-31/3/067), possesses a cyclone-shaped pre-separator. Separation is effected by a membrane filter with a 50 cm^2 catchment area. A 24V D.C. motor operates the pump, its lead battery providing 6 to 7 hours operation. A potentiometer enables air currents of from 0 to $2m^3/h$ to be regulated. The device is equiped with instruments indicating the air current at any time and the total volume of air aspirated. Motor, battery and potentiometer are housed in a flame-proof casing, the entire device weighs 10,5 kg. The device has not been mass-produced. Instead, adaption of a device for monitoring air pollution, the CPM Dust-Sampler, was started for the special requirements in mining, in which a rotating foam ring acts as a fan and fine dust separator. This CPM device ("capteur poussières mines") is to be used with a cyclone of the gravimetric sampler TBF 50 (see below) as pre-separator.

The TBF 50 (Research project 6251-31/1/012+)) gravimetric dust sampler, developed in collaboration between Bergbau-Forschung GmbH of the Steinkohlenbergbauverein, Essen and the Ingenieurbüro van Tongeren, Heemstede, Netherlands has one cyclone for prior separation of the coarser suspended dust and a second cyclone to separate out the fine dust (see figure 24). The separation dividing line for fine dust was adjusted to the alveoli deposition curve by appropriate selection of measurements in both cyclones. Pressure loss in the device is approximately 70 mm water column. An air current regulator behind the second cyclone ensures maintenance of an air current of 50 l/min. If it is required to use also the finest dust, which is not separated out in the second cyclone, for assessing the dust conditions, for example, to determine fineness indices, a filter component (a membrane filter with an effective filtering surface of 16 cm^2) can be attached behind the second cyclone. The separated dust adhering to the cyclone sides can be easily removed by a specially developed flushing device.

The total suspended dust is thus divided into three fractions by the TBF 50 device, into:

- "coarse dust", which gives an indication for the part of the dust deposited in the upper air streams,
- "fine dust" according to alveolar depositions,
- "very fine dust", which corresponds to the small proportion of inhaled dust which leaves the lung with the exhaled dust.

+) Breuer, H.: The gravimetric dust sampler vT/BF 50 to determine the concentration, composition and fineness of coarse and fine dust. Contained in: Results of investigations into measures against dust and silicosis in coal mining. (Silicosis report North Rhine - Westphalia) Vol. 8 Essen: Verlag Glück auf, 1971, pp. 47/56.

Initially the device was equipped with an ejector, because the extensive compressed air "grid" existing in the coal industry of the German Federal Republic provides a reliable and cheap power source for the device. If compressed air is not available, a blower operated by a mains or battery motor is used for suction.

2.2.2 Instruments to establish size consist

Particle size is a geometric concept which cannot be defined without detailed information about the method of definition. These may include linear measurement, surface or the volume of particles. Since none of these magnitudes can be directly measured with the irregularly shaped particles, size is generally described by one of the following auxilliary magnitudes:

- aerodynamic diameter = diameter of a sphere, whose density and speed of fall in still air correspond to that of the dust particle;
- projected diameter = diameter of a circle equal in area to that of the particles' projection;
- diameter after screening = the particle size providing a separation efficiency of 50% weight. This particle size approximately corresponds to the average mesh size of the screen or with the average hole aperture, i.e. in micro-screens;
- indirect size, i.e. with the Coulter-Counter, where the measured electrical resistance is a measure for the particle volume.

For the assessment of dusts from the occupational hygiene viewpoint a knowledge of the aerodynamic or equivalent diameter is particularly important, since the decision whether an inhaled dust particle is deposited in the upper respiratory ducts or the alveoli largely depends on the sedimentation speed of the particle.

Because suspended dust - especially in the fine and very fine dust range - does not usually consist of isolated, dispersed particles only but also of dust aggregates, there is an advantage in fractionating the dust when sampling. Methods of investigation in which the dust is first collected and then subjected to sedimentation analysis in the laboratory, say in a liquid, can give no reliable information about the dust in its suspended form and what portion was respirable. Dust aggregates broken up into single particles in the liquid are assessed in a way which differs from their aerodynamic behaviour in suspension.

The following equipment and methods were developed to settle the problem of dust fineness in suspension:

- the spectrometer of the Silikose-Forschungsinstitut, Bochum (Research project 6152-32/1/042),
- the split channel apparatus of the Steinkohlenbergbau-verein, Essen, initially used in animal "dusting" installations (Research project 6152-31/1/005),
- the method of measuring size distribution in dust using multi-stage cascade impactors, developed by the I. Physical Institute of Vienna University (Research project 6251 - 31/0/068).

In a proposal by Timbrell (see figure 25a) a fixed proportion of dusty air is added to a dust-free air stream flowing through a horizontal channel at a pre-determined point. All dust particles fall the same sedimentation distance and are carried varying distances by the carrier air stream depending on their sedimentation speed.

The dust particles range themselves according to their sedimentation speed on a specimen tray on the floor of the channel. Particles $< 1 \mu m$ are no longer trapped. To avoid this loss of fine dust, the Silikose-Forschungsinstitut, Bochum+), suggests that the sample is not trapped on the floor of the sedimentation channel but is guided to a membrane filter at the end of this channel (see figure 25b). By selecting an appropriate filter, for example, an MF 100, without softener, it is possible to achieve a quantitative sampling, even though the separation of the sample in the range $< 1\,\mu m$ is no longer quite precise due to the heat transfer of the particles. 14 ml/s are turned round to form the carrier airstream. 1% of this is ducted away via a capillary tube and a corresponding amount sucked in again as dusty air. The correct shape of the intake slit for the dusty air is very important. The procedure is impaired if the membrane filter used does not have a sufficiently uniform penetrability or the temperature of the intake air differs by more than 0,5°C from that of the circulating air. The temperature differences are measured by built-in thermo-couple elements. The correlation between the aerodynamic diameter and the sedimentation distance was established by means of a calibration curve. For this purpose colouring particles were used. The filters are rendered transparent after sampling by careful vapour application with a solvent (for example, acetone).

In the slit channel device ++) (see figure 25c) the dusty air to be tested,instead of the dustfree carrier air

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+) Walkenhorst, W.and Bruckmann, E.: Determination of minerals in suspended dust graded according to particle sizes. Staubreinhaltung der Luft 26 (1966), N° 5, pp.221-25.

++) Polley, H. and Friedberg, K.D.: Slit-channel dust measurer for gravimetric determination of suspended dust fraction concentrations. Contained in: Results of measures against dust and silicosis in coalmining. (Silicosis report, North Rhein-Westphalia, Essen: Verlag Glückauf, 1971, pp. 57-75.)

current, flows in through the entire inlet area in a 1m long channel (height 1 mm, width 30 mm). For this reason mono-dispersed dust is not deposited at one specific point of the channel, as is the case with the two first mentioned devices; instead a uniform layer is formed of different size fractions covering the distance between the channel opening and a maximum length, determined by those particles which were at the upper limit of the slit on entry (see example in figure 25 c).

With poly-dispersed dusts the layering of dust particles of different sizes produces an overall precipitation whose thickness decreases with the distance from the channel inlet depending on the fineness of the dust. To assess the sample the dust is wiped up with a pre-weighed paper dabber from the floor of the slit channel, section by section, and the dust-laden dabber is weighed on an electronic micro-balance (weighing range 10 mg, sensitivity 1 μg). Dust masses established in this manner enable the proportion of a specific dust fraction to be determined. For useful evaluation the total separated dust mass should be at least 1,5 mg. Given a dust concentration of 5 mg/m^3 the minimum sampling period is 66 hours.

The I. Physical Institute of Vienna University followed an entirely different course to determine the particle distribution in suspended dust and the mass concentration of dust fractions+). Since dusts with equivalent diameters between 0,5 and 20 μm can be divided

+)Berner, A.: Determining the distributive function of an aerosol using multi-stage cascade impactors. Staub-Reinhaltung der Luft 26 (1966) N° 4, pp. 167-69.

into several fractions by cascade impactors, a number of impactors were built with five perforated ring stages, whose mechanical parameters had to be as close as possible. Each of the perforated ring stages possesses a relatively large number of identical drill-holes arranged along the ring. The number and drill-hole diameter of the individual stages were adjusted in such a way that the diameter of the average particle separated out at each stage differed from the next by a factor of 2. If identical cascade impactors are set up in parallel but still in such a way that the aspirated volume in each case differs by a factor of $\sqrt{2}$, the results are the average diameters in μm given in table 1, as applicable to stages 2 to 5. The same values are obtained if the same cascade impactor is used for several separate, consecutive samples with correspondingly different volume streams. This method was first tested in a paraffin mist using a single cascade impactor, through which different volume streams were sucked in succession. In a trial with coal dust in the test channel of the Steinkohlenbergbauverein, Essen, four identical devices were used in parallel, the individual impactor stages being coated with vaseline for improved adhesion of the coal dust. The total volume to be aspirated was adjusted to the dust concentration. With concentrations of about 5 mg/m^3, each impactor needs no more than 500 l of aspirated volume to obtain samples capable of useful evaluation on an analysis balance with an accuracy of 0.01 mg. Precipitation amounts of 1 mg per stage are regarded as adequate.

2.2.3 Methods of determining types of minerals

The Steinkohlenbergbauverein, Essen (Research project 6251-32/1/015 and 6251-32/1/014) extended the well-established radiographic and infra-red spectroscopic methods of quartz identification to the qualitative and quantitative determination of dusts in coalmining+) ++).

To determine X-ray absorbtion and in diffraction investigations an automated measuring device was developed which enabled X-ray diffraction diagrams of 20 samples to be recorded in one to four days, during day and night working, and without either supervision or attention during the period. The period of recording in each case depends on the minerals contained in the sample. The test requires 100 mg of material. Since the effort needed for measurement and evaluation is many times greater than the recording period, the diffraction measuring device was complemented by putting the measurements on perforated tape. Programmes which have been developed and tested in the meantime make rapid evaluation on a data processing installation possible.

With infra-red spectroscopic minerals determination, part of the sample is subjected to continuous incineration at 800°C for three hours, in order to reveal the absorption bands of the mica minerals, muscovite-illites, after destruction of the kaolinite. The rest of the sample is carefully decarbonised over several days by continuous exidation in air at 375°C, so that both koalinite and carbonates can still be clearly identified. Sample material of particle sizes above 5 μm is first ground in agate mills. The tablets used for recording the absorption diagrams normally contain 1 mg dust and 249 mg spectroscopically clean material, ground to sizes below 10 μm. If bands with frequencies of > 330 cm^{-1}

+) Schliephake, R.W.: Radiographic phase analysis with electronic data processing. New mineralogical year book. Proceedings, 11 (1970) 3, pp. 302-19.

++) Gade, M.: Quantitative determination of minerals in mine dusts. Contained in: Advances in Silicosis research. Vol. 2. Dinslaken: Niederrheinische Druckerei, 1967, pp. 409-12.

have to be used, KI is used as embedding material which has a permeability of up to 200 cm^{-1}. To avoid time-consuming evaluation of diagrams, the infra-red spectroscopic method was also converted to perforated tape recording and existing calculation programmes for multiple-component systems suitably amended.

2.3. Results of dust research

2.3.1 Comparative measurements using different measuring devices

The Steinkohlenbergbauverein, Essen (Research project 6251-31/1/078)+) set up a test channel (see figure 26) to carry out comparative measurements with dust measuring devices. This channel was 7 m long with a cross-section area of 0.4 x 0.4 m and contained apertures at front, top and bottom for installing measuring devices, power supply and outlets for partial ventilation streams. The coal or stone dust used for testing is fed via a dust weigher to an ejector which disperses it and is then passed to a classifier (dynamic wet separator or cyclone with different separation limits). Systematic alteration of the dust feed, classifiers and regulation of air streams of different volume, makes it possible to produce dust streams of differing concentration and dust fineness in the measuring channel. With air velocities of between 0.7 and 2.9 m/s, coal dust concentrations between 1 and about 130 mg/m^3 can be investigated and stone dust concentrations of between 2 and 180 mg/m^3.

+) Stuke, T. and M. Emmerichs: Trial of a test channel for comparing measurement values of dust measurers. Contained in: Results of measures against dust and silicosis in coalmining. (Silicosis report - North Rhine-Westphalia) Vol. 8.Essen: Verlag Glückauf, 1971, pp. 43-46.

In this test channel a number of prototypes of measuring instruments were tested and compared, both one with another and with other dust measuring instruments; they included: dust sampler TBF 50 of the Steinkohlenbergbauverein, Essen; the CPM apparatus of CERCHAR and the multi-stage cascade impactor of the I. Physical Institute at Vienna University.

The comparative measurements carried out by the Stof-instituut, Limburg (Research project 6251-31/6/050) in the Netherlands coal industry showed that the newly developed "Siter" general dust filter, with its air through-put of $4m^3/h$, was superior to the previously employed CP apparatus, which had an air through-put of $1m^3/h$, particularly with low dust concentrations, because it provides samples which can be evaluated more quickly.

Tests carried out by the Institut d'Hygiène des Mines, Hasselt (Research project 6251-31/2/028) aimed at comparing not dust measurement results but the "assessment criteria" for the harmfulness of the environment as it can be deduced from these results, in conformity with the regulations in force in each of the Community countries.

The apparatus used was: the Staser filter sampler (Belgium and the Netherlands), the standard thermal precipitator (IHM method-Belgium), the Morin-CERCHAR membrane device (France) and the tyndalloscope III and the "Bergbau-konimeter" (German Federal Republic). In addition, the long-service thermal precipitator was also employed (apparatus recommended in Great-Britain until 197o).

During these measurements, mainly carried out in face air return roadways, attention was given to siting all these instruments at the same points and using them over the same periods of time.

Critical analysis of results led to the following conclusions:

- There was agreement, in the mean, between the different methods of ranging the environments in an ascending order of harmfulness, if the dustiness classes are regrouped into 3 categories - I, II and III, IV.
- Comparison of dustiness measurements taken by <u>two instruments leads to a significant correlation in each case</u>. If there is no agreement between methods in distinguishing so-called "good" environments (I and II) and "bad" environments (III and/or IV), this lack of homogeneity is due to the choice of class thresholds and not to the measurements as such.
- On the basis of objective considerations it is possible to put forward modifications to the existing limits. These new class thresholds lead not only to good overall agreement but also to a sound homogeneity of the "good" and "bad" classifications. The new threshold values proposed make it possible to relate on to another all the environmental measurements made by one or other of the instruments mentioned.

The comparative measurements carried out by the Steinkohlenbergbauverein, Essen, in the German coal mines with the fine dust BAT I filter, the TBF dust sampler (minus filter), the MRE Gravimetric Dust-Sampler and the tyndalloscope (Research project 6251-31/1/012) provided the results shown in Table 2 in part. Index z of suspended dust fineness was taken to be the ratio of the fine dust mass to that of very fine dust, as obtained by measurement with the TBF dust sampler.

The fineness of the dust had a pronounced effect on the specific diffused light intensity, i.e. on the relationship between the tyndalloscope measurement value I and the mass concentration of the fine dust.

2.3.2 <u>Identification of minerals and size distribution</u>

The Clinica del Lavoro, Milan, compared the quartz content, in percentages of particles of respirable dust, obtained by the phase-contrast method, with the corresponding weight % values obtained by chemical or radiological methods (Research project 6251-31/4/022-001). In coal dust with a 3,2% quartz content, the quartz proportion established by the phase-contrast method was about 85 to 90% of the weight ratio. 2,6% pyrites yielded far greater divergencies which can be explained by the differing densities of quartz (2,65) and pyrites (5,5). The quartz proportion in percentages of particles was in this instance about twice as large as the percentage obtained on a weight basis. The question, which of these two quartz percentage values should be used for comparisons with MAK values in the equations, was resolved by deciding that the quartz proportion in percentages of particles should be used when numerical critical values were available, and the quartz proportion in weight percent when gravimetric critical values were available. Previous investigations by the Clinica del Lavoro, Milan (Research project 6251-31/4/022) had made use of maximum layer thicknesses for bright-field counts with different magnifications.

The Steinkohlenbergbauverein, Essen (Research project 6251-32/1/006)+) carried out special investigations in eleven pits in the Ruhr and one in the Saar to establish whether gravimetric links existed between the mineral content of the standing coal and fine dust. Attempts were also made to discover whether there was an intrinsic relationship between type of mineral and particle size distribution. The minerals were identified by means of infra-red spectroscopic measurement. It proved impossible to deduce the mineral content in the fine dust range from data on the

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+) Leiteritz, H: The mineral composition of suspended dust in coalmining. Contained in: Results of investigations into measures against dust and silicosis in coalmining. (Silicosis report: North Rhine - Westphalia, Vol. 7. Detmold: Bösman 1969, pp.27-33.

mineral composition of solid rock or rock drillings. Even qualitative deductions can only be made with certain reservations. Although all minerals in the respirable suspended dust are necessarily also contained in the solid, it does not follow that all the minerals in the solid form part of the respirable suspended dust. The predominant mineral constituents within the fine dust range - as a rule more than 80% of the dust - are the clay minerals illite and sericite and kaolinite. The presence of feldspar could not be proved.

The stone dust is normally finer sized than coal dust. The geometric mean values of the normally distributed logarithmic diameters of coal, quartz and stone particles were approximately 2.2 μm (coal), 1.6 μm (quartz) and o.9 μm (stone).

Research into particle size and composition of dusts samples in Belgian winning workings (Research project 6251-31/2/976, Institut d'Hygiène des Mines) has also shown that the size distributions can be represented by the Gauss law as a function of the logarithm of particle diameter (normal logarithmic distribution). The results, grouped according to the ash content of dusts and the volatile matter of coal, have been statistically evaluated.

- The percentage, in terms of numbers, of particles under 1 μm does not depend on the volatile matter; it rises asymptotically from 28 to 34% when the ash content increases from 10 to 75%.
- The average numerical diameter is reduced exponentially when the ash content rises moving to 1.41 μm. Above a 50% ash content the type of winning has some influence.
- With pneumatic pick winnings (geometric variation σg = 2.18) or with drum shearers (σg = 2.26), the results are independent of volatile matter and ash content - at least when above 50%. In plough winning the dispersal varies in a clearly parabolic manner as a function of

volatile matter, MV (σg = 2,12 between 15 and 2o% MV and σg = 2,45 for 5 and 30% MV).

- Assuming a normal logarithmic distribution it is possible to calculate the weight proportion p_5 of particles below 5 μm. This percentage varies exponentially between 10 and 7o% ash with pneumatic pick winning (p_5 = 14...18%) or drum shearer (P_5 = 18...23%). In the case of ploughs p_5 varies according to a "bell"-shaped curve as a function of volatile matter, the maximum 20% being in the region of 15...20% MV and minimum values (p_5 = 6%) near 5 and 35% MV (in this case the influence of ash content is weak).
- There is a significant linear correlation between the free silica content (measured chemically) and the ash content of dusts, but it has not been possible to demonstrate the effect of types of winning. The regression equation is: $q = o{,}363_c - 4.23$, where q represents the silica content and c the ash content.

Investigations on dust samples in Netherlands pits by the Stofinstituut, Limburg (Research project 6251-41/6/052) showed that ash content and fineness of dust decreased with rising dust concentration during coal winning and increased during withdrawing operations. In all types of operations the proportion of fine dust increased as the ash content rose.

3. RESEARCH INTO PNEUMOCONIOSIS (PNEUMOCONIOSIS AND ENVIRONMENTAL FACTORS)

3.1 Methods and historical evolution

The success of dust suppression can be assessed from the measurement results of routine dust monitoring; ultimately it affects the development of pneumoconiosis in the workers. Changes in dust-affected lungs are, however, the outcome of protracted exposure to dust. It is, therefore, important to find a way of expressing short-term changes in the development of pneumoconiosis to be able to recognise the effect of operational measures which can make lasting changes in dust conditions. It is possible to establish appropriate indices from the frequency of transitions from one pneumoconiosis phase to the next in workers in a pit or a group of pits within a set period, depending on length of service, which are termed "transition probabilities" in short.

These make it possible to:

- compare the trend in pneumoconiosis development at different times and for different groups of workers,
- assess from this the effect of dust suppression measures, even without knowledge of the dust level,
- and to forecast the pneumoconiosis risk as a factor of dust levels.

This demographically based method has been used in the French coalmining industry for some years+). It was the subject of several discussions in the ECSC Working Group on "Pneumoconiosis and Environmental factors" after interest had spread to the other countries. Using one pit in the German Federal Republic as an example the informative character of the indices in relation to number of miners covered and length of observation is currently being checked. An appropriate programme of electronic data processing and evaluation is being prepared for the general application of this method in the coalmining industry of the Federal Republic.

+) Quinot, E: Definition of criteria enabling the degree of harmfulness of dust levels to be measured; II Test to determine permissible dust levels and its application in the Nord and Pas-de-Calais coalfield. Revue Médicale Minière 1970, 2nd Series, Nos 1 and 2 (Issue devoted to the medical conference on 6th and 7th November 1969 organised by the Charbonnages de France) pp.89-99.

In addition to this indirect method, direct investigations into the different factors influencing pneumoconiosis are being undertaken in Belgium, the German Federal Republic and Italy. Exposure to dust is the most important of these factors. It includes the amount of fine dust available in fine dust concentrations in the working, the period of exposure and the specific harmfulness of the dust. But other factors, such as the time the dust remains in the lung, the personal susceptibility and other environmental influences, contribute to the development of pneumoconiosis (see figure 27).

Clearly these latter epidemiological investigations require more effort because individual data, particularly of dust exposure over long periods of observation, have to be collected. The aim of these is to establish dust thresholds for the workers and other criteria for employment which will ensure that no changes in dust-affected lungs impairing health occur and that even miners exhibiting preliminary stages of pneumoconiotic changes can continue to be employed without undue risk. In this way guidelines for well-directed dust suppression and effective deployment of workers can be provided.

In Belgium the Institut d'Hygiène des Mines, Hasselt, started in 1957 to give the underground workers at the Houtpalen pit special medical check-ups and initiated a systematic programme of measures to discover the dust levels in workings (Research project 6231-41/2/629). Up to the end of 1965 the dust measurement results with a thermal precipitator (particle counts per cm^3 between 0.5 and 5.0 μm sized particles and the quartz content in these particles) and other technical information on the working site of each miner have been recorded every fortnight in a card index and on punched cards. These investigations were made more difficult from 1963 onwards by fluctuation and contraction in the work force and were finally halted in 1966.

The introduction of an index card entitled "Working Activity and dustiness levels" in 1954 in the German Federal Republic made the introduction of these investigations possible. This card, one of these being held for each miner in the West German coal industry, records monthly returns about dust exposure, the working activity and both geological and operational conditions at the working site. Also available are the radiological lung data established by industrial doctors and maintained in medical records. Evaluation of those data with the aid of punched cards was started by Steinkohlenbergbauverein, Essen, in 1960. By now results from 10 pits over an observation period of 10 years are available (Research projects 6251-41/1/016; 6251-41/1/017; 6251-41/1/018). They are now being extended to 14 years and to additional pits by continuing investigations (Research project 6251-41/1/018/001).

In Italy similar epidemiological investigations have been in hand since 1966 by the occupational medicine institute of Cagliari University in the Sulcis coalmines in Sardinia (Research project 6251-41/4/069). Here too the dust levels at various workings and at fixed intervals are being established according to the method used in Belgium. Data for each miner, covering information about the working site, the length of time spent there and the annual medical records are also entered in a card index and prepared for computer evaluation. The evaluation made to date helped to provide an overall picture of the dust and climatic conditions and the health record of the workers. Results regarding the relationship between environmental conditions and the development of pneumoconiosis are not yet available. They are awaited with particular interest as the coal deposits in Sardinia are of tertiary origin, while the other research covered carbon deposits.

Here the epidemiological research started in 1953 in 25 pits in the British coal industry should be mentioned, which forms part of the Pneumoconiosis Field Research programme. They have already yielded valuable results and a comparison with the results obtained in ECSC countries should prove informative+).

3.2 Results of epidemiological research

3.2.1 Effect of dust exposure

The main focus of investigations to date was to classify the effect of both dust concentration and length of exposure on the development of pneumoconiosis.

It was established at the Houthalen pit in Belgium (Research project 6251-41/2/029) that the dustiness level in coal winning workings and development work was greatly reduced since 1957 due to intensive dust suppression.

The koniotic index i or harmfulness index, is used here to denote the dustiness level:

$$i = 3.32 \log C.t - 9.3$$

which includes both fine dust concentration C, particles per cm^3 air between 0.5 and 5 μm particle size, and the quartz content t(%) in these particles, and constants (function of the sampling and evaluation methods recommended by the Institut d'Hygiène des Mines). From 1957 to 1965 index i has on average been reduced by one unit (from 4.7 to 3.8), showing that the fine dust concentration has been reduced by half, the quartz content remaining unchanged.

The success of these measures is reflected in the health of the workers. Thus the average working age of miners with lung changes of category m_1 (according to the International radiographic classification - Genève 1958)

+) Jacobsen, M.,Rae, S.,Walton,W.H. and Rogan,J.M.: New dust standards for British coal mines. Nature 227 (1970) N° 5257, pp. 445-47.

has risen from 13 to 18 years between 1957/58 and 1965/66 and that of miners with changes in categories m_2 and m_3 from 16,5 to 20,5 years. In addition, in the period 1958 to 1964, the probability of undergoing certain lung changes within 2 years has been reduced in all working-age groups, as shown in Table 3. For purposes of comparison Table 3 also shows the corresponding probabilities in another pit (C.B.L.).

After 10 to 20 years underground at Houthalen in 1958 there was a better chance of retaining a normal-subnormal radiographic image than after 5 to 10 years at C.B.L.

In 1964, thanks to dust suppression measures, the situation has improved in the two pits, but workers with 10 to 15 years underground at Houthalen still had as good prospects of staying in good health as those at C.B.L. a 5 to 10 years of service. It should be noted that the dustness levels in the two pits were markedly different. The weighted averages of mean values obtained between 1966 and 1969 during winning were as follows (expressed in mg/m^3 of total dust):

28 mg/m^3 (27,5% ash) at Houthalen and
42 mg/m^3 (21% ash) at the C.B.L. pit.

Moreover, the annual average dust levels for the previous 10 years should not have exceeded 40...45 mg/m^3 at Houthalen while they were probably above 70...80 mg/m^3 (total dust) at the other pit.

After comparing the medical and technical data gathered during the above research work, it would appear that the risk of pneumoconiosis is nil after 10 years if the air harmfulness index i (IHM method) is $\leqslant$4,35 and virtually nil after 14 years if i $\leqslant$4,2. There is every reason to think that an index i $\leqslant$ 3,85, or a total concentration of the order of 25 mg/m^3 of coal dust with less than 30% ash is not dangerous.

These latter values correspond to about 2000 particles, cm^3 (5-0,5μm) with a quartz content of 4...5% or a weight concentration of 25...3 mg/m^3 of coal dust below 5 μm.

In France it has been calculated, for the conditions prevailing in the Nord and Pas-de-Calais Coalfield, that a fine dust concentration of less than 2000 particles between 0.5 and 5 μm per m^3 represents an under 10% risk of the onset pneumoconiotic changes of category 2 and above for a 30 year period of work underground+). The current objective of dust suppression measures there is to keep below this figure in all cases. The risk level has been worked out on the basis of partly estimated earlier dust levels in workings and the incidence of pneumoconiosis as related to working age. This calculation rests on the assumption that a change in the period by factor $\sqrt{F}$ would produce the same risk factor. Should, for example, the dust level be halved, the same risk would involve an exposure time longer by only factor $\sqrt{2}$.

The investigations in the coal industry of the German Federal Republic have proved that the changes in pneumoconiosis are mainly attributable to the cumulative effect of dust exposure (Research project 6251-41/1/016 of the Steinkohlenbergbauverein, Essen). The total dust value

$$\sum_{j=1}^{j=n} (k_j \; S_j)$$

where the tyndalloscopic fine dust concentration is k, obtained for each month j at the working site, and the duration of exposure related to the number S of shifts

+) See footnote on page 91

worked, makes it possible to assess the pneumoconiosis risk in certain conditions+).

The period of time in which a certain dust total has been reached - investigated up to 15 years - has not demonstrated any influence on the risk, in contrast to the above mentioned French assumption. Figure 28 shows the risk of the onset of certain pneumoconiotic changes depending on total dust for average conditions in 10 representative pits in the Ruhr. Deployment of workers is, therefore, an option presenting itself beyond a threshold of dust exposure, i.e. beyond a certain total dust value, a practice already employed in the Saar.

On the assumption that a miner is exposed to dust for an average of 200 shifts per year and that the period in which a certain dust total is reached has no influence on the risk, the following risks were established for a working life of 35 years and an average tyndallometric fine dust concentration of k = 18:

55% for the onset of at least very slight (-I),
20% for the onset of least slight (I) and
5% for the onset of at least slight to medium (I-II) pneumoconiotic changes according to the 1930 Johannesburg classification. The latter corresponded approximately to category 2 of the 1958 international Geneva classification. Taking into account the conditions of concentration en-

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+) Reisner, M.T.R.: Pneumoconiosis and dust exposure. Results of epidemiological investigations in the Ruhr over a 10 year period. Contained in: Results of investigations into measures agains dust and silicosis. (Silicosis report - North Rhine - Westphalia). Vol. 8. Essen: Verlag Glückauf 1971, pp. 221-31.

countered, a k value of 18 corresponds to a gravimetric fine dust concentration of about 1 mg/m^3, measured by the BAT I fine dust filter+).

Epidemiological research in the British coal industry has surprisingly led to the same result.++) It was established there that, with an average fine dust concentration of 4.3 mg/m^3, a risk of 3.4% for the development of lung changes in category 2 (Geneva 1958) can be expected after an exposure period of 35 years, the dust being measured with an MRE Gravimetric Dust Sampler. Comparative measurements show that the mass concentration of 4.3 mg/m^3 (MRE Sampler) is very close to the guide values of 1 mg/m^3 (BAT I apparatus) and the 18 k values (tyndalloscope).These values should not be taken as limits above which employment was no longer permissable but rather as guide values for average dust conditions. It is on these guide values that the new gravimetric dust standards are based which were introduced in the British coalmining industry in 1970.

The commission of the German Research Association (Deutsche Forschungsgemeinschaft) examining working materials harmful to health has used the results of epidemiological research to include for the first time a value for quartz-bearing fine dust in the MAK list of values (maximum working site concentration),+++) fixing it at 4 mg/m^3.

+) See footnote +) and ++) on page 64

++) See footnote on page 94

+++) Deutsche Forschungsgemeinschaft: Maximum Working Site Concentration. Communication VII of the Commission investigating the health hazards in work materials, 29/6/1971.

This value is applicable to the coalmining industry provided the quartz content doe not exceed 5 weight % in fine dust. Fine dust, in this context, is dust which passes through a pre-separator in a dust sampler, such as the MRE Gravimetric Dust Sampler, which separates 100% of the particles with an equivalent diameter of 7.1 μm and 50% of the particles with an equivalent diameter of 5.0 μm, as recommended by Johannesburg 1959.

3.2.2 Effect of other factors

In addition to dust exposure the effect of other factors on the development of pneumoconiosis have also been established. The risk increases, for example, with increasing age when first exposed to dust but also the longer the dust remains in the lung (see Research projects 6251-41/2/029 and 6251-41/1/016, already referred to). A specific influence of the different mining activities could, however, not be established (Research project 6251-41/1/017 of the Steinkohlenbergbauverein, Essen).

A surprising result was that, given comparable total dust amounts, lung changes became less frequent as the proportion of stone in fine dust increased. This is explained by the tyndallometric method of measurement+). The diffused light intensity of the dust measured by the tyndalloscope depends on the fineness of the dust. In particular, the particle size range around 1 μm is heavily overvalued. This applies especially to measurement of stone dust. These connections were already referred to in Section 2.

Measuring techniques can also partly explain the differences in pneumoconiosis risks in different pits and in differing geological and operational conditions at working sites. In addition, such differences have a bearing on the problem of the specific harmfulness of dusts. Attempts

+) See footnote ++++) on page 64

have often been made to define harmfulness of dust in terms of its composition, special weight being given to quartz. Following the improved knowledge derived from pneumoconiosis research and the clearer picture of dust conditions obtained over the last two decades from numerous dust measurements, it is now doubted whether quartz still occupies a prominant place in coalmining today.

A study by the Silikose-Forschungsinstitut, Bochum (Research project 6251-32/1/047) of the composition of lung dust compared with suspended dust showed that the minerals contained in both coal particles and rock particles can be found in the lung in roughly the same quantities as they had been found in suspended dust. The view that the amount of quartz dust found in the lung was indicative of the seriousness of the silicosis could not be confirmed.

As yet epidemiological investigations of the Steinkohlenbergbauverein, Essen, have been unable to prove that quartz increases the risk of pneumoconiosis in coal miners in existing conditions (Research project 6251-41/1/018)+). ++). Investigations in different seam horizons of the Ruhr coalfield show that, with the low quartz contents in fine dust - on average 2% - generally found today, even higher quartz contents and concentrations in fine dust have led to a lower proportion of miners with simple pneumoconiosis and vice-versa. This points to the effect of quartz being overridden by other factors which have still to be identified.

+) Reisner, M.T.R.: The prevalence of pneumoconiosis in relation to dust conditions in different seam horizons in the Ruhr. Contained in: Results of investigations into measures against dust and silicosis. (Silicosis report North Rhine-Westphalia).Vol.8. Essen: Verlag Glückauf, 1971, pp. 215-19.

++) See footnote on page 94

This fact was taken into account by the Commission for examining working materials harmful to health of the Deutsche Forschungsgemeinschaft when laying down the MAK - value for quartz-bearing fine dust in the coal industry.+)

3.3 Continued research

Physical, mineral and biological research is currently being carried out in various countries into dust samples from selected pits and the results compared with the incidence of pneumoconiosis at these pits in order to find a valid index for the specific harmfulness of dusts. This work will continue to have special priority in the future.

In addition, information on partly resolved or as yet unanswered questions is hoped for from this continued epidemiological research, for example, on:

- the risk trend with higher dust totals than could be assembled over a 10 year observation period and on the incidence of medium and serious changes,
- the influence of the time the dust is retained in the lung,
- and the development of lung changes in relation to previous and future dust exposure, for all of which long periods of known dust exposure are needed.

An important aspect for underground employment is the individual response of the miners to the effect of dust in the inhaled air. For this reason more intensive research should be carried out on this subject, previous research having been hampered by ignorance about the exposure to dust.

Last but not least, adequate data should be collected to have available a basis for the gravimetric assessment of the dustiness limits derived from the various investigations in this field.

+) See footnote on page 98

Annexe 1

Table 1

Average diameter of fractions of a multi-stage cascade impactor in μm for different air streams

	Air stream in l/min			
	10,00	14,14	20,00	28,28
Stage 2	12,57	10,57	8,89	7,48
Stage 3	6,33	5,32	4,48	3,76
Stage 4	3,18	2,68	2,25	1,89
Stage 5	1,59	1,34	1,13	0,949

Table 3

Annexe 1

Probability - in 1958 and 1968 - of undergoing pneumoconiotic changes within two years for two Belgian pits, related to the working age underground.

Working age underground	Houthalen		Liège	
	1958	1964	1958	1964
	%	%	%	%
< 5	1,8	0,0	9,6	9,6
5 - 10	9,2	3,9	26,4	14,7
10 - 15	18,0	15,0	28,0	19,3
15 - 20	19,1	17,0	-	21,7

Annexe 1

TABLE 2

Comparative figures of measurement values of different dust measurers with different coal winning methods

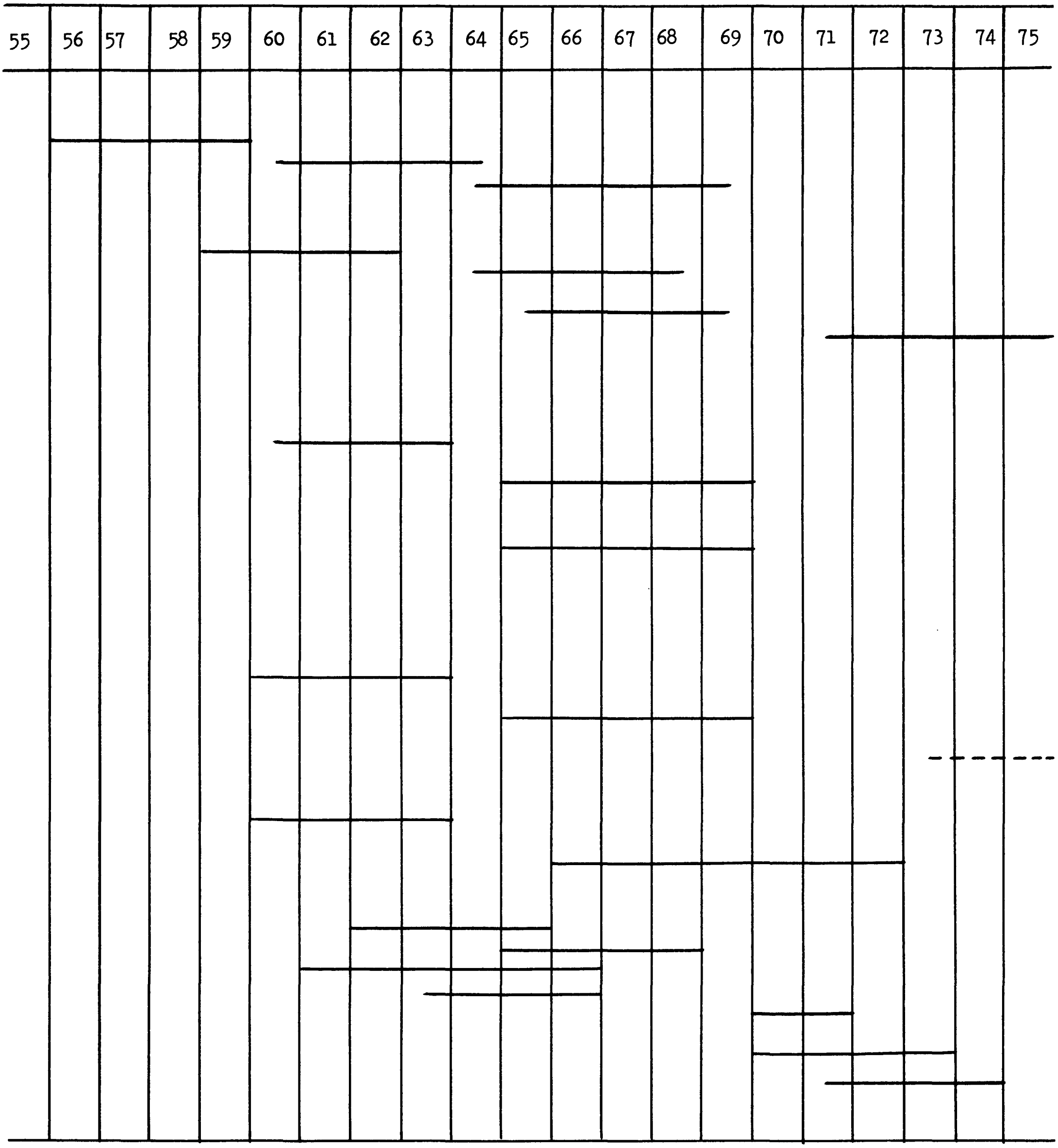
Winning method and type of stowing	fineness index z	ash content weight %	Comparative index of measuring values of the instruments				
			TBF 50	MRE-GDS	MRE-GDS	Tyndalloscope	
			BAT I	BAT I	TBF 50	BAT I & TBF 50	
Cutting coal winning	11,33	38,1	4,19	4,70	1,13	19,51	5,05
Stripping coal winning with pneumatic stowing	14,85	18,2	4,89	5,58	1,14	15,63	3,22
Stripping coal winning with caving	17,83	17,6	5,54	6,98	1,27	16,67	3,06
Pneumatic pick winning with rams	34,29	6,7	6,62	5,52	0,83	8,34	1,30

PROGRAMME OF RESEARCH IN INDUSTRIAL MEDICINE, HYGIENE AND SAFETY, UP TO 31 DECEMBER 1971

Field covered and designation	Decision of :	Budget (round figures, in units of account)	
		Total budget	Research contracts signed
A - INDUSTRIAL MEDICINE AND HYGIENE			
a) Physiopathology and clinical medicine			
1st programme (industrial medicine)	5-10-1955	1 200 000	1 200 000
2nd programme (industrial medicine)	7- 4-1960	2 800 000	2 856 000
3rd programme (physiopathology and clinical medicine)	28- 4-1964	3 000 000	2 680 000
b) Traumatology and rehabilitation			
1st programme (rehabilitation) (1)	5-12-1957	500 000	500 000
2nd programme (traumatology and rehabilitation)	19- 6-1964	1 800 000	1 100 000
3rd programme (burns)	18- 5-1966	1 500 000	560 000
4th programme (chronic respiratory dideases)	13-10-1970	2 500 000	60 000
			8 956 000
B - INDUSTRIAL PHYSIOLOGY AND PSYCHOLOGY			
a) Human factors and safety			
1st programme (human factors and safety) (1)	5-12-1957	1 000 000	1 000 000
2nd programme (human factors and safety) (2)	4-11-1964	1 200 000	
b) Ergonomics			2 416 000
1st programme (physiology and organization of work) (2)	4-11-1964	2 000 000	
			3 416 000
C - INDUSTRIAL HYGIENE			
a) Measures against dust in mines			
1st programme (technical measures against dust in mines) (1)	5-12-1957	900 000	900 000
2nd programme (technical measures against dust in mines)	21-12-1964	6 000 000	5 236 000
3rd programme (health in mines)	28- 7-1971	4 500 000	-
b) Technical measures against dust in steelworks			
1st programme (technical measures against dust in steelworks) (1)	5-12-1957	600 000	600 000
2nd programme (technical measures against airpollution in steelworks	14- 6-1967	4 000 000	2 295 000
c) Separate research projects			
Red fumes in convertors	18- 7-1961	1 000 000	1 000 000
Red fumes in convertors (3)	19- 6-1964	1 825 000	1 025 000
Climatic factors in mines	16- 3-1966	116 000	116 000
Defluorization of gases	16- 3-1966	66 875	65 000
d) Large-diameter drilling to rescue trapped miners	19-12-1969	70 650	68 590
e) Stopping erected	19-12-1969	250 039	242 756
f) Roadway fires and underground combustion	28- 7-1971	502 267	487 635
			12 035 981
TOTAL :		37 330 831	24 407 981

(1) This programme is part of a single budgeting plan, under the general title of "Safety", and comprising four programmes.
(2) This programme is part of a single budgeting plan, under the general title of "Human factors and ergonomics", and comprising two programmes.
(3) Extension requested until 30 June 1968.

Duration initially envisaged for the overall programmes



Legend :

——— Programmes completed or in progress

- - - - - Programmes in preparation

Annexe 2

SECOND PROGRAMME OF RESEARCH

"TECHNICAL MEASURES OF DUST PREVENTION AND SUPPRESSION IN MINES"

DETAILED LIST OF RESEARCH PROJECTS

Name of requesting research institute (receiving financial support)	Purpose of the research project
Bergbauberufsgenossenschaft, Bochum	The addition to pneumatic stowing material of additives reducing the amount of dust freed.
Bergbauberufsgenossenschaft, Bochum	Dust suppression measures during winning and transport in thick seams of iron ore.
Bergbauberufsgenossenschaft, Bochum	Research into new methods of stemming for shotfiring.
Bergbauberufsgenossenschaft, Bochum	Dedusting at loading points.
Bergbauberufsgenossenschaft, Bochum	Development of a process for separating respirable dust according to size by sedimentation. Comparison of the diameter projected in the microscope and the Stokes diameter.
Bergbauberufsgenossenschaft, Bochum	Development of automatic spraying system to bring down dust produced during ploughing.
Bergbauberufsgenossenschaft, Bochum	Measures to suppress dust produced by shearers.
Bergbauberufsgenossenschaft, Bochum	Development of water infusion in deep holes.
Bergbauberufsgenossenschaft, Bochum	Use of evaporation-retarding substances in bad climatic conditions.

Name of requesting research institute (receiving financial support)	Purpose of the research project
Bergbauberufsgenossenschaft, Bochum	Research into the mineralogical composition of "respirable" dusts before and after inhalation, so as to determine their pathogenical action in pneumoconiotic diseases. Research into the possibility of selective separation of the dust in filters and in the air passages.
Bergbauberufsgenossenschaft, Bochum	Elimination of dust deposited by coaldust-aspirating apparatus.
Bergbauberufsgenossenschaft, Bochum	Relationships between diffused light and the magnitudes indicated by the tyndalloscope for the surface area of dust particles. Comparison of the tyndalloscope reading - making allowance for the magnitudes indicated for the surface areas of the particles - and the readings given by other measurement devices.
Bergbauberufsgenossenschaft, Bochum	The influence of additives on de-dusting by wet methods on cutter loaders with drums taking into account know-how on the optimum design of hydraulic systems and using devices already developed for water precipitation of dusts.
Bergbauberufsgenossenschaft, Bochum	Development and experimentation of special de-dusting devices for new types of loading points in highly mechanised faces.
Bergbauberufsgenossenschaft, Bochum	Use and experimentation of newly designed de-dusting equipment for cutter loaders with two drums of different types.
Bergbauberufsgenossenschaft, Bochum	Determination of relationships between the pressure of overlying strata and the suitability for drilling and impregnation of the coal.

Name of requesting research institute (receiving financial support)	Purpose of the research project
Bergbauberufsgenossenschaft, **Bochum**	**Further development of a filter for materials in suspension with enhanced fine particle separation qualities at low-flow resistance.**
Bergbauberufsgenossenschaft, Bochum	**Comparison of the individual dust burden measured gravimetrically with the gravimetrically determined dust concentration in the final state of dustiness at a winning face.**
Cerchar, Paris	Study of winning and of dust aspiration in the face.
Cerchar, Paris	Study of the best conditions for water infusion in the solid coal.
Cerchar, Paris	Development of a simple, portable and independent continuous dust-sampling apparatus.
Cerchar, Paris	Practical investigations into water infusion.
Cerchar, Paris	Research into the development of an apparatus indicating the dustiness level for immediate reading, giving accurate values in moist conditions and capable of use underground.
Cerchar, Paris	Measures to suppress dust during vertical transport.
Chambre syndicale des Mines de Fer de France, Paris	The de-dusting of continuous miners.
Chambre syndicale des Mines de Fer de France, Paris	Dust suppression in drilling.
Chambre syndicale des Mines de Fer de France, Paris	Elimination of nitrous vapours produced by diesel engines and shotfiring.
Clinica del Lavoro, Milano	The use of wetting agents to reduce the degree of dustiness.

Name of requesting research institute (receiving financial support)	Purpose of the research project
Clinica del Lavoro, Milano	Research on the power of separation of microscopes used for the counting of dust particles.
Clinica del Lavoro, Milano	Research into ventilation of heading faces.
Clinica del Lavoro, Milano	Comparative study of degrees of dustiness produced by drilling machines.
De Gezamenlijke Steenkolenmijnen in Limburg	Establishing a comparison between different methods of measuring dust with a view establishing threshold dustiness values.
De Gezamenlijke Steenkolenmijnen in Limburg	Dust-suppression measures in mechanised faces during caving.
De Gezamenlijke Steenkolenmijnen in Limburg	Comparison of the criteria for assessing dustiness levels, by means of measures carried out in underground mine workings.
De Gezamenlijke Steenkolenmijnen in Limburg	Development of a recording dust-measuring device.
De Gezamenlijke Steenkolenmijnen in Limburg	Research into the emission of gas simultaneously with dust during shotfiring, in particular carbon monoxide and nitrous vapours.
De Gezamenlijke Steenkolenmijnen in Limburg	Water infusion in an unworked panel.
De Gezamenlijke Steenkolenmijnen in Limburg	Investigation of water infusion where very high back-pressures occur.
De Gezamenlijke Steenkolenmijnen in Limburg	The investigation of certain factors having an influence on the climate of underground workings in collieries.
Faculté polytechnique de Mons	Protection of the surrounding rock of coal seams against the effects of water infusion.

Name of requesting research institute (receiving financial support)	Purpose of the research project
Institut d'hygiène des mines, Hasselt	Comparative measurements of the degree of dustiness in underground working. Comparison of the "assessment criteria" of the dust nuisance adopted in different Community countries.
Institut d'hygiène des mines, Hasselt	Investigation of degrees of dustiness in relation to the working activity and medical history of mine-workers.
Institut d'hygiène des mines, Hasselt	Water infusion combined with shotfiring in seams subject to instantaneous outbursts of methane.
Institut d'hygiène des mines, Hasselt	Infusion of water in a panel before working, to some depth, working from existing roadways or roadways which may have been driven for the purpose (advanced remote infusion).
Institut d'hygiène des mines, Hasselt	Investigation of water spraying under cowls with the use of evaporation-retarding additives. Effects on the cleaning of conveyor structures.
Institut d'hygiène des mines, Hasselt	Investigation of the penetration of water into the solid coal with the purpose of ensuring longer lasting wetting of the coal brought down without bad effects on climatic conditions.
Institut d'hygiène des mines, Hasselt	Study of the granulometry and the nature of dusts sampled in underground workings.
Institut national des industries extractives (INIEX), Liège	Development of an adequate apparatus for suppressing dust on a driving and loading machine in a rapid-advance face.
Institut national des industries extractives (INIEX), Pâturages	Reduction of nitrous vapours in shotfiring fumes.

Name of requesting research institute (receiving financial support)	Purpose of the research project
Institut national des industries extractives (INIEX), Pâturages	Cleaning conveyor structures and eliminating dust deposited in district roads.
Istituto di Arte Mineraria del Politecnico di Torino	Technical measures against dust during pneumatic stowing.
Istituto di Medicina del Lavoro dell'Università di Cagliari	Systematic control of dust concentrations and of the chemical nature of the dust in the Sulcis (Carbonia) coal-mines, together with the relationship of these factors with the development of pneumoconiotic diseases (2)
Musée d'histoire naturelle Luxembourg	Measurement of dust in iron-mines and analysis of the dusts.
I. Physikalisches Institut der Universität Wien	Measurement of the distribution function of dust by means of cascade impactors.
Steinkohlenbergbauverein, Essen	Research into the different factors causing stirring-up of dust during shot-firing. Development of new processes intended to reduce the production of dust and to precipitate it.
Steinkohlenbergbauverein, Essen	Behaviour of the dust in the ventilation air. Research into: a) distribution of the dust in the ventilation air; b) the sedimentation of the dust; c) the influence of the air quantity, air velocity, turbulence and direction of ventilation on the dust concentration; d) the behaviour of the dust in a turbulent current of air (theoretical and experimental investigation).
Steinkohlenbergbauverein, Essen	Development and trial of new dedusting processes using aspiration and precipitation:

Name of requesting research institute (receiving financial support)	Purpose of the research project
	a) used with winning machines and roadway-heading machines; b) used in stowing operations; c) used at moving or fixed transfer points; d) used during shotfiring; e) used in roadways driven in the solid associated with faces of high dustiness.
Steinkohlenbergbauverein, Essen	Development of apparatus for measuring fine dusts, intended to operate over long periods and based on fractional separation of the dust.
Steinkohlenbergbauverein, Essen	Research into the relationships existing between the quantities and the mineralogical composition of suspended dust which enter into the workers' lungs, and the nature and structure of the substances giving rise to the dust and the way in which they break up.
Steinkohlenbergbauverein, Essen	Infusion of water into the seam, in particularly intensive mechanised faces with high rates of advance, paying particular attention to deep or remote infusion, coupled with the development of apparatus, high-pressure hoses and armatures required for these applications.
Steinkohlenbergbauverein, Essen	Measures against dust produced by winning and loading machines.
Steinkohlenbergbauverein, Essen	Shots fired in water.
Steinkohlenbergbauverein, Essen	Physical principles and development of apparatus intended to determine the concentration of dust in mines and to produce size analyses thereof.

Name of requesting research institute (receiving financial support)	Purpose of the research project
Steinkohlenbergbauverein, Essen	Development of recording dust-measuring apparatus: - allowing of transmission of the measured values to a central control point; - allowing of remote indication of the removal of dust beyond dedusting installation.
Steinkohlenbergbauverein, Essen	Development of the B.A.T.I. filtration sampling apparatus for fine particles of dust, in the form of a self-powered sampling device.
Steinkohlenbergbauverein, Essen	Research into the physical properties of coals and rocks and the behaviour of the dust formed therefrom.
Steinkohlenbergbauverein, Essen	Research into the spectroscopic determination of the inorganic components of mine dusts and of the dusts which penetrate into the lungs.
Steinkohlenbergbauverein, Essen	Development of a routine quantitative X-ray analysis method to determine the mineral content of dusts occurring in coal-mines.
Steinkohlenbergbauverein, Essen	Research into the relationship between pneumoconiotic diseases and dustiness.
Steinkohlenbergbauverein, Essen	Research into the influence of activity, geological conditions and occupation of the development of pneumoconiotic diseases.
Steinkohlenbergbauverein, Essen	Special research in certain mine workings with regard to anomalies in the frequency and seriousness of pneumoconiotic diseases.
Steinkohlenbergbauverein, Essen	Study of the physical properties of coal and rock and the behaviour of coal and rock dust with

Name of requesting research institute (receiving financial support)	Purpose of the research project
	particular reference to semi-conductor properties.
Steinkohlenbergbauverein, Essen	Experimentation with products (hygroscopic salts, for example, which may be added to liquids for infusion.
Steinkohlenbergbauverein, Essen	Comparative measurements using different dust measuring devices, taken in an experimental channel in which the construction, size distribution and the nature of the dust can be varied.
Steinkohlenbergbauverein, Essen	Influence of air speed on the raising and giving off of dusts of a different composition, granulometry and humidity.
Steinkohlenbergbauverein, Essen	Development of a photoelectric system for measurement of diffused light for the purpose of determining the concentration of dusts, including the development of measuring devices.
Steinkohlenbergbauverein, Essen	Water injection into the solid coal: basic research to improve methods of wetting the coal and to determine the wetting mechanism by the use of indicators. Tests on the development of impregnation for strike faces from winning roadways. Experimental use of advance remote infusion from the face. Further development of the remote infusion process. Impregnation by high viscosity liquids. Further development of impregnation and drilling equipment.
Steinkohlenbergbauverein, Essen	Development and tests on processes and equipment to control dust by aspiration and precipitation of dusts given off around shaft sinking and rise drifting machines and for faces with heavy concentrations of dust.

Name of requesting research institute (receiving financial support)	Purpose of the research project
Steinkohlenbergbauverein, Essen/Bergbau-Berufsgenossenschaft, Bochum	Control of dust caused by shearers.
Versuchsgrubengesellschaft mbH, Dortmund	The use of hygroscopic salts as a means of protection against dust and against explosions in coal-mines.

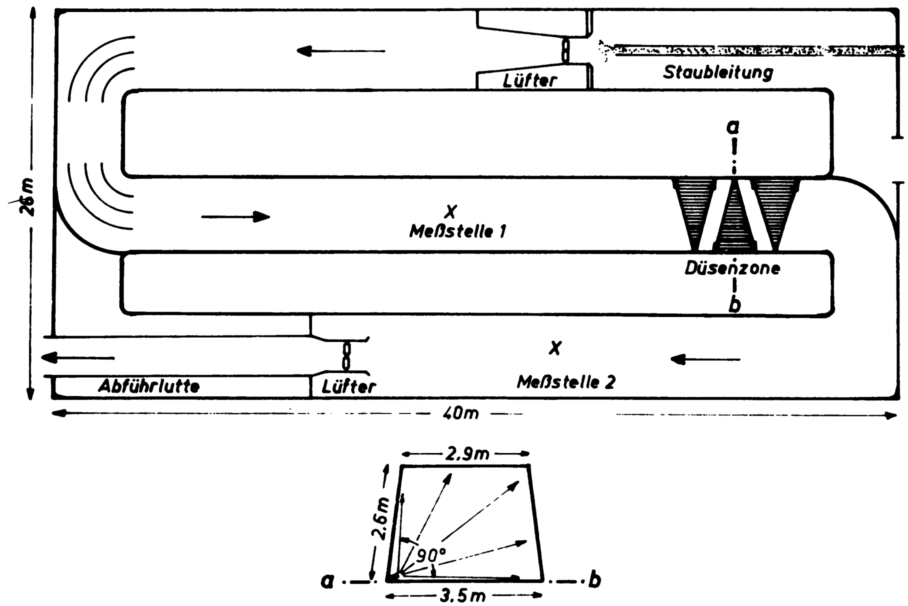


Fig. 1. Diagrammatic representation of test procedure in the dust tunnel of Bergbau AG Oberhausen (formerly HOAG Bergbau) for investigating the effectiveness of flat-jet sprays.

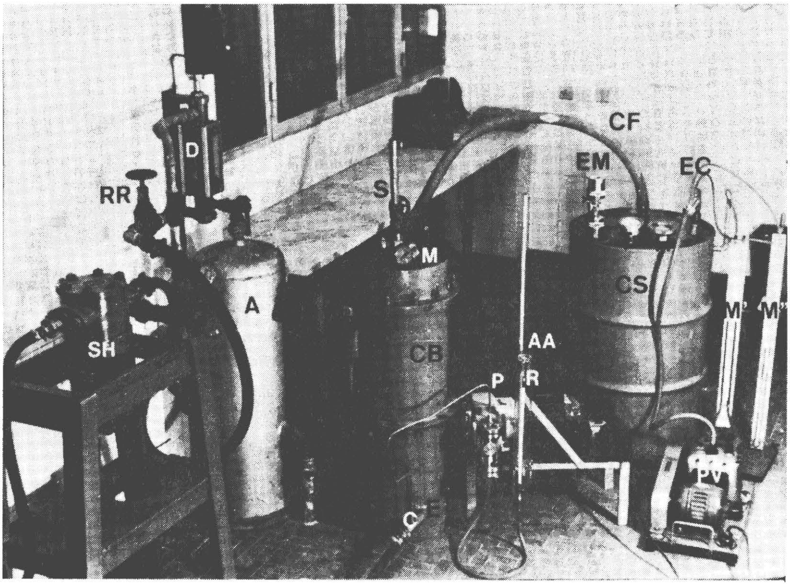


Fig. 2. Pneumatic abrasion chamber for simulating the pneumatic transport of pneumatic stowing material (Mining Department of the Turin Polytechnic).

SH	=	oil separator
RR	=	compressed air regulator
D	=	low gauge for compressed air (flow meter or integrating Rotameter)
A	=	compressed air tank
CB	=	pneumatic grinding chamber
E	=	air inlet for grinding chamber
C	=	injector for reagents
M	=	manometer
S	=	safety valve (= relief pressure valve)
P	=	piston pump for reagents feed
R	=	burette for reagents feed
CS	=	sedimentation chamber
AA	=	inlet for dusty air
M^{l}	=	U-tube manometer, water-filled
EM	=	dust sampler with membrane filter
EC	=	dust sampler with cyclone and paper filter
PV	=	vacuum pump driving EC
M^{ll}	=	U-tube manometer for regulating air quantity from EC
T	=	thermometer
H	=	hygrometer
CF	=	outlet pipe (connected to an electro-filter)

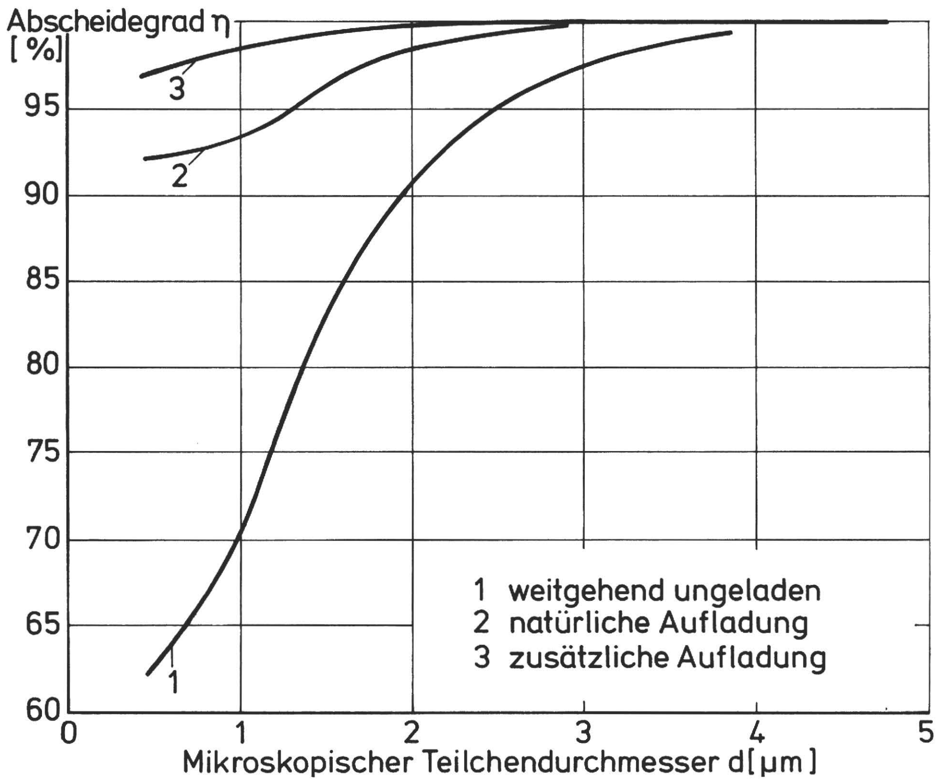


Fig. 3. Interdependence between degree of permeability ε (%) and pressure loss Δp (kp/m^2) throughout the dedusting system based on investigations with wet dedusters.

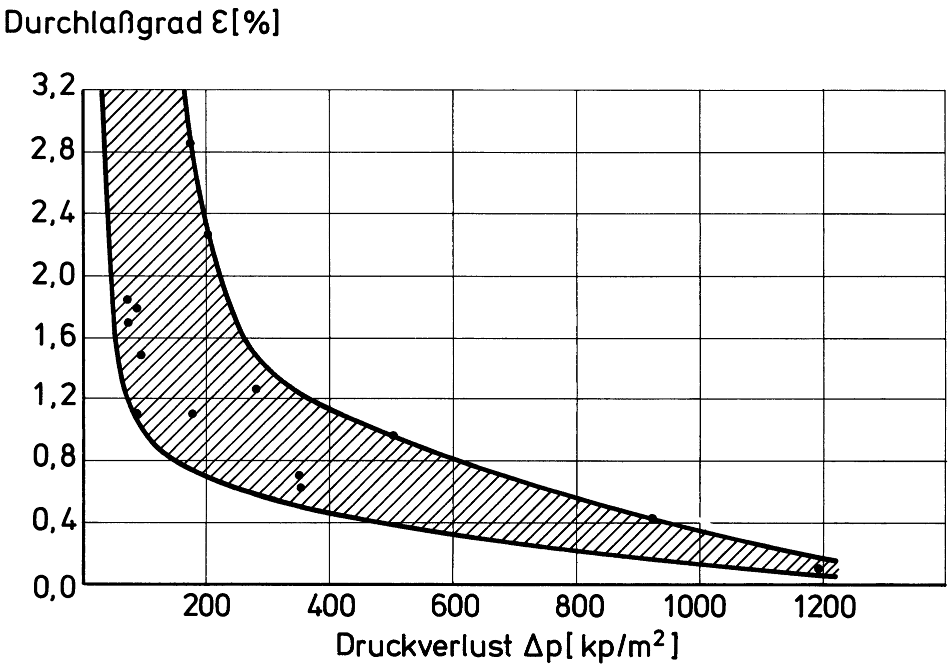


Fig. 4. Degree of separation ϑ (%) of the fine dust filter for different microscopic particle diameters d (μm) in relation to the electric charge of the coal dust.

Filter area: 25 cm^2 (5 cm x 5 cm)
Initial flow velocity: 10 cm/s

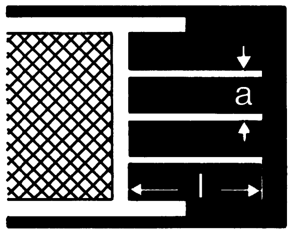
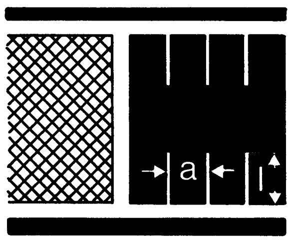
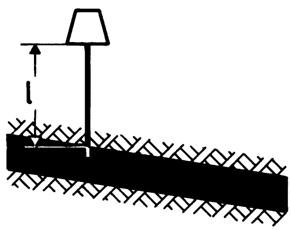
Aus dem Strebraum	Nahtränkung		l = b + 0,5 m a ≈ 1,5 bis 2l
	Tieftränkung		l ≦ 12 m a ≈ 1,5 bis 2l
	Ferntränkung		l = 5b Bohrlöcher täglich versetzt angeordnet
Aus den Begleit-strecken	Langfront-tränkung		l = 15 bis 80 m a = 15 bis 60 m
Aus Gruben-bauen außer-halb der Flözebene	Vorfern-tränkung		l = Abstand Strecke - Flöz

Fig. 5. Characteristics of the coal face infusion method

a = distance between boreholes

b = daily rate of advance

c = length of borehole.

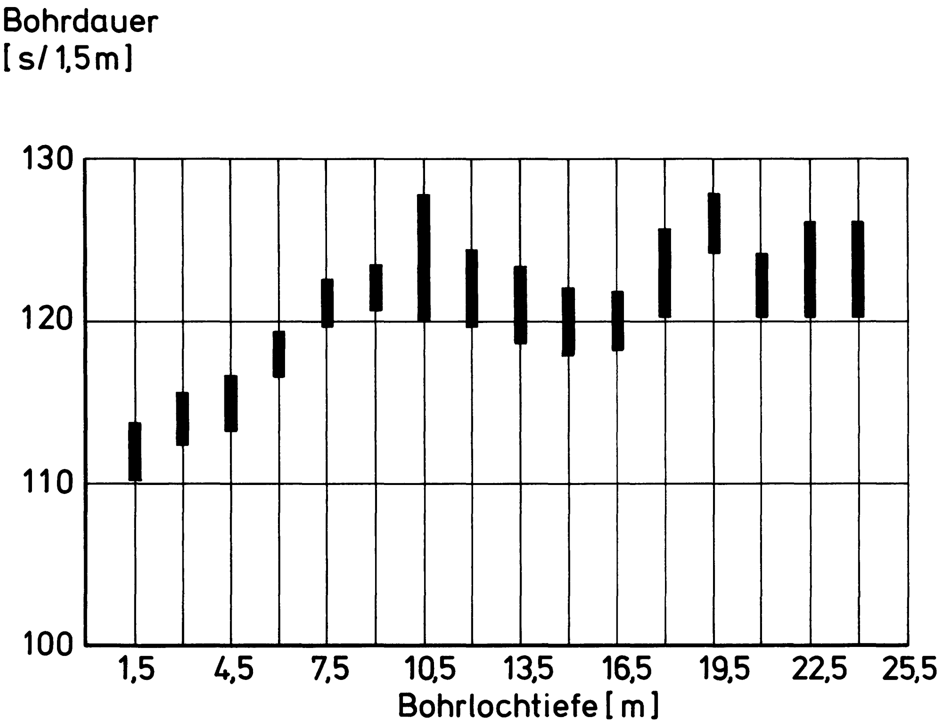


Fig. 6. Dependance of drilling time (s/1,5 m) on borehole depth (m) when drilling infusion holes. One column shows the confidence interval of the average of individual tests.

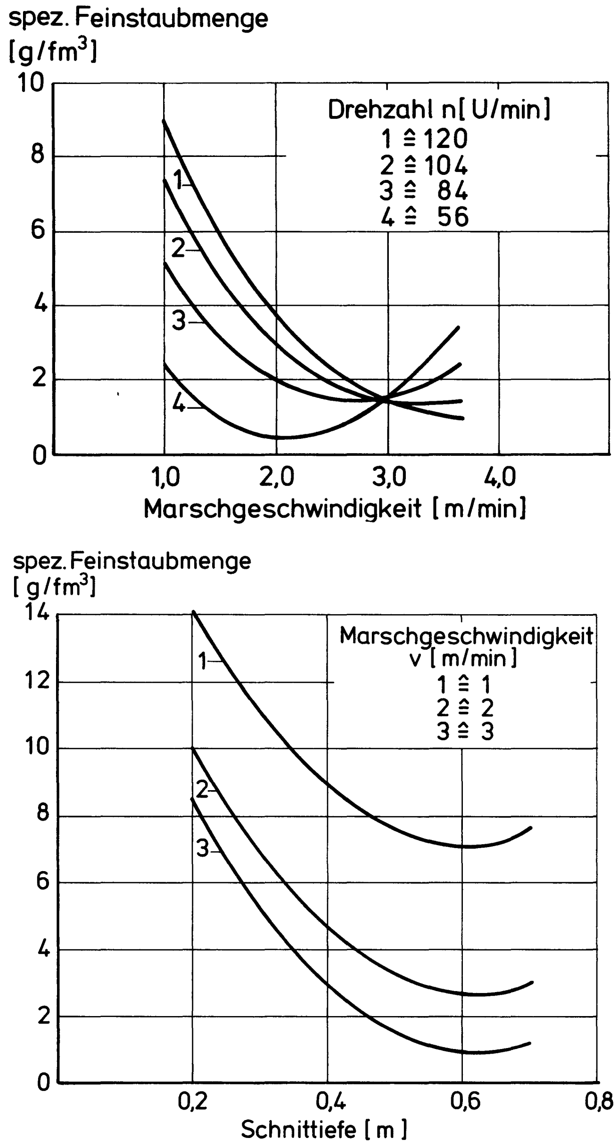


Fig. 7. Connection between:

a) specific fine dust quantity (g fine dust/fm^3 coal) and machine speed (m/min) for drum rotations of 120, 104, 84 and 56 rev/min.

b) specific fine dust quantity (g per fm^3) and cutting depth (m) of the drum for machine speeds V of 1,0; 2,0 and 3,0 m/min.

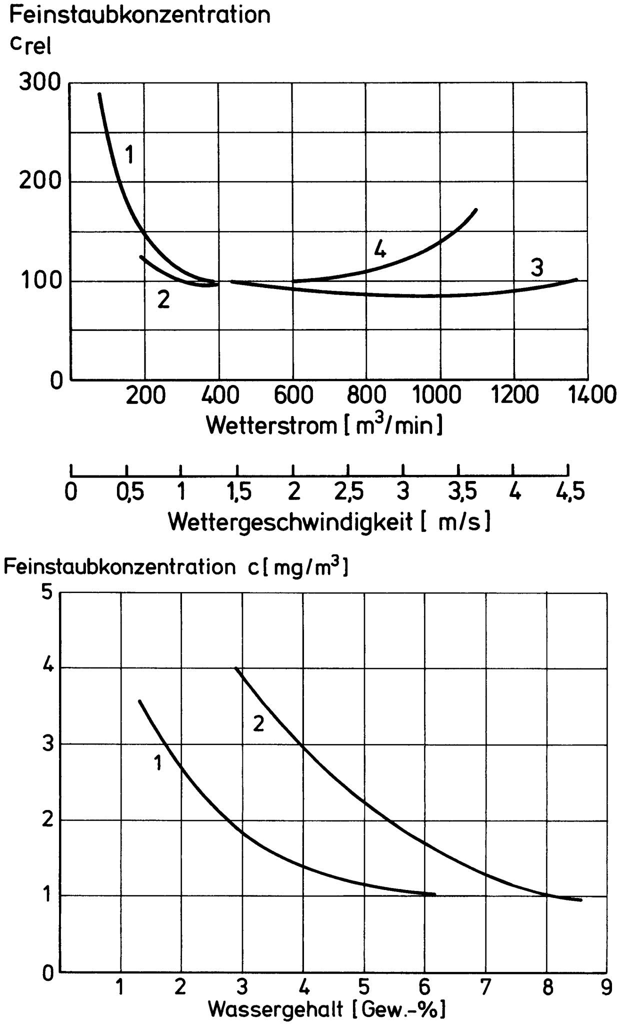


Fig. 8. a) Relative fine dust concentration c_{rel} related to the ventilation stream (m^3/min) and ventilation velocity (m/s).

Measurements in pneumatic pick workings

1 - steep seams

2 - flat seams

Measurements in mechanised workings

3 - flat seams

4 - in an experimental working with drum shearer.

The fine dust concentration is related to the same concentration c_{rel} = 100 at about 5oo m^3/ min.

b) Fine dust concentration c(mg/m^3, BAT I apparatus) related to water content (weight %) of the transported product < 10 mm in workings:

1 - with ploughs

2 - with drum shearers

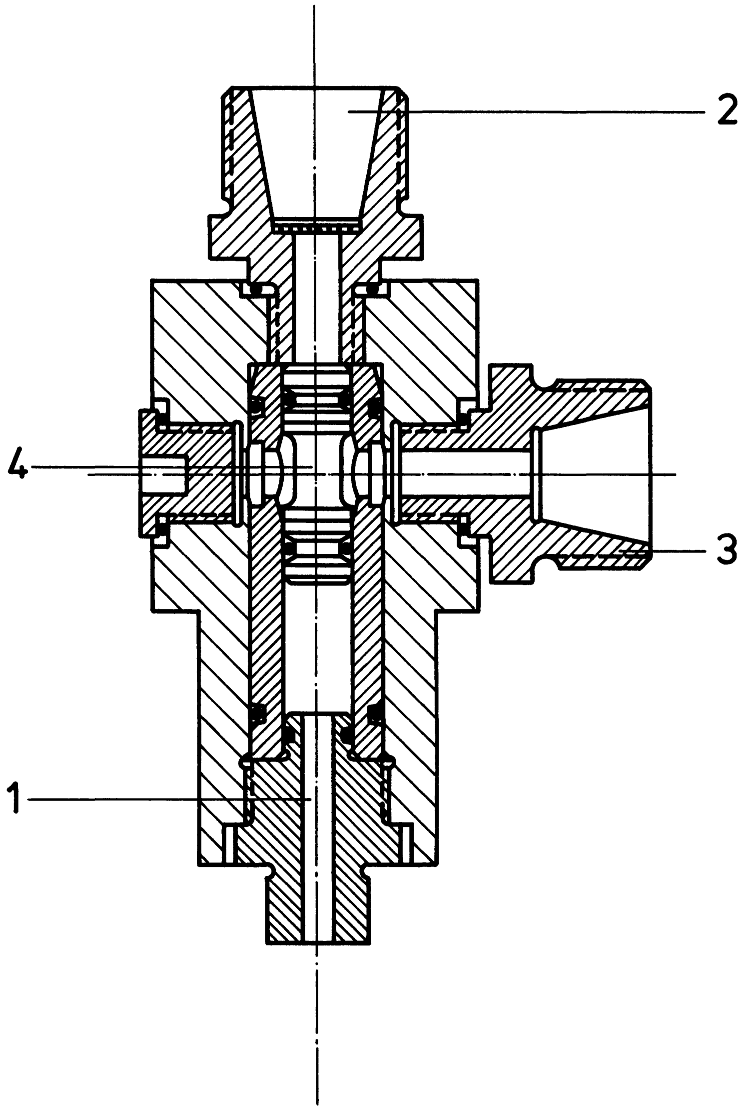


Fig. 9. Section through the operating valve of the automatic installation for spraying the caving area when using hydraulic powered supports.

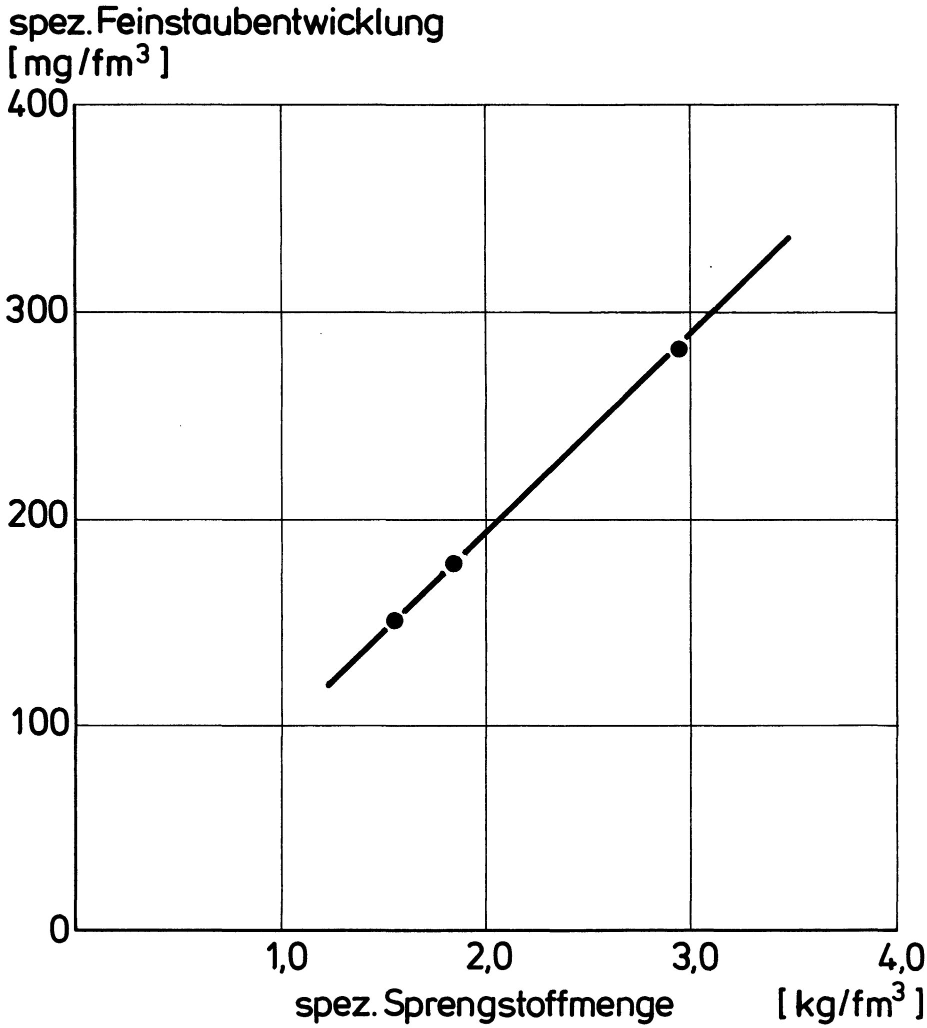


Fig. 10. Influence of specific explosives consumption (kg explosive/fm^3 standing coal), when breaking in, on the formation of fine dust (mg fine dust per fm^3 standing coal).

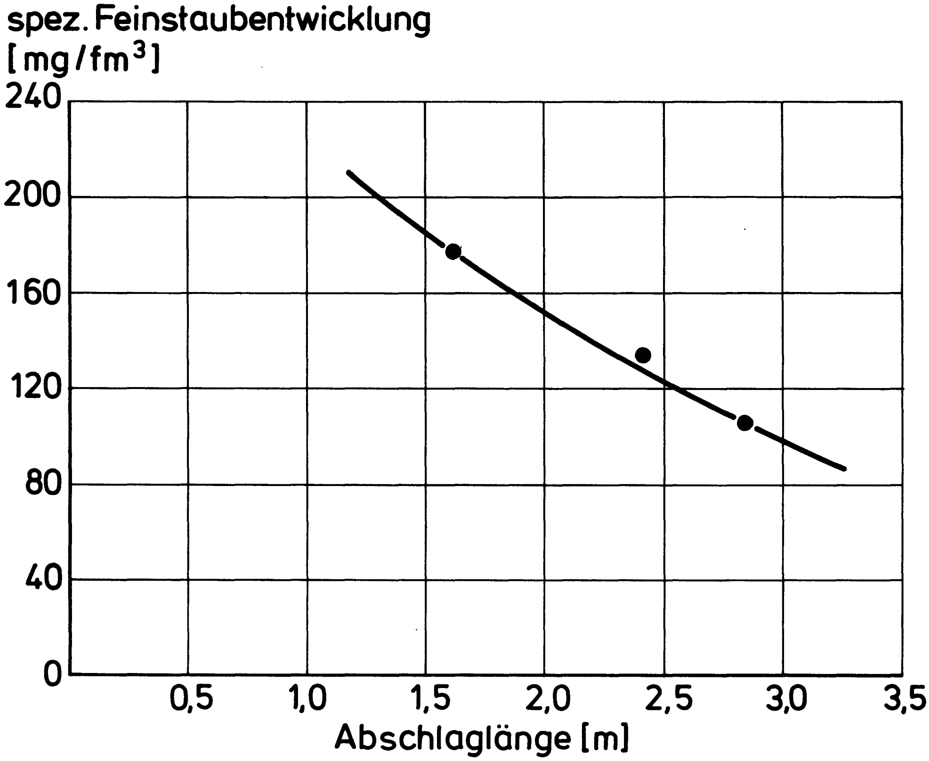


Fig. 11. Influence of the depth of pull (m) on specific fine dust formation (mg/fm^3).

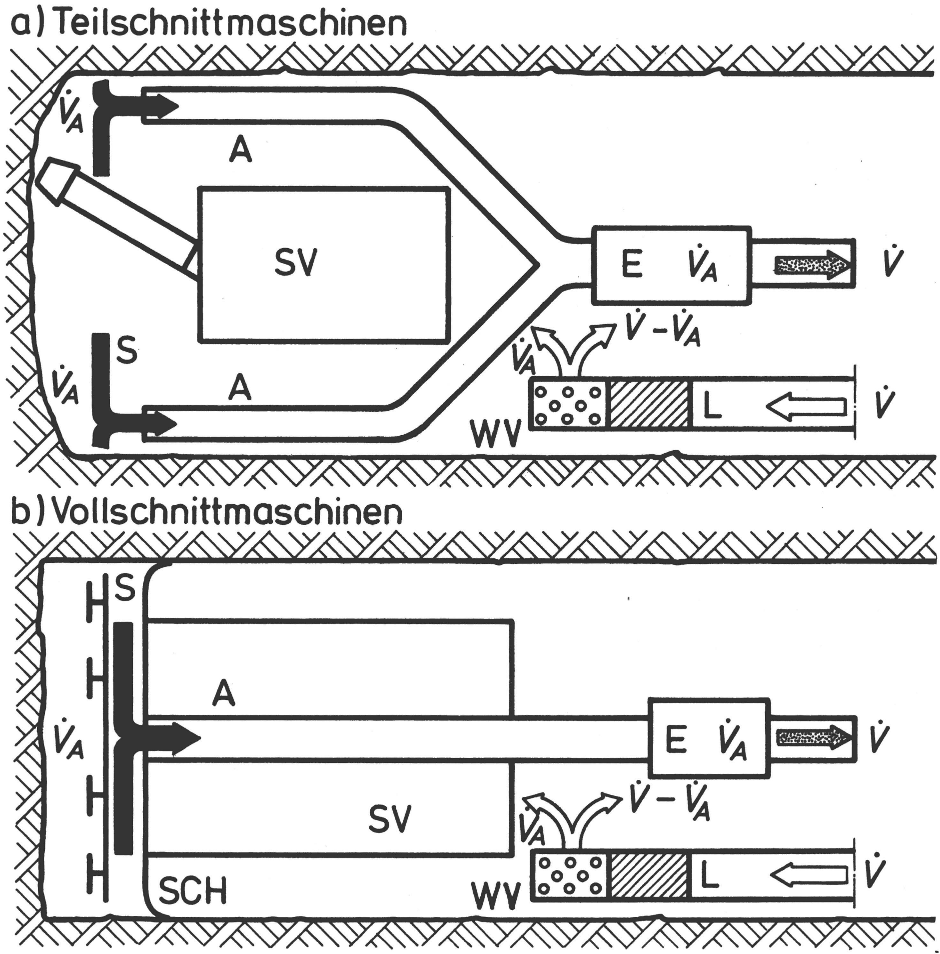


Fig. 12. Ventilation and dedusting layout in mechanised road heading

a) partial road headers
b) full-facers

L	=	ventilation ducting
WV	=	ventilation distribution
$\dot{V}$	=	total ventilation current
$\dot{V}_A$	=	aspirated ventilation current
S	=	**dust door** a) open b) closed
SCH	=	shield
A	=	aspiration duct
E	=	deduster
SV	=	roadheader

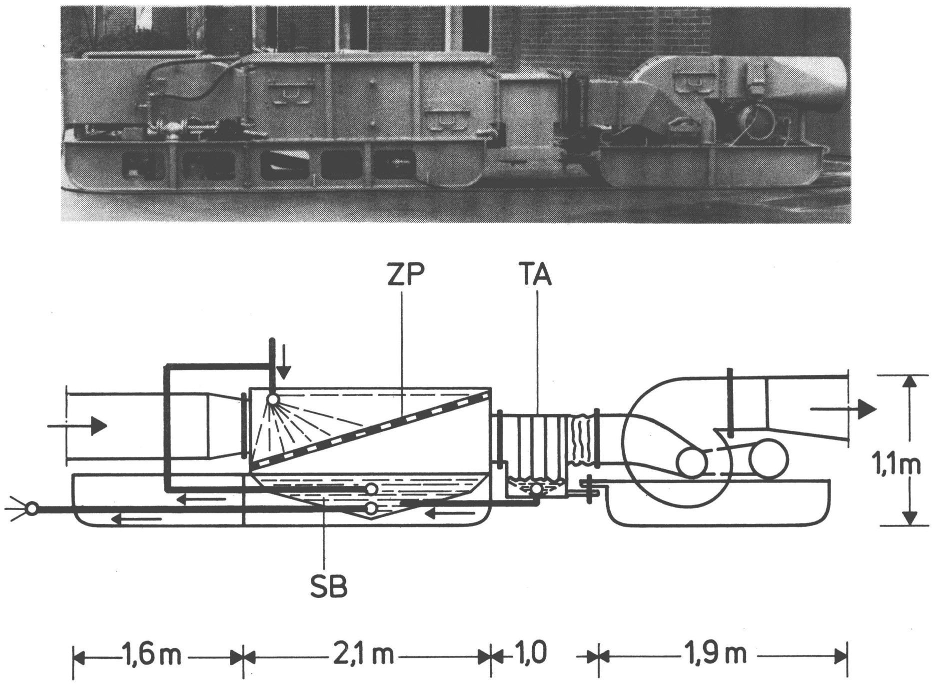


Fig. 13. Overall view and diagrammatic representation of the operation of the wet deduster, Büttner-Schilde-Haas AG, Krefeld; cyclonette type.

ZP = cyclonette plate
SB = slurry container
TA = drop separator

Volume of suction throughput $\dot{V}$ = 150 m^3/min
Pressure requirement Δ p = 450 kg/m^2
Specific water consumption = 0.5 l/m^3 air
Dimensions of apparatus: 6.0 m x 0.9 m x 1.1 m

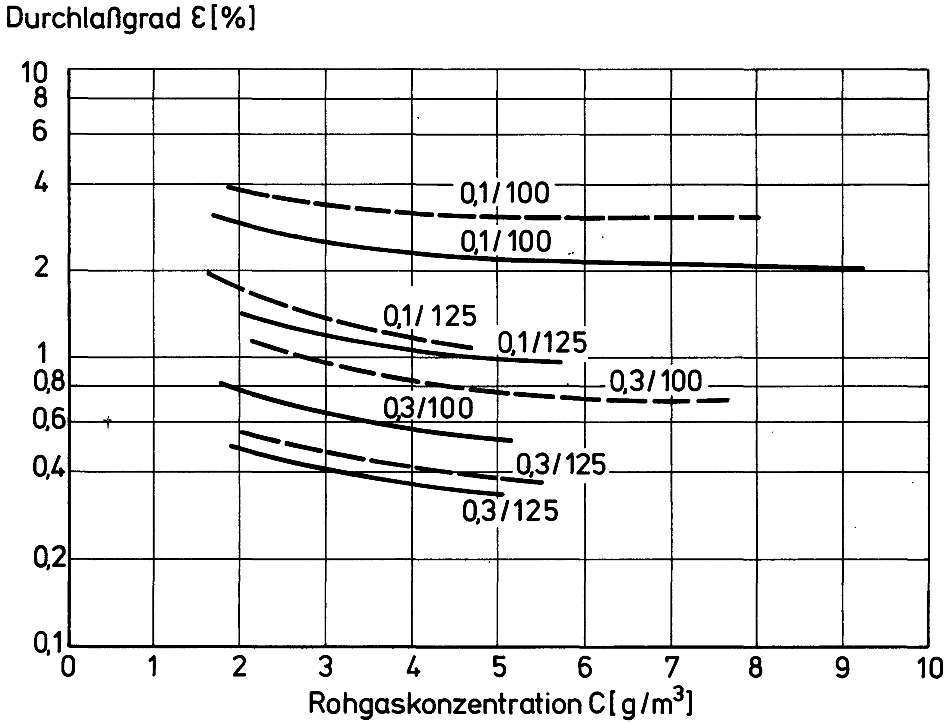


Fig. 14. Filtering $\mathcal{E}$ (%) of the Rotovent deduster of Hölter and Co., Gladbeck, depending on the crude gas concentration C (g/m^3) fed for compressed air operation.

Fan operation (-----) or mixed (———), with 0,1 or 0,3 l water/m^3 air and an air throughput of 100 or 125 m^3/min; use of an air-water jet (X).

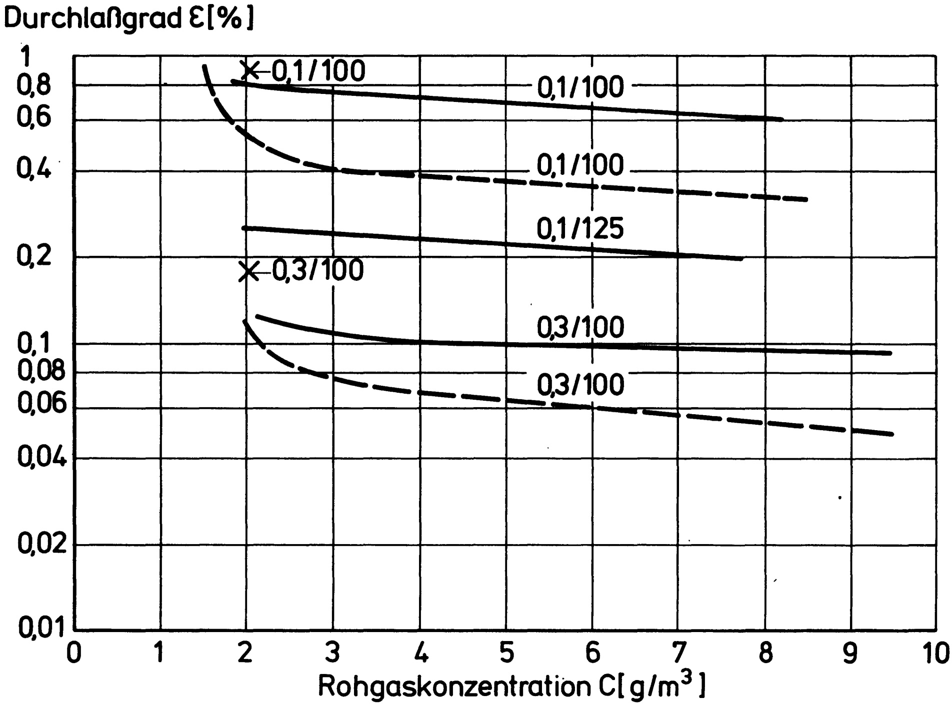


Fig. 15. Filtering ε (%) of the Rotovent deduster, depending on the crude gas concentration C (g/m^3) fed for compressed air operation.

With air-water jet (-----), without air-water jet (———), with a specific water quantity of 0,1 or 0,3 l/m^3 air throughput, and 100 or 125 m^3 air throughput per minute.

(X = fan operation with air-water jet, with 0,1 or 0,3 l water/m^3 air, and an air throughput of 100 m^3/min.).

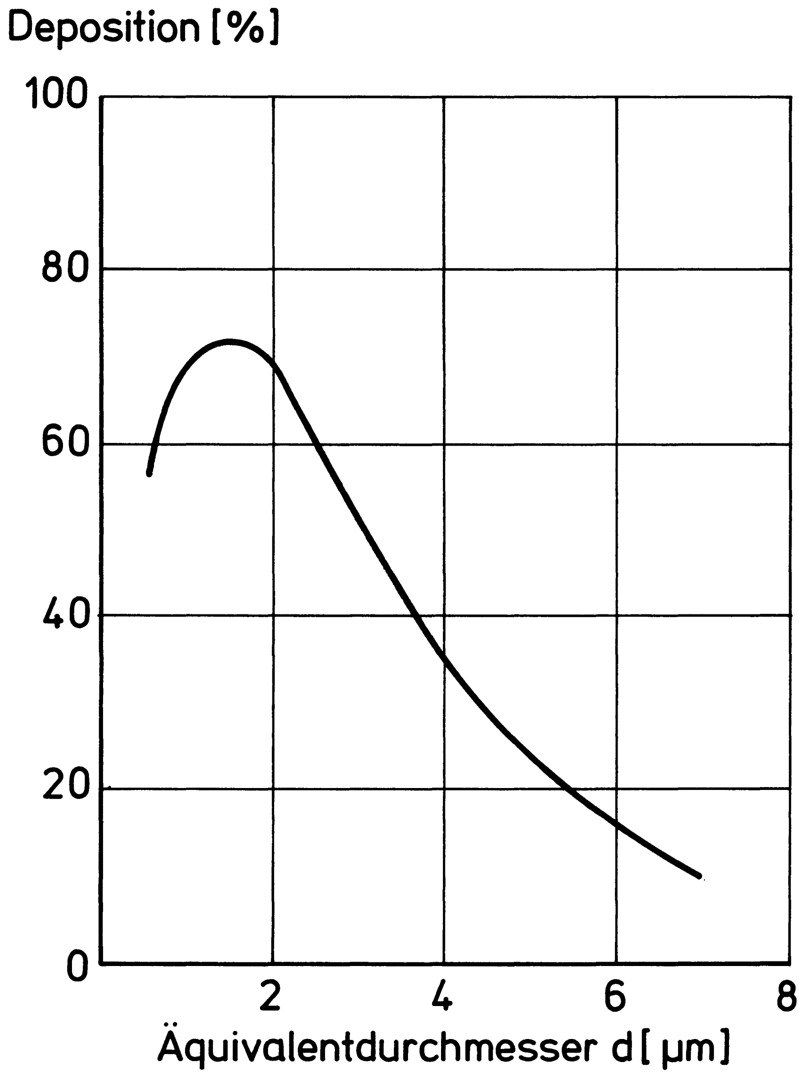


Fig. 16. Deposition curve for dust in lung alveoli according to T.F. Hatch and P. Gross (1964). The deposition is related to equivalent diameters d(μm) of particles with a dust density of $\varrho = 1.0$ g/cm^3.

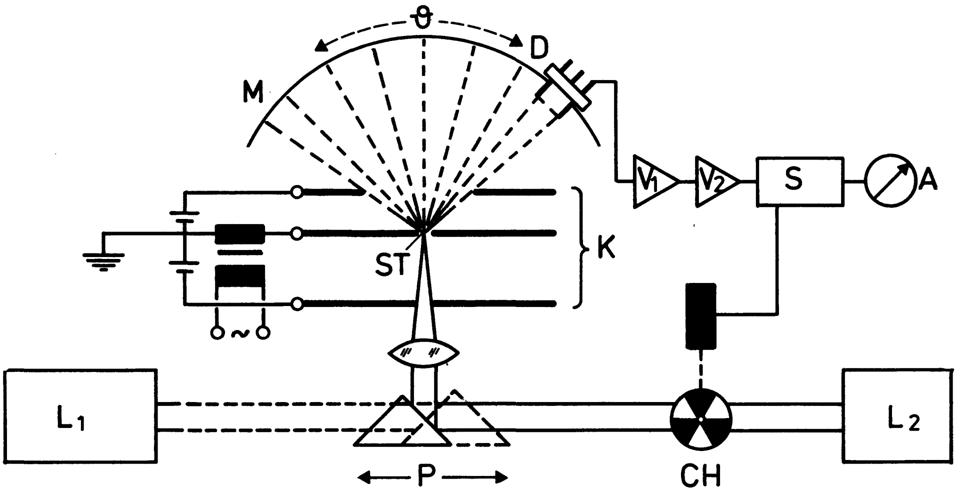


Fig. 17. Layout of test procedure for measuring diffused light intensity of single particles dependent on the scatter angle.

K	=	Millikan condenser
ST	=	dust particles
L_1	=	laser (λ= 630 nm)
L_2	=	infra-red laser (λ= 3390 nm)
M	=	glass plate or film
ϑ	=	scatter angle
D	=	infra-red detector
V_1 V_2	=	pre-amplifier
S	=	synchronizing amplifier
CH	=	modulator
A	=	indicator
P	=	deviating prism

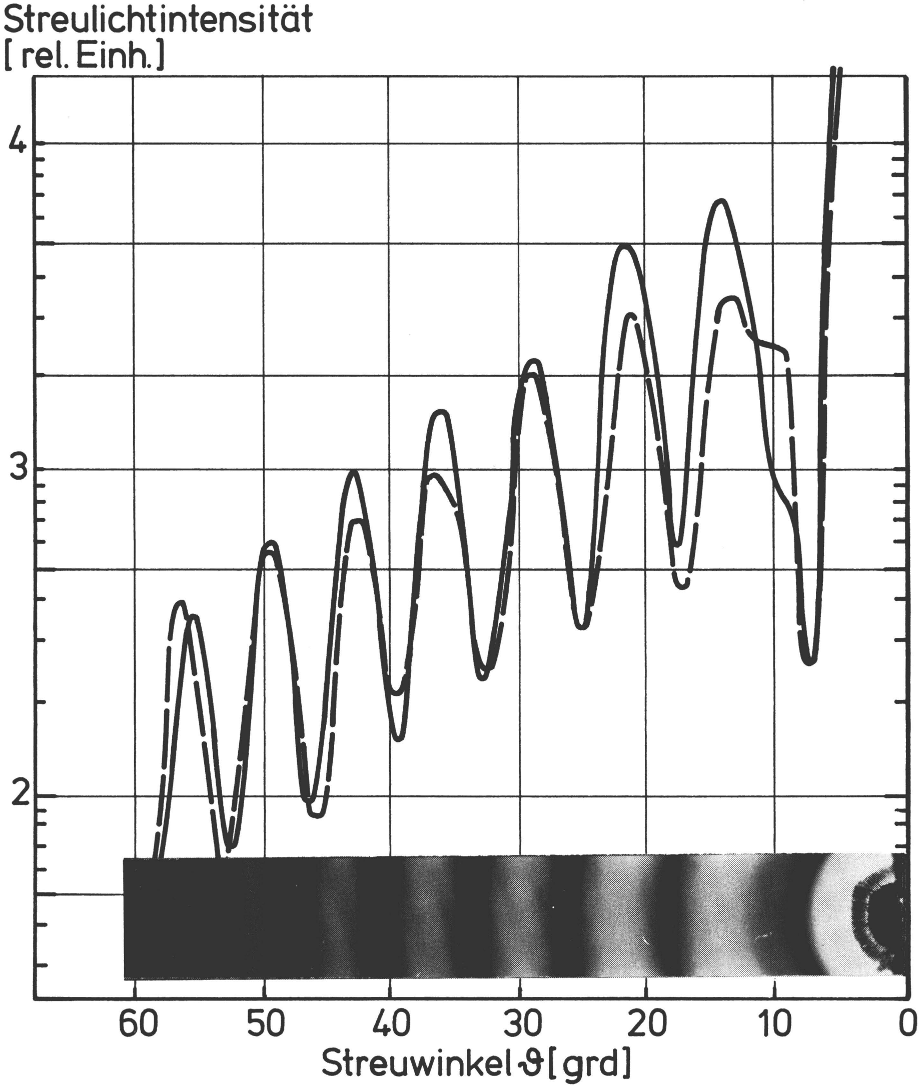
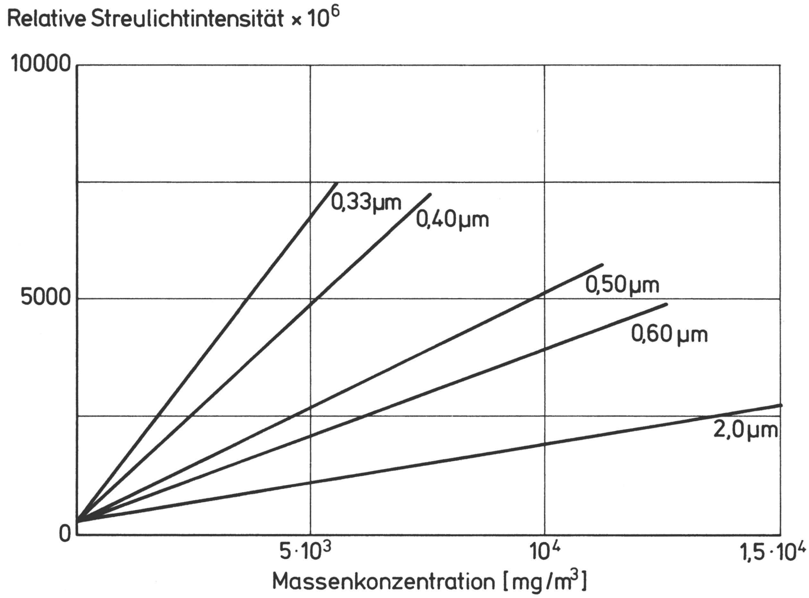


Fig. 18. Diffused light intensity related to the scatter angle of a glass sphere

$d = 6\,\mu m$ $n = 1.5$ $x = o$ $\lambda = 630$ nm

solid-line curve : experiment

broken-line curve: theoretical calculation



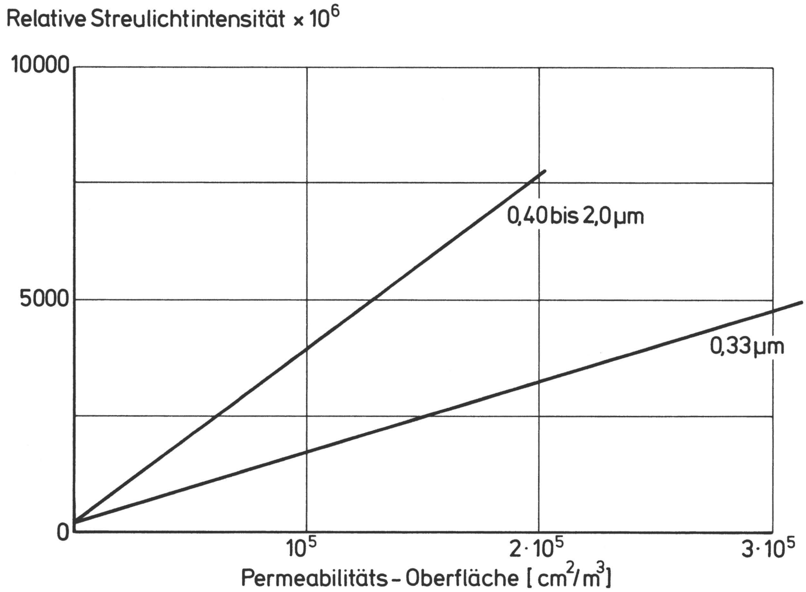


Fig. 19. a) Relative diffused light intensity related to mass concentration (mg quartz/m^3 water) of poly-dispersed quartz particles.

Maximum particle size : 0.33 to 2.0 μm
Scatter angle 30°, white light

b) Relative diffused light intensity related to specific surface area (cm^2 quartz/m^3 water) of poly-dispersed quartz particles.

Maximum particle size : 0.33 to 20 μm
Scatter angle 30°, white light.

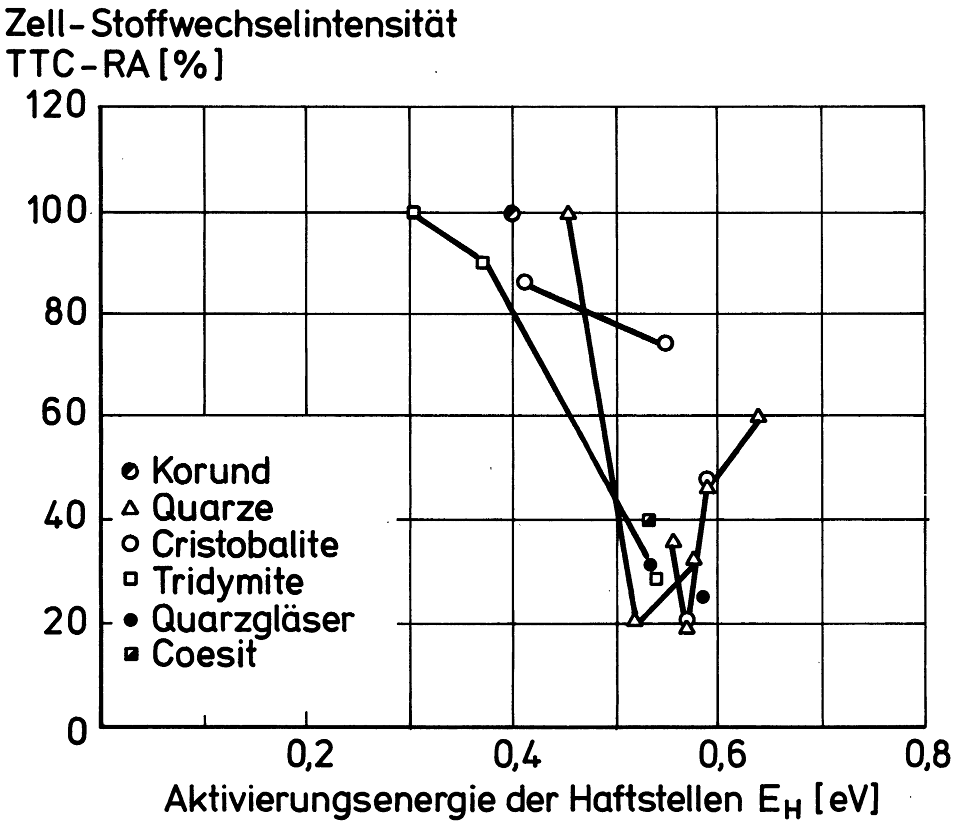


Fig. 20. Metabolic action of cells after a dust impact lasting 120 minutes as a function of the activating energy of electron adhesion points for samples of different SiO_2 modifications.

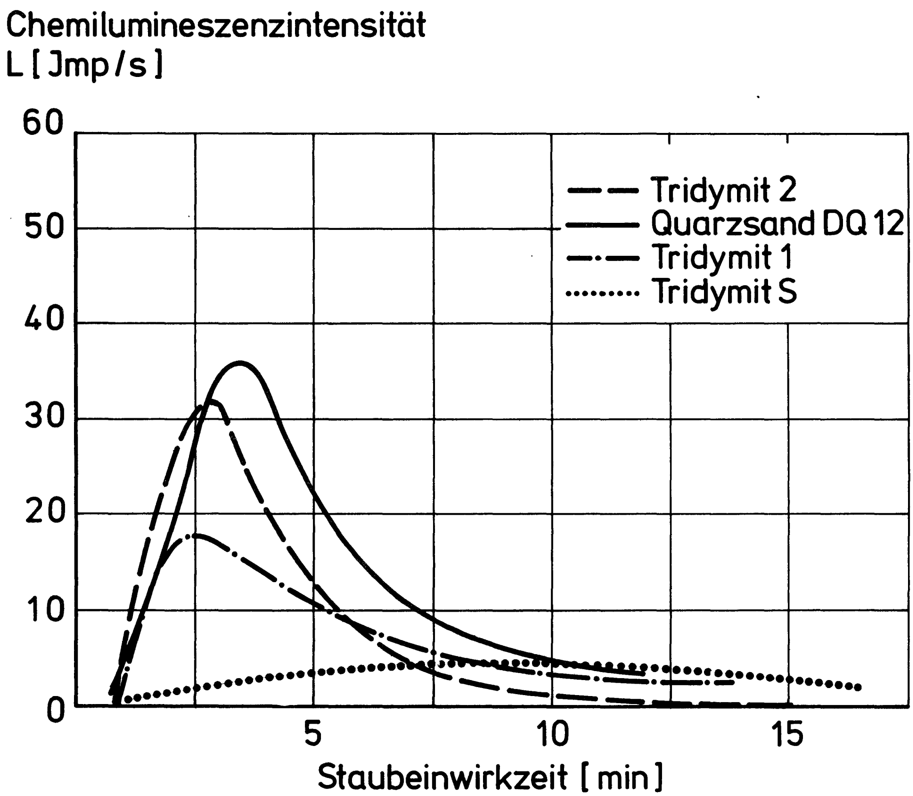


Fig. 21. Intensity of chemical luminescence as a function of the impact time of 4 different SiO_2 samples.

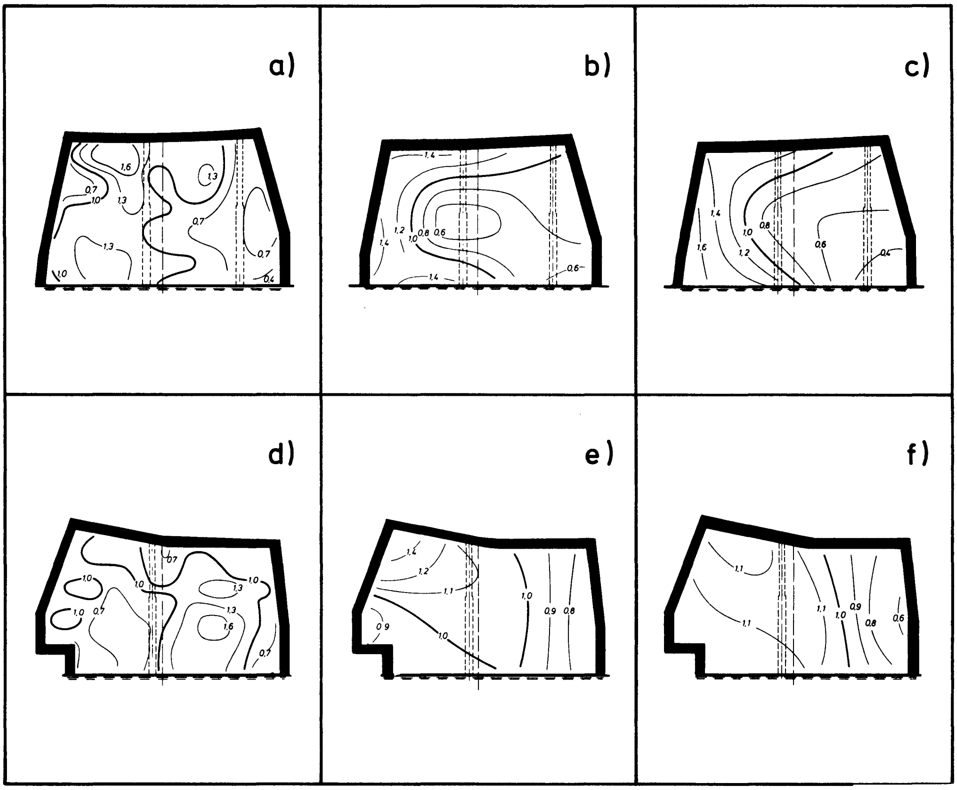


Fig. 22. Distribution of ventilation velocity ("Isotachen", a), d)), fine dust concentration ("Isokonien", b) e)) and coarse dust concentration ("Isokonien", c) f)) for two measuring levels in the return air roadway of an advancing face.

Distance from face: 3 m(a) to b))and 30 m (d) to f))
Floor width : for a) to c): 3.8 m, start of face right, upper half.

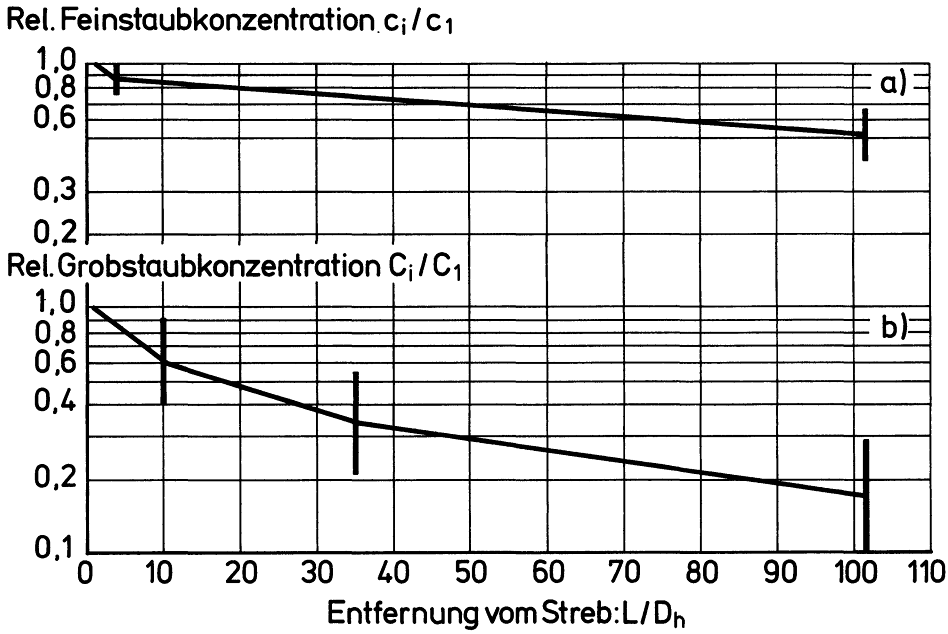


Fig. 23. Changes in the concentration of suspended dust along the return air roadways of faces related to the beginning of the roadway.

a) relative fine dust concentration
b) relative coarse dust concentration.

The entered areas show the dispersal range found for three face return air roadways and the return air roadways of a simulated face with 4 ventilation velocities.

Distance from the face: relative values L/D_h.

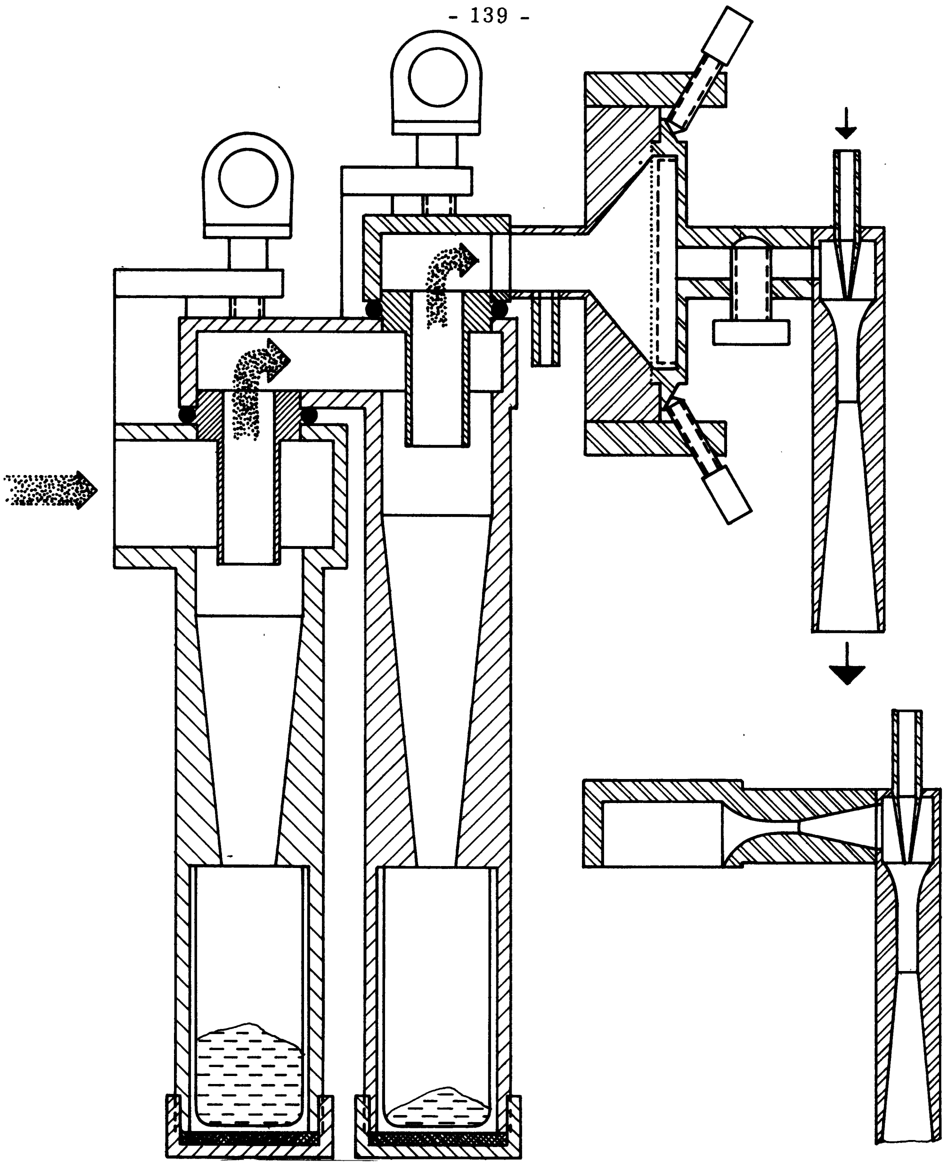


Fig. 24. Section through the TBF 50 gravimetric dust sampler
Aspirated air stream : 50 l/min
To the second cyclone any of the following may be connected:

- filter component and compressed air ejector (see figure)
- compressed air ejector only
- pump or blower instead of ejector.

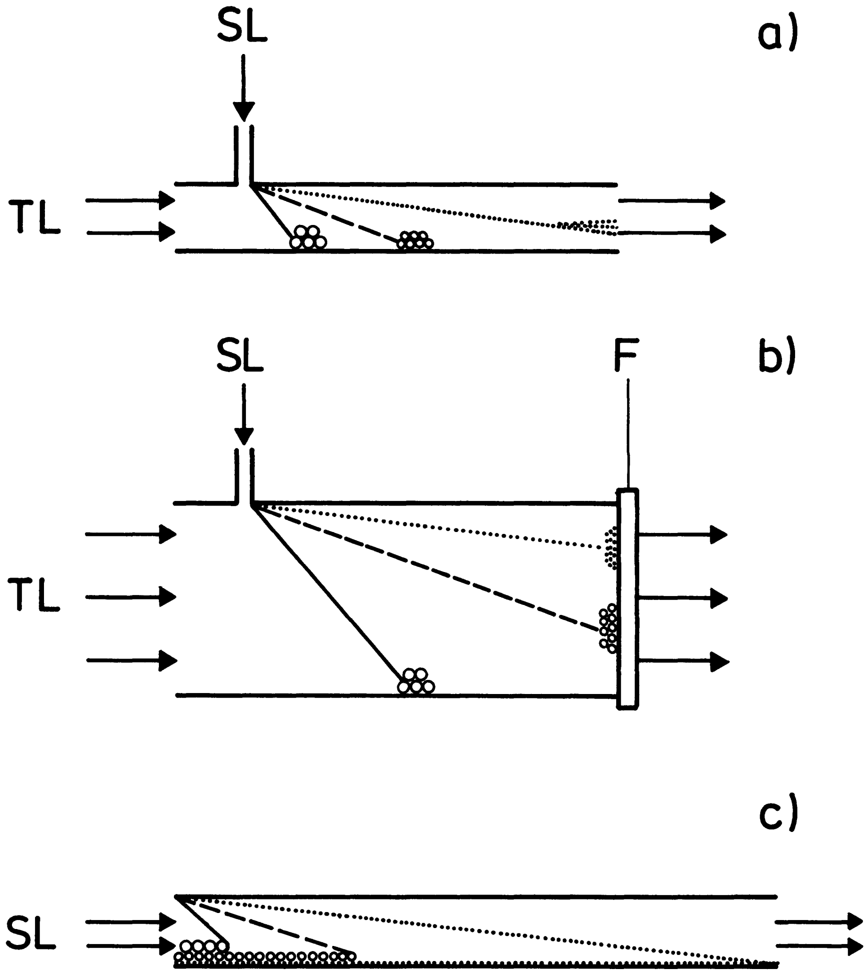


Fig. 25. Methods for fractionating suspended dust.

a) Fractiometer according to Timbell

b) Sedimentometer of the Silikose-Forschungs-institut, Bochum

c) slit-channel device of the Steinkohlenberg-bauverein, Essen

SL = dusty air

TL = carrier air stream (dust-free)

F = filter

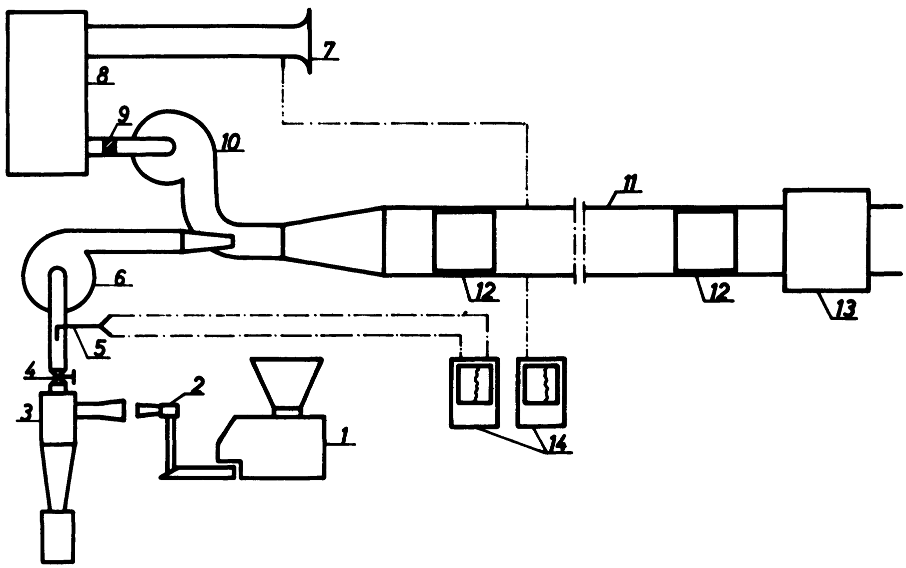


Fig. 26. Diagrammatic representation of a test channel for dust measurers.

1. dust feed balance
2. atomiser
3. classifier
4. valve
5. Prandtl-pipe
6. fan (100 m^3/h)
7. inlet jet
8. electro-filter
9. regulator
10. fan (100-1500 m^3/h)
11. measuring channel (7mlong)
12. built-in aperture (0,4 x 0,4 m)
13. discharge filter
14. air volume recorder

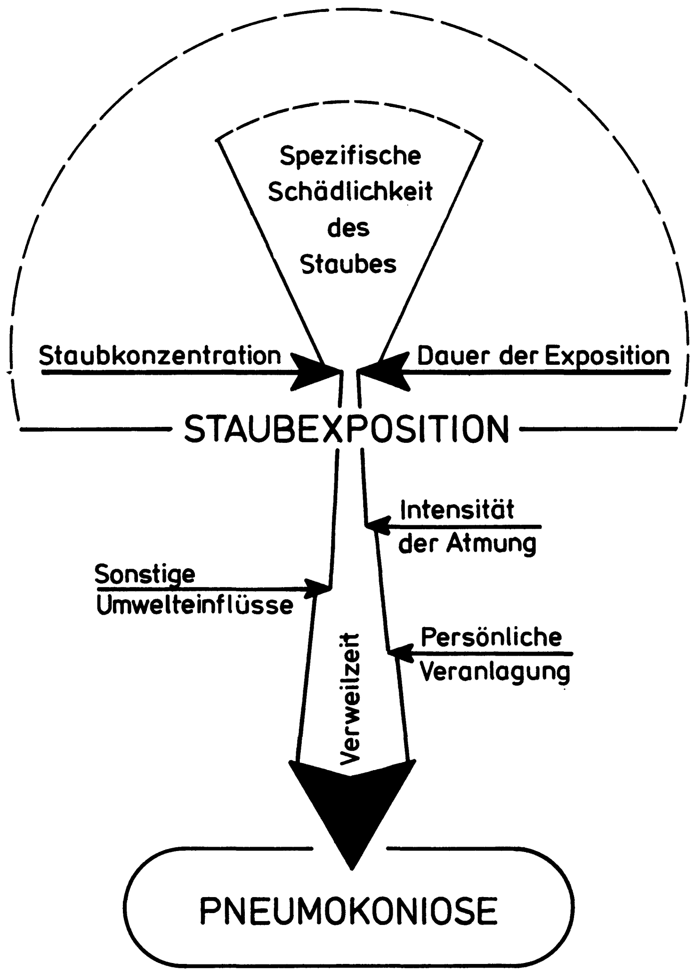


Fig. 27. Factors influencing the onset of pneumoconiosis.

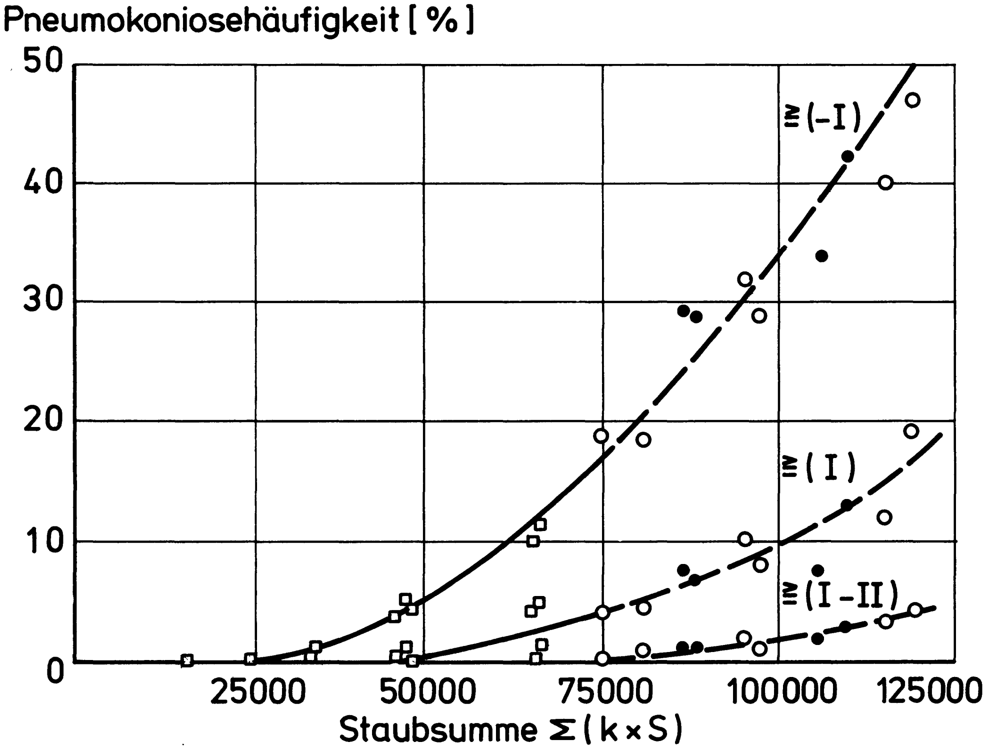


Fig. 28. Pneumoconiosis risk (%) as a factor of the total dust count. Total dust count Σ (tyndallometric fine dust concentration k x number of layers S) for at least very slight (-I), at least slight (I) and at least slight to medium (I-II) lung changes.

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