EUROPEAN COAL AND STEEL COMMUNITY - THE HIGH AUTHORITY

SERIES ON INDUSTRIAL HEALTH AND MEDICINE

Technical measures of dust prevention and suppression in coal-mines

VOLUME 1

LUXEMBOURG 1966

TECHNICAL MEASURES OF DUST PREVENTION AND SUPPRESSION IN COAL-MINES

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Report on the results of research
sponsored by the High Authority of E. C. S. C.
(1960-1963)

LUXEMBOURG 1966

NOTE TO THE READER

This Volume I is a compilation of the results of the research carried out in accordance with a first programme, and for this reason contains only broad general information.

The High Authority proposes to follow up this volume by a second, which will contain the detailed research reports, giving more detailed and specific information as to the working methods adopted and the results obtained. To allow the reader to refer without difficulty to a given research report published in Volume II, footnotes have been provided, indicating the appropriate appendix to be consulted.

While waiting for the second volume to appear, those readers wishing to have further details of research carried out may apply to the following organizations or institutes:

— Haute Autorité de la C. E. C. A., 2, place de Metz, Luxembourg.

— Centre d'études et recherches des charbonnages de France, 35, rue Saint-Dominique, 75 Paris-7e, France.

— Institut d'hygiène des mines, Havermarkt 22, Hasselt, Belgium.

— Steinkohlenbergbauverein, Hauptstelle für Staub- und Silikosebekämpfung, Frillendorfer Strasse 351, 43 Essen-Kray, Germany.

— Silikose-Forschungsinstitut der Bergbau-Berufsgenossenschaft, Hunscheidtstrasse 12, 463 Bochum, Germany.

— Stofinstituut van de Gezamenlijke Steenkolenmijnen in Limburg, Treebeek, Netherlands.

— Clinica del Lavoro "Luigi Devoto" della Università di Milano, Via S. Barnaba 8, Milan, Italy.

— Bergwerksgesellschaft Walsum A. G., Postfach 100, 4103 Walsum/Niederrhein, Germany.

FOREWORD

The High Authority of E.C.S.C. is bringing out a new publication in its Industrial Health and Medicine series, devoted entirely to dust prevention and suppression in mines.

It will be in two volumes, of which this, the first, gives an overall account of the results of the research programmes completed in 1960-1963, while readers wishing to go more fully into particular points mentioned will be able to refer to the more detailed reports in the second.

In 1954 the High Authority first started its promotion of research to help improve health and safety standards in the Community mines and iron and steel plants.

One of its top priorities in the field of industrial health was miners' pneumoconiosis, a most acute problem both from the human and from the economic angle.

The work has throughout been organized along two main lines—the first essentially medical—with the object of pinpointing the process which brings about the damage to the lung and helping to ensure correct diagnosis and treatment, and the second concentrated on the actual dusts and their production and on methods of reducing both their amount and their injuriousness. The High Authority has sponsored active research in both these mutually complementary connections.

One aspect which I feel should be especially emphasized is the close and regular co-operation on the research among all those concerned, starting indeed with the actual drafting of the programme itself on a basis of consultation between the research establishments, the industries and the Governments. This consultation enabled a picture to be built up, of the deficiencies needing to be made good by research in the different mining areas, from which the programme developed more or less of its own accord.

Subsequently, through the committees set up by the High Authority, the three groups were able to keep in touch with the progress of the work and to note interim results, and the definitive findings here described were assembled and evaluated in the same way.

Thus over quite a number of years a team of men from several different countries have worked up a system of close, smooth and efficiently-functioning co-operation with the disinterested aim of benefiting others. I feel that they are the more deserving of praise in that the research network so organized has required the help of specialists on a great variety of subjects, and it has often been necessary to disregard cherished traditions and doctrines in particular fields.

My warmest thanks to all those, advisers and researchers, who have helped with the work. It is quite extraordinary what an admirable job they have done considering the comparatively limited funds which were available for the programme.

In view of these remarkable results, and the active response of the industry in putting them into practice, the High Authority has unhesitatingly decided, with the encouragement of the various bodies it consults in planning its research, to make a larger appropriation for the follow-up programme which it is intended to conduct over the next few years.

There can be no doubt that its grants for research on dust prevention and suppression in mines will enable substantial progress to be made towards the prime objective of a speedy improvement in working conditions in the mining industry.

J. FOHRMANN,

Member of the High Authority.

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Preface

When in 1956 the High Authority began to encourage research in industrial health and medicine—particularly with respect to pneumoconiosis—it became clear that its action could not be restricted to medical research, but that it was essential to study the technical problems of dust prevention and suppression as well.

The Authority hoped in this way to get to the root of the problem, by active measures to suppress the dust placed in suspension in the atmosphere during the various phases of industrial production.

The High Authority therefore decided on December 5th, 1957, to make available three million E.M.A. units of account to further research into:

(a) dust-suppression measures in coal mines, iron mines and steelworks;

(b) the human factors which affect working safety;

(c) the rehabilitation of the victims of industrial accidents or diseases.

The present report sets out to present the results of research concerned with that part of the programme dealing with technical measures to combat dust in mines (coal and iron-ore mines).

In the discharge of the responsibility to assist in encouraging research, placed upon the High Authority by article 55 of the Treaty, the Authority hoped that by establishing a basic programme it could facilitate the development of technical means of eliminating dust production or of suppressing dust once produced, of measuring the degree of dustiness, of determining its constitution and, finally, checking by long-term studies whether the dust-suppression measures adequately protect the health of the mineworkers.

In the light of this basic programme the High Authority, assisted by three Consultative Committees (scientific, professional and governmental) assigned to the problems of dust suppression in mines the total sum of 900 000 A.M.E. units of account, spread over the period of the campaign of research, which ran virtually from 1960 to 1963 (4 years).

In this way financial aid was granted to 37 research projects submitted by 14 institutes or organizations.

In preparing this report it seemed logical to recognise the close links between all the various techniques to be applied both to assuring effective and integrated dust-suppression measures and to determining the degree of dust nuisance in the underground mine workings.

It is thus necessary, in the first place, to invent, perfect, adopt and generalize the processes and techniques most likely to reduce the amount of dust produced during mining operations. But it must then be possible to assess with certainty—quantitatively and qualitatively—the degree of dustiness and, as a result, the improvement brought about by using the suppression techniques. This postulates the perfecting of sampling and measuring devices, as also of the methods of analysing the dust samples obtained. Moreover, dust measurements are essential as a means of deciding how to deploy miners already suffering from pneumoconiosis, who have to be placed at less dusty working-points.

Finally, as a long-term measure, it is necessary to check whether the entire group of dust-suppression measures applied has improved the degree of protection offered to the men, and to what extent.

This check will, essentially, be based on the periodical comparison of statistics of exposure to dust, together with other environmental factors, with chest X-ray films of the mineworkers.

The real emphasis must primarily be put on the dust-suppression techniques.

The report therefore falls into four main chapters:

I. Technical measures of dust prevention and suppression during winning operations.

II. Technical measures of dust prevention and suppression during operations other than winning.

III. Dust measurement and analysis.

IV. The link between pneumoconiosis and the environmental conditions.

In a field such as that of dust suppression in mines, the advances achieved are largely the fruits of perseverance in research and the patient perfecting of methods of operations.

These advances are also governed by developments in mining technique; this is changing very rapidly. Hence the need for continuous development of the means of prevention and for unceasing vigilance.

Technical measures of dust prevention and suppression during winning operations

Seam infusion

Of all the techniques available for the suppression of dust in winning workings, there is a special place for the method of water infusion in the solid coal; this method is a decidedly positive one.

Of recent years, by the combined efforts of both researchers and practical men in mining, this technique has been much developed and its range of application widened, (a) because of the improvement in equipment, and (b) because the method has become better understood.

The research carried out in this first programme has greatly contributed to accelerating this progress. When the research programme began, the only method in use was that of short-hole infusion, with holes normal to the coal-face.

In inclined seams, the texture or friability of the coal hindered the development of the method, which was also banned for safety reasons where the surrounding rock was permeable and liable to be weakened by water, giving rise to roof falls and to floor penetration.

Seams—steep or semi-steep—which are predominantly anthracitic and seams which are irregular in appearance and constitution, or which are subject to instantaneous outbursts of gas were mostly considered to be non-infusable or to "resist" infusion.

At the time there was also a lack of suitable equipment which would have allowed of infusing to greater depths, and consequently at higher pressures, while providing a regular flow of water.

Two principal shortcomings were ascribed to shot-hole infusions:

(a) irregular and non-uniform wetting of the infused coal, because the water flowed through a system of wide cracks;

(b) its unsuitability to the working cycles which provide rapid advance of the face, based on several winning shifts per day and increased mechanisation.

The programme of research put forward therefore had the following main objectives:

(a) improvement of the infusion equipment, by perfecting the pumps, pipes, tubes etc., particularly with a view to modifying these elements to accept higher pressures;

(b) extension of the application of seam infusion to difficult cases: seams subject to instantaneous outbursts, steep seams, irregular seams broken up by dirt bands;

(c) development of techniques of water infusion in the seam such as to make this process more or less independent of the winning cycle and thus adapting it to mechanised faces.

Perfecting infusion devices [1]

It is obvious that to carry out seam infusion properly one (fig. 1) must have proven apparatus. In particular, the equipment must be suitable for use both at the high pressure which are becoming essential and under the rugged conditions of service underground.

The trials dealt with infusion pumps, hoses, tubes and measuring apparatus. A testing station was established in Germany, to test this equipment intensively and to make it possible to carry out repeated trials. Here an "artificial coal-face" was built, consisting of tubes in which the infusion pressures are reproduced.

Attempts were also made to simulate the solid coal by a drilled concrete block. The pump characteristics were established by means of the throughput and pressure figures recorded.

The characteristic curves (throughput as a function of back-pressure) show that the electrical types of pump can give throughputs which fall off with increasing back-pressure far less than do those provided by compressed-air pumps.

The compressed-air pumps still have certain advantages however, because they start up gradually, because their throughput can be varied, and because they can be used at points where the methane content is high.

The *hoses* (fig. 2) were particularly tested with respect to:

(a) their resistance to shock, to tensile stress, to wear etc.;

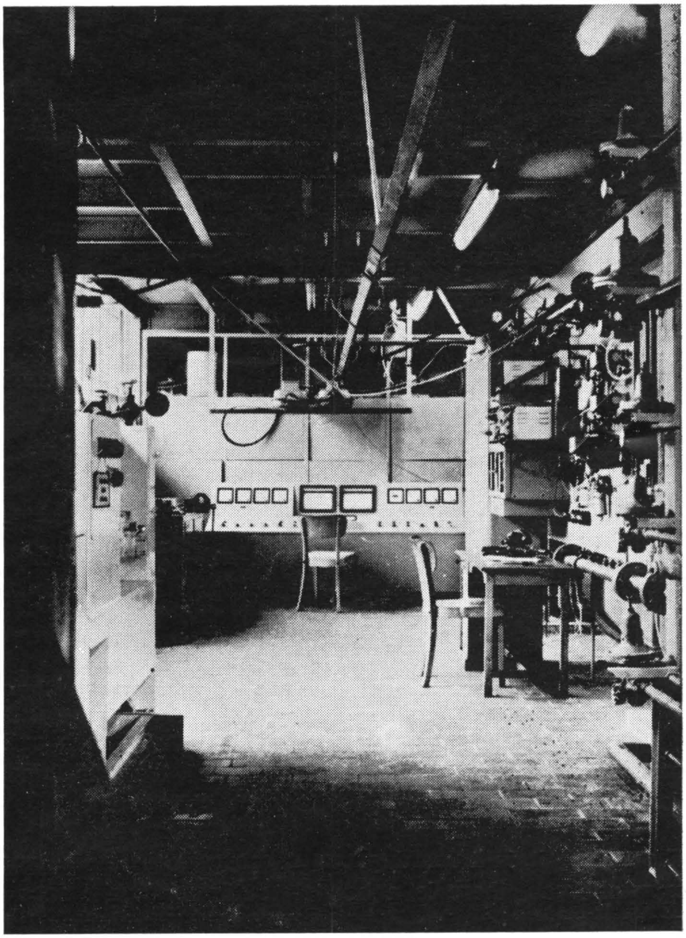
(b) the loss of pressure they cause: it was proved that a 19-mm hose causes one-sixth of the pressure loss a 13-mm hose, over equal lengths of hose;

(c) their resistance to attack by the fluids handled;

(1) Research carried out by the Steinkohlenbergbauverein, Essen, Volume II, Appendix 1.

Fig. 1

Test installation for infusion devices



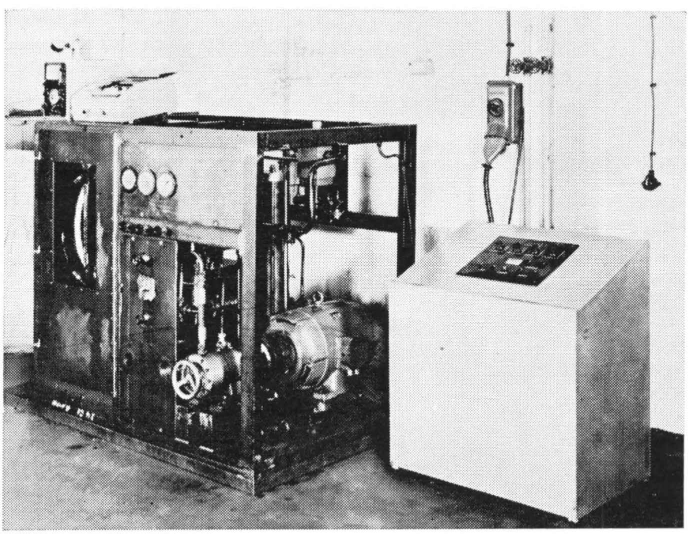


Fig. 2

Machine for testing infusion devices under dynamic stress

(d) their behaviour under dynamic stresses (tests combining shock waves and fatigue phenomena).

With regard to the last point, a device was built capable of automatically applying periodic loadings to samples of hose.

The gripping power of various types of *infusion tube* was determined.

The results obtained on the test-bench were regularly checked against underground experiments, at different pressures and depths.

Following all these trials it was possible to draft standards, which were made known to the makers and users, to ensure correct manufacture and application.

Extending the use of seam infusion

During the first test campaign, three items of research were devoted to extending the use of seam infusion to deposits where it had not found any wide application, owing to the nature of the coal or of the surrounding rock.

Seams subject to instantaneous outbursts of gas (1)

The fear of initiating an instantaneous outburst has until recently caused it to be thought dangerous—and therefore, inadvisable, if not forbidden—to infuse seams subject to such phenomena.

There are, it is true, degrees of severity in instantaneous outbursts. In the extreme case, there is a ban on cutting into the face with any kind of tool, except for the drilling of shotholes, where shots will be fired later, perhaps even from the surface after the mine has been evacuated. In such instances, the production process simply consists of loading out the coal which has been shot down.

The mere allusion to the precautions to be taken when working such seams will explain why it was necessary to approach the investigation of water infusion —which naturally causes reactions in the solid coal—very cautiously.

The process of seam infusion moreover, was scarcely reconcilable with that of inducer shotfiring which was, until quite recently, the most widely-used method of preventing instantaneous outbursts of firedamp.

The research carried out in Belgium has shown that the substitution of inducer shotfiring by relaxation boreholes of large diameter, whether in association with winning by shotfiring or not, made it possible to carry out infusions, provided certain precautions were taken.

(1) Research carried out by the Institut d'Hygiène des Mines, Hasselt, Volume II, Appendix 2.

It will be remembered that the large-borehole method involves drilling large relaxation boreholes along the whole length of the coal-face ; these holes are 115 mm in diameter, 15 metres long and set at intervals of from 3 to 6 metres apart. The holes are re-drilled as soon as the face has advanced by 10 metres.

The adoption of this method has made it possible to apply plough methods of winning, to increase the daily advance of the working and, naturally, to raise the output. An output of 600 tons per day has thus been achieved, a figure never previously obtained in seams subject to instantaneous outbursts of gas in the coalfield where the research was carried out. But what concerns us particularly here is that it was in this case possible successfully to apply seam infusion.

The trials examined the depth of drilling, the position of the sealing-off device in the borehole, the infusion pressure and the degree of wetting achieved. The best arrangement for this type of working was deduced from these data, namely to drill the shotholes at 3-metre intervals and at a height half-way up the seam, giving them a length of 2.50 metres, while the infusion chamber was 0.50 to 0.70 metres long.

In these circumstances, the infusion pressure did not exceed 75 kg/cm^2 (tests carried out before the ploughing operations showed that the infusion pressure reached a minimum of 100 kg/cm^2).

With regard to the reduction in dustiness, it was found that the infusion of a quantity of water equal to 0.85% of the weight of the net coal output brought about a 70% reduction in the weight of dust left in suspension in the air at the top of the face, and a reduction of from 25 to 30% in the number of particles between 5 and 0.5 um produced in the face.

This index of efficiency corresponds to a reduction of from 50 to 60% in the number of particles between 5 and 0.5 um as compared with the degree of dustiness that would have been observed had the same tonnage being won with the normal inducer shots.

In faces worked in seams subject to instantaneous outbursts and in which ploughing is not practised (this method having been an exception hitherto in such faces), a large number of operations have to be fitted into the working cycle. In point of fact, time must be found to carry out the following operations: drilling the large relaxation boreholes, drilling the infusion holes, carrying out the infusion itself, drilling the shotholes for the coal-winning shots, and the firing of the winning rounds. This clearly shows that such faces present special organizational problems, and that research work into special methods for dust suppression is justified. In particular, it was envisaged that the coal-winning shots should be carried out using pulsed-infusion shotfiring, a measure which would contribute to reducing the time occupied by one operation without losing any of the effectiveness in regard to the cleanness of working conditions.

Steep seams [1]

It has always been difficult to apply to steep seams those methods of dust suppression which were considered conventional before 1958. In faces using the stepped stoping method, the dustiness measured at the top of the face very frequently exceeded the limit presently thought to be acceptable, in spite of the use of pneumatic picks with water sprays and the installation of sprays at the foot of each stope.

Tests carried out in a colliery in the South of Belgium have demonstrated the possibilities of infusion combined with these techniques. The reductions in dust produced in the face, in the size range from 5 to 0.5 um, rose successively to 40, 55 and 80% as the result of better homogenisation of the water infused to greater depth into the coal, although the actual quantity used was less.

The infusion to a depth of 2.50 metres of a weight of water corresponding to 1.5% of net production, using two 9-metre holes per step, was combined with the use of water-flushed pneumatic picks and individual sprays supplying a quantity of water not more than 1.2% of the net output of coal.

This made it possible to reach dustiness levels which are consistently below the value accepted as the threshold of health risk, without any reduction in the safety of work (i.e. without affecting the behaviour of the coal or the surrounding rock). In this way, the moisture content of the coal was ultimately brought up to 4.6%.

Infusion in irregular seams containing dirt bands [2]

When seam infusion was first applied, it was observed that seams of very widely-differing appearance and composition were unsuitable for this process, even where the coal bands, considered in isolation, seemed to be capable of infusion.

The introduction around 1956 of booster injectors able to produce back-pressures in the order of 80 to 90 kg/cm^2, brought about an advance in dust prevention, because they made it possible to carry out infusion both in coal, and in thin, and only slightly compacted dirt bands.

In these circumstances, the working method became simpler: in theory, drilling followed by infusion could be carried out at irregular intervals without having to work only in the coal bands and to alternate the position of the drill holes, as had been the case up till then.

Nevertheless, the difficulties remain in cases where there were compact dirt bands of a fair thickness, such as are frequently found in seams of varying thickness where the fissuration zones are very irregular. In fact, dust with a

(1) Research carried out by the Institut d'Hygiène des Mines, Hasselt, Volume II, Appendix 3.

(2) Research carried out by the Institut d'Hygiène des Mines, Hasselt, Volume II, Appendix 4.

high silica content is brought into suspension in the air the moment that thick and water-resistant bands (which form a barrier against the entry of the water) are cut into by the cutter tools; quartz contents of 10% are not exceptional.

Without waiting for water infusion techniques in deep boreholes to become adapted to irregular seams, when it was very clearly necessary first of all to perfect these methods in the more favourable seams, attempts were made in this case to find first of all a means of infusing to normal depth. However, the purpose was to be able to impregnate the shale bands in addition, by using a higher pressure.

A colliery in the South of Belgium proposed and developed a prototype pump, which could be carried along the face and was capable of producing a back-pressure of more than 450 kg/cm^2 for a low quantity of water supply (of the order of 2 litres per minute), in order to avoid excessive disturbance of the rock surrounding the faults and bends of the roof strata.

Nevertheless, this high pressure was found to be unnecessary in practice. Studies were made over a period of eight months in a working where seam thickness varied within a range of several metres.

When the moisture content of the coal—measured in the 0/10 mm size fraction of the run-of-mine coal sampled at the bottom of the face—rose by an average of 2% solely as a result of wetting by water sprays above the face conveyors, it was possible in the most favourable conditions to eliminate from 25 to 30% of the particles between 5 and 0.5 um brought into suspension in the air, for an output of approximately 200 tons net.

When, in addition, water was infused from the front of the face to a depth of 1.50 metre under an average pressure of between 150 and 200 kg/cm^2, so as to raise the moisture content of the 0/10 mm run-of-mine coal from 1.9 to 5.4% (increase: 3.5%), a reduction of between 65 and 70% was obtained in the dust particles between 5 and 0.5 um.

But, however interesting these results may be, it was observed that—in order to maintain the dust levels at the top of the face within acceptable limits by means of shallow-hole infusion—it was frequently necessary to infuse until the moisture content of the coal was of the order of 5%, raising this to about 7% by supplementary spraying of water at the bottom of the face.

Such quantities of water are excessive and are not without risk from other points of view.

It thus seems necessary to search for infusion techniques—for irregular seams containing dirt bands—which will make it possible to obtain more uniform wetting of the coal while supplying less water. It will be seen that deep-hole infusion, penetrating into zones beyond the area of macro-fissuration, is capable of meeting this requirement.

Investigation of the mechanism of water infusion [1]

The first series of research studies was carried out in France, jointly by Cerchar and the testing service of the Lens-Liévin Group of the Nord and Pas-de-Calais Coalfields. These studies had two purposes:

(a) the analysis of the mechanism and observation of the migration of water in the solid coal;

(b) the perfecting of methods of normal and deep-hole injection with holes normal to, or parallel to, the coal-face, and a comparison of their effectiveness.

The objective set was an extremely useful one since, up to the present moment, it must be stated quite honestly that the technique of seam infusion had not been free from a certain degree of empiricism.

To carry out these experiments, observations were made of the course of the flow of water infused under a constant pressure of 100 kg/cm^2, this being followed by determining the distribution of the water in the seam.

The fusion holes were in most cases 11 metres deep, with an infusion chamber 4 metres deep.

The migration of the water was determined by measuring either the humidity of the drilling fines taken every metre from holes drilled on either side of the infusion hole, or by measuring the humidity (of samples) taken along the coal-face, every day, at intervals of 3 metres and to a depth of 0.50 metre into the face and in the middle of a block of coal.

This made it possible to draw up a map of the zones of equal humidity, referred to a plane running through the seam at half-height.

In the case of the trials close to a coal-face, the drillholes were bored between 10 and 30 metres ahead of the face; where it was desired to eliminate the disturbing factor due to the solid coal, the drilling was carried out more than 50 metres ahead of the face.

The underground measurements were supplemented by laboratory experiments during which the influence of the fissuration of the coal on its injectability was examined.

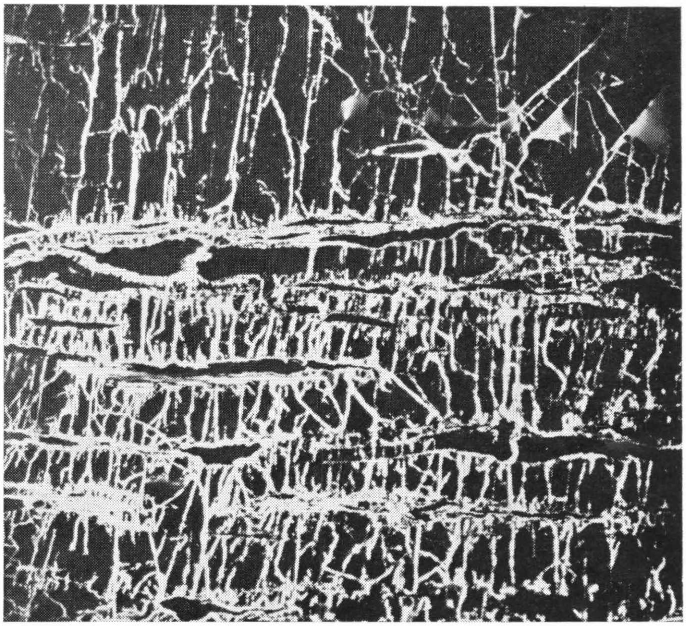
It was thus possible to show, by means of the autoradiographic technique, (figs. 3 and 4), differences in the mineralogical composition of the coal. This makes it possible to reduce the capacity of the coal to absorb water: e.g. bands of fusain can contain between 6 and 7% of their weight in water, whereas vitrain is incapable of absorbing water.

Moreover, a device was developed which makes it possible to determinate the relationship between the moisture of the coal and the quantity of dust which it

(1) Research carried out by Cerchar, Paris, Volume II, Appendix 5.

Fig. 3

Omérine seam—visual representation of infusable zones. There are no major clearly-marked areas



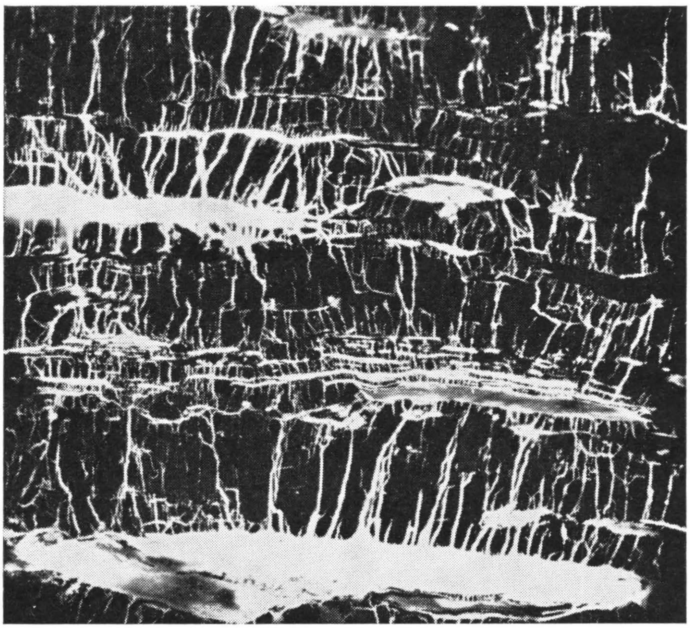


Fig. 4

Ste Barbe seam—visual representation of infusable areas is capable of freeing when fragmented. This device comprises a crushing chamber within which there are two counter-rotating toothed drums ; cubes of coal wetted to various degrees are inserted in this chamber. The crushed material drops on to the screen, while the dust produced is drawn out of the crushing chamber by a rising current of air and trapped on a micropore membrane filter.

The series of tests carried out in different seams by means of holes drilled parallel to the coal-face has shown that, *in an undisturbed zone,* i.e. a zone effected by an overlying working—either active or abandoned— and situated at least 40 to 50 metres from a coal-face, infusion is slow and difficult even at a pressure of 100 atm. and the water is irregularly distributed.

This irregularity of distribution can be explained:

(a) by the mineralogical composition of the coal (more or less frequent occurence of beds of vitrain or fusain);

(b) by the degree of fissuration of the coal.

It has been observed that a fissure must be more than several microns in width in order for the water to pass; as against this, a fissure above 100 microns in width drains off the water into preferred channels. For these reasons the mass of coal is wetted irregularly.

In the undisturbed solid, as defined above, the curve of injectability at constant pressure shows that the amount of water infused falls off with time in accordance with a decreasing exponential curve.

However, when the initial absorption rate exceeds 250 litres per hour, the quantity absorbed rapidly reaches a constant level.

These curves are specific to one type of coal or to one seam. They are therefore the *characteristic curves* of a seam.

Conversely, when it is necessary to determine the characteristics of the seam which has to be treated, preliminary trials of infusion at constant pressure can give information about the technique to be employed or the difficulties which will have to be overcome.

The conditions of infusion in *a disturbed zone of solid coal* are those which apply when the characteristics of infusion in an undisturbed zone are modified:

(i) when, simultaneously with the operation of infusion, a working passes above the zone in which the infusion holes are situated:

It is considered that the disturbing effect of the passage of the working dies away in the seam under investigation after a period varying from one to four months;

(ii) when pillars—either of small area or serving as boundary pillars— are present vertically above the infused zone of solid coal.

If a pillar of small area is present on the level above the seam, the deformation takes place locally and permanently, and the smaller the area of the pillar the greater it will be. It can be imagined that such an effect on the surrounding ground can cause major breaks and as a result affect the infusion of water;

(iii) when the infusion chamber is in or near a deformed section of road, a pinch in the seam or a junction of major roadways.

Such a set of infusion conditions cannot provide effective wetting of the ground. In actual fact, the most it can do is to provide a means of detecting faults or pillars, or a means of estimating the degree of fissuration. Every effort must be made, as far as possible to drill the holes outside zones such as those just described, where any infusion carried out can only be completely ineffective or absolutely inadequate.

When a face nears an infusion hole which is under pressure, a new set of conditions is set up—*the conditions of infusion in a fissured zone ahead of a face.*

These conditions are characterised by the fact that as the face approaches, the absorption of water, which has until this moment remained roughly equal to that of infusion into an undisturbed zone in the solid—and specific to that seam—begins to increase rapidly.

The existence of this "limit distance", which corresponds to the boundary of the zone of fissuration brought about by the influence of the face, indicates that the quantity of infusion water absorbed is dependent not only on the structure of the coal, but also on the local fissuration of the seam.

In general terms, infusion only becomes effective beyond this "limit distance", which is specific to a given seam. This distance lay between 4.30 and 8 metres for one seam, and was 33 metres for another.

Experience has shown that water infusion in the long holes parallel to the coal-face is an effective method.

It is considered that a face can be treated in this way, using only two holes which will be drilled from the roadways, so that the entire coal-face will be clear for winning operations.

It will however be necessary to continue work on developing and perfecting the drilling equipment and the devices for sealing the holes.

This research has given water infusion a more scientific foundation, by confirming the existence of characteristic infusion curves and by explaining the differences in shape of these curves by means of studies of the structure of the coals.

The stabilized level of water absorption, which is different for each of the seams studied, makes it possible to classify them according to infusibility; the structure and compactness of the coal would seem to be the factors affecting the infusibility of the coal.

As far as depth of infusion is concerned, it may be concluded that there probably exists an optimum depth, which produces maximum moistening of the coal, and that this depth lies between the coarsely-fissured zone—where results are decidedly bad—and the undisturbed solid. In this optimum zone, infusion operations benefit to the greatest extent by the presence of micro-fissures caused by the existing rock pressure, without any difficulty being caused by premature leakage of water through the large fissures.

It has in fact been observed that when infusion is being carried out by long holes drilled from the roadways the best results were obtained by continuing to infuse for as long as possible, until the moment when the coal-face reached the immediate vicinity of the hole.

In short, the possibility of injecting water, i.e. to make a seal hold and to achieve real infusion of a seam without any major leakage of water, depends on the geological influences to which the working is subjected and on its position with relation to already-worked panels in neighbouring seams.

The extreme cases are:

(a) on the one hand, the regular seam, situated in absolutely undisturbed ground. This seam can be infused more or less readily, but it absorbs and stores the water;

(b) on the other hand, the seam disturbed by various causes: faults, pinch-outs, pillars left in the neighbouring seams, working going on in an overlying level, or having recently taken place there. This presents the following alternatives: either the sealing device does not seal at all or the water rapidly finds a way out and does not remain in the seam.

Outside an undisturbed zone, the best case is that of a zone in the solid, subject only to the influence of an overlying working, provided that this working—which should have been finished at least a year before—had advanced regularly without any pillars being left.

It is useless to try to infuse a panel by means of holes drilled into the zones where disturbances of the kind referred to above have caused excessive fissuration of the coal.

In any case, and as a general thing, injection into the undisturbed solid, a long way away from the winning workings, is possible only with small quantities of water, without the hope of very much effectiveness.

In the case of infusion into the fissured zone ahead of the face, it is not at the moment possible to indicate for a seam the "limit distance" beyond which the quantity absorbed begins to rise fairly rapidly. As a result, in the technique of injection by holes parallel to the coal-face, the holes must be infused once the distance which separates them from the face has reached some 35 to 40 metres. In this way, there is no risk of missing the most favourable conditions.

The search for techniques making the infusion process independent of the winning cycle

The wish to make infusion independent of the winning cycle has led to experiments with infusion in long holes paralled to the coal-face. This technique presupposes however that the roads were headed in advance, sufficiently far ahead of the faces, or that retreating working be adopted. Such arrangements are not always possible or allowed, because of the rock pressures which obtain or for reasons of safety with regard to methane emission.

In a Belgian pit (1), experiments were carried out with two different techniques intended to modify water infusion to suit mechanised coal-faces, so that the winning cycles were not upset.

(a) One method envisaged carrying out infusion normal to the coal-face, in one day, to a depth corresponding to the face advance for one week. In this way an attempt was made to reduce to an absolute minimum the number of holes perpendicular to the coal-face, seeing that it was finally shown that two deep holes at each end of the face were sufficient.

(b) A second method was then tried, involving infusion of a panel before ever it began to be worked, carrying out the infusion from main or gate roads lying outside the working in question.

As far as the first of these methods is concerned, the purpose of the trials was to carry out water infusion at an increasing depth beyond the zone of microfissuration, to perfect the equipment and the methods of using it, to determine experimentally the infusibility curves of the seams—taking into account their special features and the working conditions— and finally to derive working methods or practical infusion standards.

The method of deep infusion at right-angles to the coal-face was tried out in a level face producing 500 tons of coking coal per day. The infusion holes, 10 metres deep, were set at 20-metre centres.

The trials showed that, to achieve good dust suppression in a face of this kind, it was necessary to infuse a quantity of water corresponding to at least 1% of the net production. If this minimum level is not reached, it is not possible to eliminate the dust production caused by the cut coal falling at the bottom of the face, even if the quantity of spraying water at this point is doubled.

A better degree of overall effectiveness is obtained at the top of the face by infusing an additional 0.5% of water, rather than by spraying an additional 1.5 to 2% of water at the bottom of the face.

The experiments have shown that, to obtain a high suppression efficiency, it is of advantage to infuse as deeply as possible; in addition, this method of infusion virtually affects only the surrounding ground.

Other observations which are of great interest were also made, particularly the

(1) Research carried out by the Institut d'Hygiène des Mines, Hasselt, Volume II, Appendix 6.

fact that it is not advisable to deepen the treated holes and that no advantage can be expected from an extension of the infusion chamber beyond 20 metres (at least as far as the Campine coals are concerned). The "long infusion chambers" have only a slight effect on the amount of infusion water absorbed. However, sometimes it is possible to achieve a certain saving in drilling costs and wages, when the use of a long hole makes it possible to advance the infusion swivel by a distance equal to the advance of the face.

It has been observed during these trials that the curves representing the counter-pressure as a function of distance between the coal-face and the infusion chamber pass through at least one minimum (the quantity of water supplied and the length of the chamber being kept constant). Thus the studies have demonstrated the existence of a band—or even several bands—of minimum counter-pressure, lying in the micro-fissured zone and through which passage of the water is made easier parallel to the coal-face. This zone might be effectively infused by holes perpendicular to the coal-face, using only one or two holes.

The second of the methods referred to above is currently known as *advance remote infusion,* which means that the infusion of a panel in a seam to be worked is carried out in advance and at a distance.

After many attempts to modify the equipment (which are being continued at present), the experiments proper began in a seam subject to working influences for the second time, i.e. by choosing a portion of the deposits where the immediately overlying seam had already been worked out. In this instance, it was actually found that the working of the overlying seam had already caused a certain amount of relaxation and this had increased the permeability of the seam which was to be infused ([1]).

The panel in which work was to be started was bounded by faults whose height of throw was greater than the thickness of the seam.

The principle of the method is as follows:

One or more *water supply holes* are drilled towards the panel to be treated, until they reach the seam. These supply holes are drilled from an old roadway or from any other point from which the seam to be treated can be reached at a carefully chosen spot. Obviously, this operation calls for precaution in respect of the drilling, the lining and the sealing-off of the borehole.

"Indicator" holes are drilled in order to follow the movement of the water in the seam. If the infusion operation is proceeding normally, then the infusion water appears at the outlet of these indicator holes at a given moment (fig. 5).

It is necessary to drill *"drain" holes* to facilitate the emission of the methane which is thrust back under pressure into the recesses marked off by the faults.

In order to provide a means of assessing the effectiveness of dust suppression provided by this method of infusion, it is necessary to make comparisons with

([1]) It is, moreover, normal procedure to work the seams in descending order.

other workings, other things being equal. In fact it is very difficult to find faces which are comparable in all respects (same seam, same level, same position with relation to previously-worked seams, etc.) which could provide datum measures of dustiness.

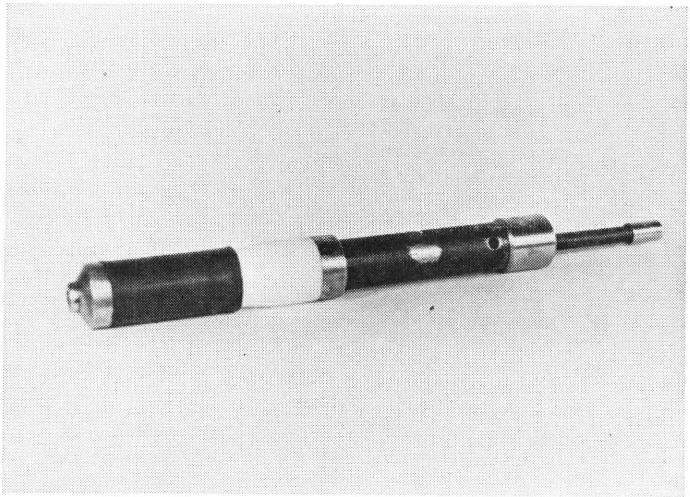


Fig. 5

Self-sealing plug 80 mm dia. for remote advance infusion

In 1963 however, it was possible to study over a period of seven months a face which had been treated by advance remote infusion, after it had advanced approximately 50 metres from the initial rise heading.

This made it possible to determine for a particular method of working the specific levels of dustiness before infusion, and to observe the changes in dust concentration after the end of the advance remote infusion.

The introduction into the seam of a quantity of water corresponding to slightly less than 0.5% of the net tonnage produced yielded an improvement in working conditions expressed in the following figures: a reduction of 55 to 60% of the weight of dust in suspension in the air, and of 25 to 30% in the number of particles from 5 to 0.5 um at the top of the face.

It may be said that in this case the reduction in the number of particles of dust discharged into the face was at least 65%, in spite of almost 30% increase in the face output.

Moreover, methane measurements showed that the emission of CH_4 during winning was reduced by almost 50%, since advance remote infusion is associated with a certain degree of continuous emission preceding the working of the panel.

All the trials carried out show that the water, which has a tendency to migrate radially from the point where the infusion borehole touches the seam, nevertheless finds preferential channels towards the places where the coal has been exposed by staple pits, cross-cuts and rise headings.

When the coal-face has reached and passed beyond this contact point of the supply borehole, the moistening seems to be less regular, even if a drain hole has been drilled in this section of the panel. To ensure that the coal-face remains moistened, it is advisable to provide additional water via a second supply hole.

A *variant* of the technique of advance remote infusion was tried out at the same pit where the preceding trials were performed. The modified method is based on the permeability of the coal. Use is made of the fissuration of the seam caused by the regular working of a seam previously won vertically above or below, in order to increase the permeability of the seam.

In Belgium, the name of *activated permeability* has been given to a degree of permeability which has been artificially increased by means of fissuration due to working.

Resort will be had to this activated permeability if a supply hole is drilled vertically and downwards, as far as and including the seam to be treated, starting from an old road which has remained easy of access.

The relaxation zone surrounding the old road and due to its very presence (this zone takes on the form of a more or less regular cylinder) has affected the underlying seam by cutting a sort of channel of greater permeability along the entire length of the road. The water can migrate more rapidly along this channel than it could do around a supply hole terminating in the centre of a panel.

This water is quicker in reaching the coal-face in the face being treated (from which the method gets its name of accelerated advance remote infusion); there it meets the band or bands—parallel to the coal-face and more markedly relaxed —which were mentioned in the paragraph dealing with deep infusion at right angles to the face, and it is here that the water tends to spread out preferentially.

This, therefore, provides us with a supplementary method which can be used either alone or to supply additional water; these two variants have been successfully used in a working at the Houthalen pit.

A great deal of research remains to be done in this field.

This technique has hitherto been applied in deposits with slightly-inclined seams (8°), in bituminous coals which are, to all appearances, easy to infuse.

Subsequently, it will be necessary to consider the extension of these methods to deposits dipping more steeply and to anthracitic coals.

It will also be desirable in subsequent trials to check whether advance remote infusion can be carried out in seams contained in a zone of the solid which has not been relaxed by previous working—conditions in which experiments have not yet been carried out.

It would be interesting to record the gas-emission phenomena which accompany the application of advance remote infusion.

This new line of research would show us whether, and to what extent, it is possible to widen the application of advance remote infusion.

Pulsed-infusion shot-firing (1)

Among the various methods of winning the coal, special attention must be paid to winning by means of explosives, this being a method which is still of considerable importance where the normal methods of mechanisation cannot be used, either because the seam is not thick enough, or very hard, or because the deposits are very irregular. Nevertheless, the ignition of the explosives used simultaneously causes the emission of dust and of fumes. It is now some years since an effective winning technique which also tends to maintain the working clean after the shots have been fired was developed; this is the method of pulsed-infusion shotfiring.

In this process, since the explosion takes place in a medium which transmits the shock-wave in a manner which is efficient for bringing the coal down, good sizing of the products brought down is obtained, and the load exerted on the supports is reduced. But at the same time, the water, which here serves as the stemming, considerably reduces the emission of shot-firing fumes and—being forced through the fissures and cleats in the coal by the force of the explosion—reduces the production of dust during the subsequent handling of the coal.

The method of operation is as follows: the explosive charges are introduced into a borehole where water infusion has already been carried out. The water pressure is then restored (25 to 30 kg/cm^2) behind a sealing-off device, consisting of a special type of infusion tube. The explosion thus occurs in a space which is filled with water under pressure.

Two techniques have been developed up to the present. In one of these, safe shot-firing in coal is sought by using conventional gas-safe explosions. Since these explosives contain salt, they have to be enclosed in a watertight sheath. The priming detonator is set laterally, so that it does not have to pierce the sheath.

In the other technique use is made of explosives which can be placed directly in the water. These explosives contain a high proportion of nitro-glycerine, and are therefore not gas-safe.

The safety in use of these latter explosives is assured if one can be certain that the explosion takes place completely within the water. This would be the case if the infusion water were able to find a channel to migrate through the fissured coal. Studies have been made of a special device which does not allow of ignition until it is certain that the cavity is entirely filled with water.

The studies were also directed towards perfecting the sealing-off devices for boreholes. These *sealing tubes* are fitted with a return valve which can resist the

(1) Research carried out by the Steinkohlenbergbauverein, Essen, Volume II, Appendix 7.

explosion shock wave and, in addition, their tightness and their adhesion to the walls of the borehole have been increased, to ensure that they remain in position when the charge is exploded. Different types of injection tube have been systematically studied in Germany in order to determine their adhesion to the coal and shale in various experimental conditions, by varying the pressure of inflation of the sealing joint and the quantity of water supplied.

It has been found that the pressures must reach at least 50 kg. The quantity of water corresponding to this pressure has been calculated.

Although encouraging results have been achieved, and the observations made were based on studies of 1 million rounds fired, it will be understood that in so difficult a field as the use of explosives, it is necessary to try to achieve even greater levels of safety by more intensive trials.

The execution of these trials has made it possible to lay down directives to be observed to obtain conclusive results with the aid of this technique. Thus a recommendation has been made to set the shots at intervals of at least 50 cm, to restrict the number of shots per round to two and to leave a gap of 50 to 80 cm between the explosive charge and the sealing-off tubes.

Excellent results were obtained with respect to the healthiness of working conditions: the shot-firing fumes were almost completely suppressed and the dust concentration reduced to a low level (1).

Up to the present time, however, this technique has not been extended to seams other than those which are only slightly, or not at all, gassy.

Subsequent research will perhaps make it possible to apply this method in more gassy seams with good hope of success.

Dust suppression in plough workings (2)

Up till now there was no effective means of suppressing dust during ploughing operations (fig. 6), except infusion of the seam.

Efforts have been made to find a method of precipitating the dust in a manner suitable to this method of working, by using water-spraying techniques. In this case the basic principle was that it was unnecessary to spray the entire coal-face continuously since coal winning is localised to the vicinity of the plough as it passes along the face. The aim was to avoid wetting both the surrounding rock and the freed coal excessively.

(1) Pulsed infusion shot-firing is widely applied in France in certain groups of the Nord and Pas-de-Calais Coalfields. At the same time reducing the mass of fumes and the quantity of dust in the face, in certain cases it also acts as an excellent means of winning the coal.
The holes are drilled to a length of 1.80 metre and spaced to approximately 1 metre intervals. Advance infusion is carried out for a few minutes using a 30 cm infusion tube. When this operation is finished, the tubes are withdrawn, the explosives introduced and the tubes replaced. The holes are then again brought under water pressure and shot-firing is carried out in the following 60 seconds.

(2) Research carried out by the Silikose-Forschungsintstitut der Bergbau-Berufsgenossenschaft, Bochum, Volume II, Appendix 8.

Several methods of controlling the sprays—either electrical or mechanical—have been put forward. But many of these proposals did not lead to any definite result, either because they were too expensive or too liable to malfunctioning because of their complicated design. Ultimately, the principle which was used was that of making use of the additional pressure caused by the passage of the plough in front of the pusher ram; this additional pressure was employed to bring the sprays into action. The apparatus used was constructed as follows: an elastic buffer (Vulkollan), which is compressed when the plough passes that point, is set between the piston-rods of the pusher cylinders and the bracket attaching to the conveyor. This movement of compression is transferred to a bearing piece which moves towards the plunger of a valve, as the elastic buffer is compressed. This gives rise to the opening of the valve, so allowing the water to pass.

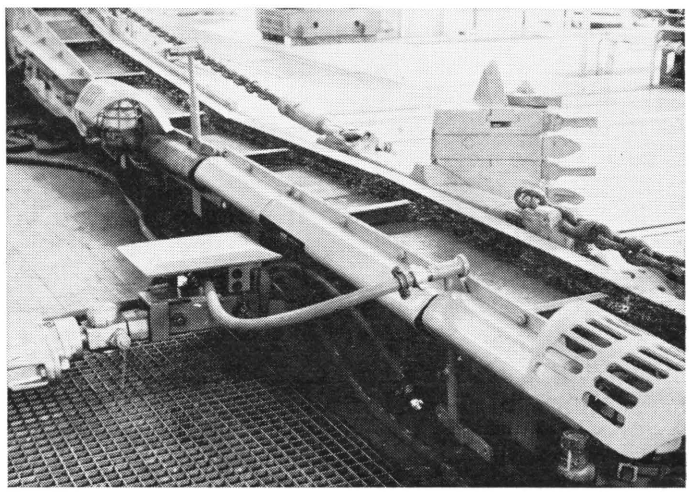


Fig. 6

Sprays triggered off by the passage of a plough

Vulkollan buffers of varying resilience can be employed, so adapting the technique to various conditions of coal-winning. The sprays are of the horizontal-jet type with a wide aperture angle. It is thus possible to bring about overlapping of the zones of action of the sprays by the appropriate choice of the distance between the tripping devices. This produces continuous spraying at the point where the plough begins to cut the face and where the coal is brought down.

These spraying devices have been fitted in many plough workings, and have been tried out in the most varied conditions, with both pneumatic and hydraulic pushing cylinders.

There are still a few details which have to be perfected in ploughing installations using drag-hook ploughs (Reißhakenhobel) or DSM ploughs (Gleithobel), especially for working in soft coals. It is in fact found that in these instances the supplementary pressure caused by the passage of the plough is not enough to compress the Vulkollan and so to trip the water valve.

Technical measures of dust prevention and suppression during operations other than winning

Pneumatic stowing [1]

It is well known that the operation of pneumatic stowing produces large quantities of dust which are particularly dangerous if they contain quartz.

As the tendency now is for stowing to be carried out more and more frequently, simultaneously with winning, the two types of dust produced can therefore be found together.

A programme of research carried out in Germany has shown very clearly and very accurately the different parameters affecting the emission of dust during pneumatic stowing. As systematic research is difficult underground in a working which is in normal industrial operation, a special experimental installation was set up at the surface in a colliery yard. This installation was designed to allow of the modification, to full scale, of one or more of the operating conditions, such as: quantity of compressed air supplied, size analysis of the material, moisture content of the material, stowing pipes used, etc.

The results of the observations made with this trial installation were then compared with practical measurements obtained in underground workings, and made it possible to highlight the following factors which affect the intensity of dustiness produced:

(a) The quantity of compressed air supplied

It is the compressed air which provides the energy; the greater the amount of energy, the greater also is the degree of crushing of the rock, and consequently the quantity of dust produced.

The concentration of fine inert dust in the air increases in direct proportion when the amount of compressed air supplied lies between 4,000 and 7,000 metres NTP per hour. Markedly higher concentrations are observed for crushed rock than for washery shale.

(1) Research carried out by the Steinkohlenbergbauverein, Essen, Volume II, Appendix 9.

(b) Size analysis of the products

For identical quantities of compressed air supplied and for stowing material between 40 and 100 mm, the concentration of dust increases and the proportion of particles above 10 mm rises.

This concentration of dust in the air supplied may even rise by a factor of two when the proportion of particles exceeding 10 mm rises from 50 to 80%.

Thus, it can be said in approximate—and somewhat oversimplified—terms that pneumatic stowing produces only half the quantity of dust when the size analysis of the stowing material is also halved.

(c) The mineralogical composition and the petrographic characteristics of the stowing material.

Stowing was carried out with crushed rock of the same size analysis, but containing a different proportion of sandstone. During its passage along the pipes, the sandstone becomes less broken than sandy shale or shale. But the concentration of dust of an inert nature is 50% greater with the sandstone than with the sandy shale, while the quartz content of these particles may even be 200% greater.

Stowing material with a high silica content should therefore be avoided.

(d) The quantity of material stowed hourly

It was observed that the concentration of dust increased in proportion to an increase in the quantity of material stowed hourly (an increase of approximately 40% when the quantity of stowing material was increased from 50 to 100 tons per hour).

(e) Diameter of the stowing pipe

The trials showed that with a stowing pipe 150 mm in diameter, it is preferable to avoid the use of pieces of rock above 60 mm in size; if 175 mm pipes are used, the maximum size of the stowing material may be increased to 80 mm.

(f) Length of the pipe range

Up to a certain length, which depends on the shape of the pipe, its diameter and the tonnage stowed per hour—the dust concentration does not depend on the length of the pipe range for a constant consumption of compressed air. But if the range is lengthened, the quantity of air supplied has to be increased and this causes an increase in the concentration of dust [by reason of the effect already remarked on in (a)].

It is therefore advantageous from the point of view of dust suppression to keep the pipe ranges short.

(g) The moisture content of the stowing material

From the point of view of the effectiveness of dust suppression, the best moisture content lies between 4 and 8%.

The lowest back-pressure, 1.6 to 1.8 atm., was most frequently recorded when the moisture content amounted to between 3 and 6% of the weight. During trials carried out with very moist stowing material, the back-pressure in the pipe range lay between 2 and 3 atm. Finally, to prevent the formation of high concentrations of dust at the beginning of pneumatic stowing operations as a result of drying out of the pipe range, all that is necessary is to insert in the pipe a water injector giving a supply of 3 litres/minute. This injector must be connected to the compressed-air valve.

The conclusions drawn from this programme of research have been summed up in a guide of good practice, with the intention of providing the pits with means of improving the working conditions in their pneumatically-stowed faces.

Caving (1)

Caving is a method of roof control which is very widely used in the pits of Western Europe. Its influence on the emission of dust is tending to become changed by reason of the fact that in modern workings caving is fairly frequently carried out during winning operations. Because of this, the particles of dust set free by the fall of rock from the roof are liable to increase the dust concentrations, as well as to raise the content of siliceous material in the air in the face, especially where the roof is of sandstone.

It was therefore necessary to determine accurately the characteristics of the dustiness caused by caving operations.

A series of measurements were carried out with this aim in faces in the Lorraine Coalfield.

Even when choosing cases where caving and winning were not simultaneous—to get a clearer picture of the phenomena which had to be investigated— considerable difficulties in carrying out the experiments were encountered because of the very marked fluctuation in dustiness levels. In a field of study such as this, the only possible place to carry out the experiments is in a real working, in which the researchers have to pay due attention to all the factors imposed by the operations of mining.

About ten faces were investigated, each for a period of one month, to determine the dustiness caused by caving operations. The interpretation of these measurements has revealed the following characteristic features:

(a) It is observed that during the periods when caving is going on, there is a marked increase in the quartz content in the total dust concentration.

(b) The dust produced is generally fine: the proportion of particles of less than 1 micron is of the order of 80%.

(1) Research carried out by Cercher, Paris, Volume II, Appendix 10.

As against this, the dustiness levels at two widely-separated points in the face cannot be distinguished and it was not possible to establish the effect of the roof falls. Nor was it possible to find a relationship between the concentration of dust at one point and the distance of that point from the source of the dust. It became very clear, that miners working in the ventilation air downstream of the caving point are just as much exposed to dust risks as the caving team themselves.

The difficulty in carrying out this work made it impossible to execute the following stage of research, which was to find the means of reducing the dust produced by caving. But this research programme has proved useful in that it has inconstestably cleared ground in a particularly complex field. It will thus assist future researchers to avoid expensive trial-and-error methods, so that their investigations will benefit from the experience gained.

It is already possible to set down the directives governing the continuation of future work in this field:

(a) to study very carefully the suitability of the equipment to be used;

(b) to set up a plan of a research in co-operation with statistical experts;

(c) to restrict work to the investigation of a small number of factors, because otherwise there is a risk that it will be impossible to determine their respective importance.

Use of wet stemming (1)

Special stemmings for shotholes, which can be used in both coal and in rock, constitute a fairly simple means of dust suppression during the operation of shot-firing. In addition to sealing off the shothole, these stemmings are intended to bring down at least one-half of the heavy concentrations of dust from the very moment of their formation.

A large number of comparative tests were carried out in the Tremonia Experimental Pit at Dortmund and in numerous collieries in the Ruhr and in the Aix-la-Chapelle region.

Certain types of wet stemming were discarded; moreover, the addition of wetting agents to the water in the ampoules does not seem to increase their effectiveness appreciably. Up to the present it would seem that the best results are obtained using ampoules with a capacity of at least 250 cc of liquid, or by "Trabant" paste stemming with an equivalent moisture content.

It may be that ampoules of higher capacity might provide even better results, but the limiting factor here is the length of the shotholes.

Recently, bent water "cartridges", shaped so that they cannot slip out of the shothole, have given good results. No additional stemming is necessary nor does

(1) Research carried out by the Steinkohlenbergbauverein, Essen, Volume II, Appendix 11.

it improve the efficiency of shot-firing, provided that the cartridges are suitably filled with water. It is advisable that they should be filled in such a way as to give them a certain degree of pressure.

As far as the Trabant paste is concerned, it will be recalled that the consistency of the paste is more important than its water content, which should be approximately 90% of the weight of the stemming, since any tendency for the paste to run out of the shothole must be avoided.

But however great may be the interest in these processes with regard to the dust produced by the breaking-up of the rock under the action of the explosive, it nevertheless has no useful effect whatsoever on the air-deposited dust which is whirled up by the blast of the explosion, so that spraying of the floor before the shot is fired still remains advisable.

Treating deposited dust by salt pastes (1)

The capacity of salts or salt pastes to fix air-deposited dust has been known for a long time.

Salt pastes of this type are made up of solutions in water of $MgCl_2$ or $CaCl_2$ (96%), a gel of $Mg(OH)_2$ (3%) and a wetting agent (1%).

The mechanism of dust fixation can be explained as follows: the presence of the wetting agent in the solution causes a link with the coal dust, so that it becomes deposited on the salt solution. As the concentration of this solution is dependent on the relative humidity of the atmosphere in the pit, either evaporation or hydration of the substance of the paste occurs. This is the reason why the salt pastes maintain their binding capacity right up to the moment when their action is completely exhausted, and why the dust remains permanently fixed. The addition of the gel of $Mg(OH)_2$ is intended to give the solution of salts a pasty consistency, so that it can be applied to the roofs and sides of roadways in a sufficiently thick layer.

The objective of this programme of research was to examine to what extent the precipitation and the fixation of dusts below 5 um can be effected by the application of hygroscopic salt pastes.

Research studies were carried out at three different places: in a small-scale model test roadway, where the ventilation and temperature conditions could be freely modified at will, in a roadway in the Tremonia Experimental Mine and in the underground roads of a Ruhr pit. It was observed that the salt pastes affect the fixation of dust in two ways:

(a) by their capacity to moisten the dust particles, to bind them one to another and to fix the agglomerated air-deposited dust;

(1) Research carried out by the Steinkohlenbergbauverein, Essen, Volume II, Appendix 12.

(b) by the change they bring about in the surface roughness of the roadway walls.

These tests have proved that the salt pastes genuinely have the capacity of fixing dust particles below 5 microns in diameter and of facilitating their deposition. The tests have also shown that the walls and supports covered with paste play a predominant part in the process, and that it is not sufficient simply to cover the floor of the roadway with the paste.

Pastes of calcium chloride or magnesium chloride can, when applied in a 5 mm layer, fix a quantity of dust equivalent to their own weight, before their capacity for fixation is exhausted. The paste-covered surfaces can fix a maximum of 360 to 400 grams of dust per sq. metre per day.

According to the quantity of dust produced, a paste-covered zone can thus maintain its effective action for several weeks and even for several months.

With regard to its action on fine dust, it has been confirmed that zones covered with paste can fix deposits of dust three times greater than those which can be held by an untreated zone.

This clearly shows how effective these pastes are as a means of preventing dust explosions.

The trials have shown that the quantity of dust held by the paste increased markedly with the ventilation-air velocity. Thus at an air velocity of 0.5 metre/sec 15% of the dust was fixed, but the proportion increased to 75% at an air velocity of 2 metres/sec.

In the trial roadways, it was observed that there was a reduction of the dust below 5 microns—from 25% up to as much as 90% on occasion—in sections of the roadway which had been treated with paste over a length of 40 or 100 metres. The quantities of coal dust or rock dust undergo the same degree of reduction.

These studies have conclusively demonstrated the influence of this process on the fixation of dust. It was observed that the dust fixed by the past showed absolutely no tendency to become suspended in the air again, as is the case with dust on untreated surfaces.

The protection of metallic objects present in the roadways (supports, machines, electrical equipment), against the corrosion due to the salts calls for special attention. It is well known that concentrated solutions of $CaCl_2$ and $MgCl_2$ have only a slight corrosive action; but this is not true of the much more dilute solutions which occur where running water dissolves the paste. At the present moment research is going on into means of providing effective protection of metallic objects against corrosion from this cause.

The work in this field has become doubly important since the application of the process of salt pastes not only makes it possible to improve the cleanliness of the underground workings, but also increases safety with respect to dust explosions.

Aspiration of deposited dust (1)

At the same time that means were being sought of fixing the deposited dust, apparatus had been proposed for aspirating the dust and so removing it from the transport roads (fig. 7). At the beginning, two possible applications had been envisaged for this dust aspiration technique: one in roadways where rail tracks were laid, and the other in roadways with continuous haulage systems. The development of the aspiration apparatus was entrusted to firms manufacturing mining equipment.

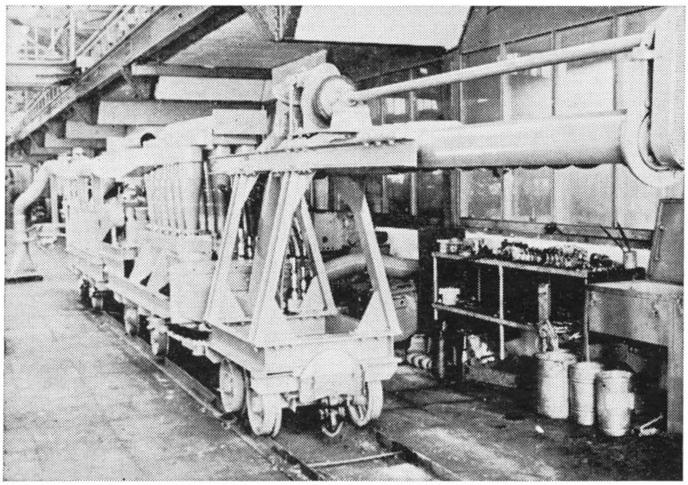


Fig. 7

Dust aspirator for roadways

As originally designed the system should have comprised a first trapping stage consisting of cyclones to separate out the coarser components. A second trapping stage was intended to retain the finer dust. The required underpressure was produced by a blower.

Many technological improvements were made and the initial design principles revised several times.

The experiments show that it was preferable to restrict the underpressure so that particles of deposited dust above a fixed size (20 mm) were not aspirated. The method preferred was that of aspirating dust after it had been brought into suspension in the air again by a carefully controlled jet of compressed air.

At this point, the complicated design of the trapping head and the difficulty of handling it made it essential to use a hydraulic control device. The conditions thought to be best for the use of the dust aspirator clearly influenced the final construction adopted.

It was essential that the apparatus should be capable of aspirating a quantity of dust-laden air of 2,000 m³/h and that the quantity of dust aspirated should be

(1) Research carried out by the Silikose-Forschungsinstitut der Bergbau-Berufsgenossenschaft, Bochum, Volume II, Appendix 13.

2.5 cu.m per hour, corresponding to approximately 2 tons of dust captured each hour. This led to the choice of a double series of cyclones in the first trapping stage and a wet trapping device of the Hydrobol type for the second stage.

Other design improvements made during the research programme dealt with the air-tightness of the various components and also the removal of the trapped dust, which is discharged into a special car by means of an endless lifting screw and an endless-screw distributor.

At the moment of writing the report at the end of this period of research, this apparatus existed only in the prototype stage and was moreover capable only of aspirating dust from the floor.

It is of fundamental interest that the work of developing this apparatus should be continued. This would make it possible to fill the gap which exists at the moment in the range of means for disposing of dust deposited in mine roadways.

Bringing down the dust by water spraying (1)

Water spraying as carried out at present over transport devices is in fact a spraying technique which combats the formation of dust at points where the coal falls or where the products are transferred from one means of transport to another at the price of an excessive degree of wetting, so that the method is actually disadvantageous.

With the aim of clearly determining the factors which govern the efficiency of water spraying as a means of bringing down the dust, a special programme of research on this subject was initiated.

The first essential was therefore to determine the theoretical basis of the effect of water spraying on a cloud of dust.

Subsequently, use was made of the data so obtained to define what can be expected of the use of water sprays, as well as what it costs in water and power consumption, to obtain a satisfactory degree of efficiency. Certain types of dedusting equipment based on this technique and intended for use in both faces and gate-roads were proposed.

Actually, two favourable cases were specially studied. There were: spraying of water under air pressure alone, and spraying under water pressure upstream of the orifice of a venturi fitted with an auxiliary fan.

These research studies were carried out in an experimental roadway, where the spraying devices can be investigated in varying conditions of dustiness.

Atomisation in water-air sprays

This type of atomisation is obtained by breaking up the stream of water by a jet of compressed air.

(1) Research carried out by Cerchar, Paris, Volume II, Appendix 14.

The water vapour mist produced is ejected via a small divergent cone. The four principal factors affecting the efficiency of the operation are:

(a) the diameter or cross-sectional area of the ejector nozzle;

(b) the compressed-air pressure;

(c) the quantity of water atomised;

(d) the amount of air to be dedusted.

It was possible to establish experimentally a relationship which indicates the effect of these factors on the efficiency of atomisation. From this relationship—which has been plotted in monogram form for convenience of use—it is possible to deduce the different values for the quantities of water and air which yield the desired efficiency of dedusting of a given quantity of dusty air. The efficiency is expressed as a percentage of the improvement measured, either visually by light diffusion, or by sampling on a membrane filter followed by counting under the microscope.

It was observed that any increase in efficiency was obtained at the price of a rapidly-rising expenditure on water and compressed air.

For example, 70% dedusting of a 6 cu. metre/sec stream of dusty air calls for:

(a) water supply at the rate of 12 cu.metres/hour;

(b) compressed air supply at the rate of 15 cu.metres/min.

which amounts to the consumption of a dozen or so pneumatic picks.

It can thus be seen that the quantities consumed rapidly become prohibitive, and that this system of dust suppression cannot economically be used as a continuous means of dedusting large quantities of air.

On the other hand, it is very suitable for dealing with dust emissions of short duration, e.g. after firing a round of shots.

Atomisation of water alone upstream of the orifice of a venturi fitted with an auxiliary fan

In very general terms the operation of the system formed by the atomiser and the venturi involves the following parameters:

Geometric parameters:

(a) type of atomiser;

(b) characteristics of the venturi;

(c) position of the atomiser in relation to the venturi orifice.

Operation parameters:

(a) pressure or throughput of water;

(b) velocity of passage through the orifice;

(c) power consumed or total pressure loss.

At the beginning the number of variables was high, but it was possible to reduce this by fixing the pressure to which the tests were carried out at 16 kg/cm^2—approximately the pressure normally used underground.

Moreover, a preliminary study led to fixing the distance from the atomiser to the orifice at three times the diameter of the orifice.

It was noted that solid-cone atomisers were preferable to hollow-cone types.

Two venturis in series offer no improvement over a single venturi. It was observed that efficiency and pressure losses both rose with the quantity of water supplied and the speed of passage through the orifice. To sum up, the efficiency of atomisation at the orifice of the venturi is a function of the power consumed by the water in the dedusting operation, whether this energy is provided by the fan or by the water itself.

Application of atomisation to dust suppression

(a) One example of the application of water-air atomisation can be found in the small dedusting devices (fig. 8) in which it is possible to use the compressed air simultaneously for atomising the water and for aspirating the air which has to be dedusted.

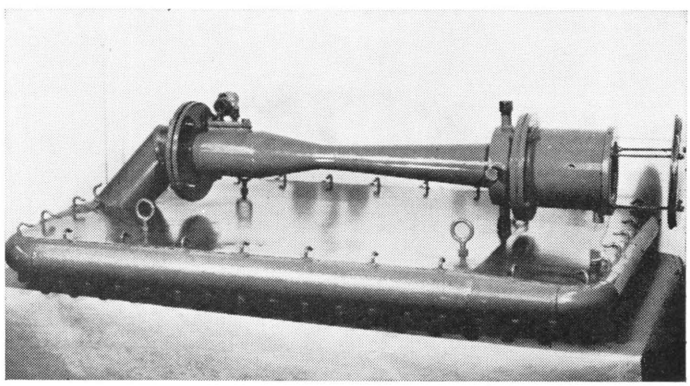


Fig. 8

Deduster for transfer points

The atomiser functions as an ejector nozzle and draws the air to be dedusted into the venturi orifice. Downstream of the venturi there is a droplet-trapping device which can, e.g., consist of a basket filled with small balls.

Such a device has been built; it operates at an air pressure of 4 kg/cm^2 and—for a water throughput of 100 litres/hour—the compressed-air consumption of the atomiser is of the order of 900 litres/hour. The capacity of the device is 100 litres/second of dusty air. Its numerical efficiency is 75% and its optical efficiency 90%.

This type of deduster is used underground to deal with dust sources which are local and can be boxed in; it is both efficient and compact.

Other examples are the dedusting of drilling operations or of transfer points.

(b) As an example of a deduster based on the principle of atomisation at the orifice of the venturi, there is the apparatus made by the Lorraine Coalfield, which can deal with a flow of 3 cu.metres/second.

The device was designed to be set behind a continuous miner or a rock-heading machine, but its potential field of application is very much greater.

The apparatus can be fitted in an 800 mm ventilation duct. It comprises 7 venturis, 80 mm in diameter and each 1.70 metre long.

The desired capacity is obtained by means of a 20 hp fan at a pressure loss of 320 mm H_2O. The water consumption is 2.5 cu.metres/hour at a pressure of 20 kg/cm^2.

The efficiency of this deduster has been measured in an underground experimental roadway.

The average performance of the apparatus is to bring down:

50% of particles less than 1/um;

75% of particles between 1 and 2.5/um;

90% of particles between 2.5 and 5/um

and virtually all particles greater than 5/um. In practice, this device can be used to dedust any installation which produces a cloud of dust which can be channelled towards the device.

Dedusting highly dust-productive equipment (1)

We understand the term highly dust-productive installations underground as covering: crushing plant for stowing dirt, skip-filling installations and central loading points (fig. 9).

The important thing is that the dedusting equipment used should not discharge excessive quantities of dust into the atmosphere—particularly below 5 microns.

A test bench was set up to investigate the extent to which available equipment was suitable for underground use.

(1) Research carried out by the Steinkohlenbergbauverein, Essen, Volume II, Appendix 15.

Nine different devices were investigated; the amount of dust allowed to pass and the characteristics of the dedusters were determined with respect to their action on dusts of rock, coal and coke, containing respectively 28 to 35%, 18 to 19% and 10 to 15% by weight of particles less than 5 microns. The quantities of dusty air supplied lay between 40 and 70 cu.metres/minute, the concentrations being adjusted to the following values: 0.5 - 1 - 2 - 4 and 8 g/cu.metres.

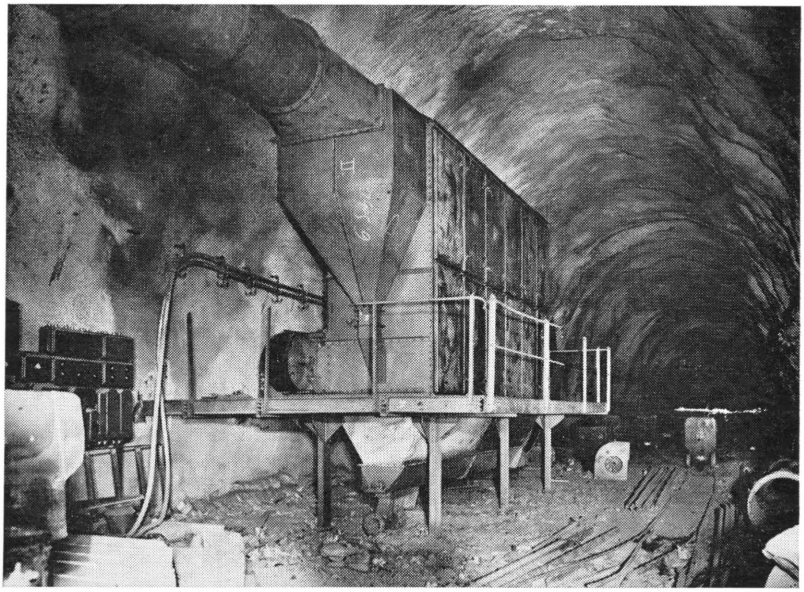


Fig. 9

Dedusting system at a skip - loading point

The amount of dust allowed to pass, expressed in terms of weight for dusts of all sizes and with an initial concentration of 2 g/cu.metre, varied with the type of apparatus from 0.9 to 8.4%. Fairly large numbers of tests were also carried out in underground installations.

At the end of this measurement programme it seems possible to choose dedusters which meet the regulation requirements which at present obtain in Germany. Good results can be obtained by dedusting with filters and, in certain conditions, by a wet method. The choice of the dedusting method to be applied for stone-crushing plant underground depends very largely on the use to which the filtered air will be put.

If the filtered air is to be recycled into the fresh-air current, attention must be paid to ensuring that the degree of dustiness of the fresh-air is not increased by the dust content of the cleaned air leaving the deduster. The high dedusting capacity called for is generally provided by cloth filters, or—when the cleaned air leaving the deduster is highly diluted by the fresh-air current—by wet dedusting devices with a high retention capacity.

The search for evaporation-retarding agents [1]

It is well known that in the pits the use of water, even for dust suppression measures, always had a bad effect on the mine climate because of the rise in the humidity of the air so caused. This unfavourable action may have serious consequences in hot mines.

This programme of research set out to reduce and check the evaporation of the water either by inserting a layer of liquid as a screen between the water and the air, or by dissolving in the water chemicals which can reduce its vapour pressure.

It will be understood that, if we can reduce the evaporation of the water which is intended to moisten the coal dust during the operations of production and transport, it will not be necessary to use such large quantities of water as was previously the case, since the effect of this water will be of longer duration.

During this research programme, comparisons were made of some forty substances of varying chemical nature; experiments were carried out in such a way as to maintain the climatic conditions which would be met in deep workings.

Alkaline and alkali-earth halides (chlorides of calcium, magnesium and sodium), as well as oils and fatty substances, are efficient evaporation-inhibition agents. By combining theoretical relationships and practical results, a relationship has been established for certain substances which allows of calculating the basic concentrations to be used to attain a given efficiency whatever may be the relative humidity of the air. Efficiency is expressed as a reduction of the evaporation coefficient of the mixture.

A start has now been made with the practical application of solutions which—by reason of the fact that they evaporate less rapidly than pure water—make it possible to fix dust for a longer period, while at the same time reducing to a minimum the quantity of liquid needed.

(1) Research carried out by the Institut d'Hygiène des Mines, Hasselt, Volume II, Appendix 16.

Dust measurement

From the beginning of the formation of the research programme, the experts noted that one problem requiring attention was that of the measurement of dust.

In point of fact, knowledge of a phenomenon can exist only if the phenomenon and the variations it undergoes can be measured accurately. The information provided by measurements facilitated in this instance the installation of dust-suppression devices at critical points and the supervision of their efficiency.

It is, of course, true that at that time there were available measuring and sampling devices, and methods for studying the dust; but the aim was to make these means easier to use, more robust, more accurate, more rapid and less expensive to use. In a word, the purpose was to perfect dust measurement and sampling equipment suitable for colliery use.

It has become customary to apply the name "dust-measurement apparatus" to devices which are in fact, for the most part, sampling devices.

This term, which has entered current language usage, should not hide the fact that the assessment of dustiness levels is possible only after the sample has been studied as a subsequent operation, either by particle counting or by weighing, in accordance with clearly-established methods.

Ultimately, it is only the combination of the two operations, sampling and sample analysis, which provides the actual dust measurement.

It was thus desired to perfect at the same time the methods of analysing the dust samples taken.

Dust measurement as understood in the foregoing description is a difficult operation. The difficulties are due to the fact that it is required to measure an emission of particles which not only varies in concentration over a period, but also varies in mineralogical composition and in size consistency. It should be added that the size fractions of interest in connection with health hazards are the finest and, consequently, the most difficult to isolate.

In addition, the devices to be used must be compact, sufficiently light, robust, accurate and flameproof. They should be sufficiently simple of operation for normally-skilled persons to be able to use them. In addition, the apparatus should, as far as possible, be independent of mains supplies of compressed air or electricity.

All this will make it clear that it is useless to expect a universal type of apparatus. It has therefore been necessary to devise categories of specialised devices to be used for particular measurement tasks.

Sampling devices

Five sampling devices have been developed.

1. Three such devices are intended for gravimetric sampling of fine particles. The sample taken by these devices is to be weighed, and the result of the measurement will be expressed in mg/m^3 of aspirated air.

Various principles have been employed to separate out the particles above 5 microns.

Pre-separation can be obtained either by the use of elutriators consisting of stacked plates, or by means of a cyclone.

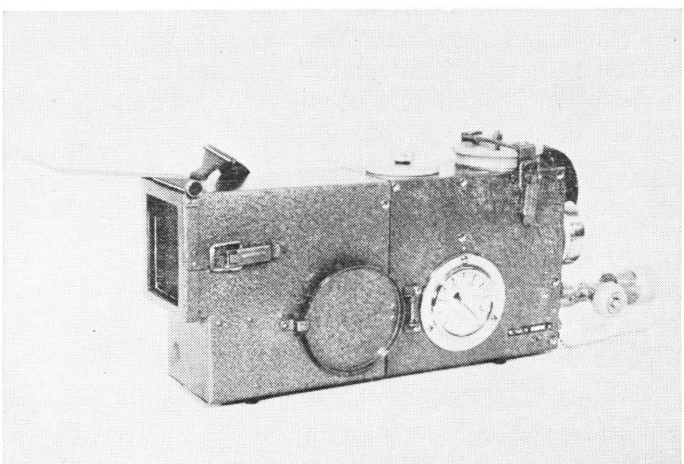


Fig. 10

Dust sampler/meter S. F. I. type, built by Dräger.

The three devices in this category are:

(a) The apparatus built by Dräger (fig. 10) with the collaboration of the Silikose-Forschungsinstitut of Bochum ([1]). This is operated by compressed-air suction. The aspiration flow is maintained constant at a given underpressure, regulated by a calibrated nozzle.

(b) The electrostatic dust-precipitation apparatus ([2]). This device is housed in a flameproof and explosion-proof housing, and can sample at the rate of 1.5 litre/sec over a period of 6 hours.

(1) Research carried out by the Silikose-Forschungsinstitut der Bergbau-Berufsgenossenschaft, Bochum, Volume II, Appendix 17.

(2) Research carried out by the Bergwerksgesellschaft Walsum A.G., Volume II, Appendix 18.

(c) The B.A.T. I apparatus [1], which has been in service since January 1963, is the sampling apparatus used in West German mines (fig. 11). It aspirated 12 cu.m of air per hour and weighs less than 5 kg. It is operated by compressed air and is designed to carry out routine sampling and to take a sufficiently large sample for the different analyses which may be necessary, in particular for quartz determination.

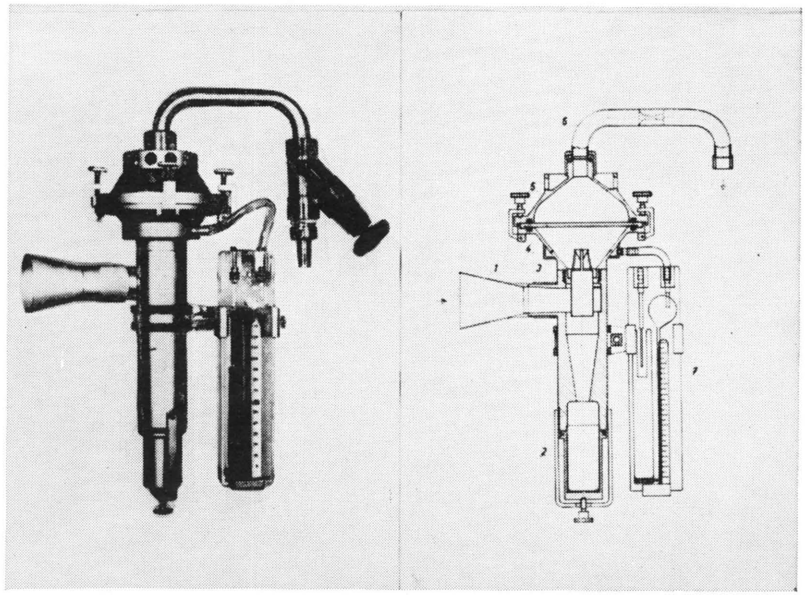


Fig. 11

Filter sampler B.A.T. I (1964)

The separation curve of the cyclone is established taking into account industrial health practice: only the dust capable of entering the lungs is trapped on the membrane filter.

A fourth apparatus [2], also gravimetric in principle, exercices a "selective separation" of the dust during the sampling operation, so that the dust can be collected in lots of decreasing size. This apparatus is known as the Zurlo type classifier.

In this device, the dusty air which circulated in a tapering channel follows a zig-zag path. The particles which are stopped by the abrupt changes of direction, because of their inertia, are collected in small lateral vessels. The increase in the velocity of the dusty air due to the tapering of the channel allows of increasingly intensive separation of the finest particles of dust. Those which are not deposited in this way can be collected on filters.

Various improvements have been made to the original design of this apparatus.

(1) Research carried out by the Steinkohlenbergbauverein, Essen, Volume II, Appendix 19.

(2) Research carried out by the Clinica del Lavoro, Milan, Volume II, Appendix 20.

2. The four devices described above are integrating types, since they provide an indication of the average concentration by weight over the entire period of sampling (as much as several hours in some instances).

The fifth device (1) belongs to the category of apparatus designed for dust-particle counting: the results of the measurements are expressed in numbers of particles per cu.m of aspirated air. The apparatus collects the dust on micropore filters made of a cellulose-based material, to permit of counting the particles under the microscope once the supporting filter has been suitabliy treated.

Contrary to the practice adopted for the category of devices referred to earlier, in this case the sampling period is very much shorter, but—as samples are taken at carefully-chosen intervals—it is possible to check the variations in the dustiness level of the air within very close approximation.

These principles are used in the Cerchar type 837 apparatus employed in the French pits. Weighing 4.1 kilos, the device is independent (it is supplied by an electric battery with a capacity of 4 amp-hours); its aspiration rate can be varied from 0 to 500 cm^3 per minute.

3. With a view to analysing the variations in dust emission with time, it is of interest to be able to pin-point the moments of maximum emission, or what are frequently known as "peaks".

To do this it is necessary to have means of checking continuously the dust concentration over a certain period, e.g. over one complete working shift.

The filtering apparatus which was designed for this purpose (2) makes it possible to obtain a delayed photo-electric recording, which is however continuous. A drum driven by a clockwork mechanism turns a disc carrying a dust filter formed by a ribbon, passing it in front of a narrow slot through which the air is aspirated. The dust particles become deposited on the ribbon.

When the dust-laden ribbon is unrolled in front of a light source, a photo-electric signal is produced whose variations can be recorded.

Three models of this device have been built, one intended for a 40-minute period of operation, a second for 8 hours and a third for 24 hours.

Analysis of the dust

Studies relating to the mineralogical analysis of the dust have continued to grow in importance in the last few years.

In fact, to enable them to advance in their knowledge of the action of dust

(1) Research carried out by Cerchar and Firme H. Morin, Paris, Volume II, Appendix 21.

(2) Research carried out by the Steinkohlenbergbauverein, Essen, Volume II, Appendix 22.

on the human organism and to determine the hazards associated with it, the medical specialists require to study more and more closely the structure and nature of the dust particles which enter the lungs.

They wish to know as accurately as possible the size distribution in the finest size fractions. They also wish to know the detailed mineralogical composition of the minerals present, not only quartz, but also other minerals which might have an aggravating effect or, on the other hand, exercise an inhibiting action on the development of pneumoconioses.

In addition, the methods of analysis must fulfil the following requirements: they must be accurate, operate on small samples, be rapid and cheap.

The following research projects to a certain extent meet one or another of these requirements.

1. A first fundamental research project is worthy of particular attention; this is the study of light diffusion by particles suspended in the air (1). This project is based on the fact that a routine direct-reading apparatus, the tyndalloscope, which is very widely used in Community mines—and especially in Germany—is in fact based on the properties of diffused light.

Obviously, it was of the very greatest importance that the physical principle on which this measurement is based should be thoroughly understood.

During the research work, the theoretical data available on the intensity of diffused light as a function of various parameters were experimentally confirmed. The variables considered here were: the size consistency, the optical constants of the particles—i.e. those governed by their nature, and the spectral distribution of the light.

It was shown that, in certain conditions, the measurement readings could be made independent of the nature of the dust particles. Several problems however, still remain to be cleared up. Thus, the result of these measurements depends, among other things, on the "shape factor" of the particles and on their size distribution.

Whatever the result may be, this research project has shown that the tyndalloscope measurements do in fact represent the dustiness level, a fact which was not obvious at first sight.

2. Another research project also presents a direct interest for collieries using the tyndalloscope as a measuring apparatus (2).

It is well known that the readings from this apparatus have to be corrected according to the rock-dust content of the cloud of dust being examined. It was therefore tempting to seek a method which would allow of determining very

(1) Research carried out by the Steinkohlenbergbauverein, Essen, Volume II, Appendix 23.

(2) Research carried out by the Steinkohlenbergbauverein, Essen, Volume II, Appendix 24.

rapidly and accurately the proportions of the principal constituents in dust found in collieries, i.e. coal and rock-dust.

For this purpose use was made of a photo-electric method based on the fact that reflected light makes the particles of coal on green membrane filters take on a brownish-black colour, so that they stand out in excellent contrast against the transparent particles of rock-dust. The intensity of light reflected by the green surface of the filter is a function of the wave-length of the incident light.

If coloured filters are inserted in the beam of incident light, it is possible (by resorting to certain devices) to count the particles of coal or of rock-dust. In the apparatus constructed, a given volume of dusty air is aspirated by means of a hand-pump equipped with a pre-separator, and deposited on a green membrane filter. A suction-meter allows the rate of aspiration to be adjusted to a constant level.

3. As it became necessary to carry out more and more analyses, in order to determine the health risk presented by dustiness levels, numerous problems were raised by the requirement to determine quartz (fig. 12) in the dust samples.

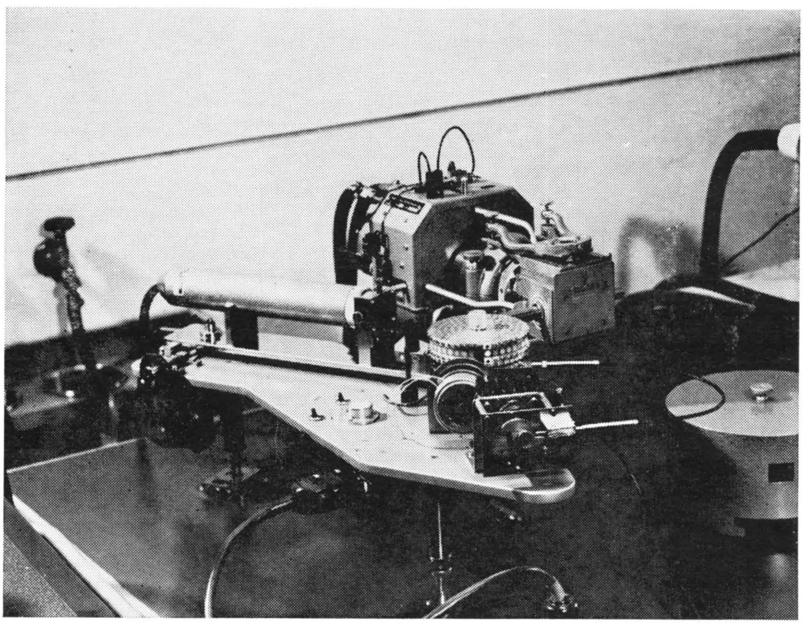


Fig. 12

Quartz-determination diffractometer for use on mine dusts. The device includes an automatic specimen-changer

The important thing is in fact that this determination should be accurate, rapid and cheap, and calling for only small samples.

Several analysis techniques have been proposed and investigated. It should first of all be recalled that in certain deposits and for certain working methods there may be a proportional relationship between the ash content of the sample and the quartz content—a fact which obviously simplifies the analysis—but that there are many cases where it is not sufficient to rely on this sort of approximation and where it is necessary to know the true content of free silica or of quartz.

If it is required to determine this content by counting the particles in a sample (e.g. on the slide of the thermal precipitator), the standard mineralogical techniques of producing coloration by using immersed objectives, phase contrast and dark-ground illumination are satisfactory, provided that particles are examined on an invariable support (glass).

When cellulose-based filters were first used for samples a number of difficulties arose because of the unforeseen variations in the refractive index of the membranes used. These difficulties have finally been overcome, after systematic research into various impregnation fluids.

4. To determine the proportion by the *weight* of quartz, chemical or physical methods (e.g. X-rays) have always been thought to be reliable and to give results which are highly reproducible.

It became clear nevertheless, that it was difficult to obtain samples of dust below 5 microns, which were needed to assess the health risk involved by various levels of dustiness. As, moreover, the number of analyses to be made is increasing markedly, it was desired to perfect existing methods, without impairing their accuracy, so that they were rapid and needed only a few operators.

The research summarised here ([1]) resulted in the automation of quartz analysis by X-ray diffraction as a *routine* process, which is rapid and accurate and requires no more than 10 mg of ashed dust.

The use of an automatic sample changer, a special diffractometer and an automatic device for measuring the absorption (as well as other auxiliary apparatus) make it possible for a well-trained operator to carry out about 7,000 quartz analyses annually, the average error in the determination being kept around 1%.

5. The investigation of infra-red spectroscopy was resumed on new lines and improved ([1]), with the aim of being able to carry out systematic silica analyses on even smaller samples—of the order of 1 milligram—and of eliminating the disturbing effect of certain minerals accompanying the quartz. By this means it was possible to make the determination of the quartz content practically independent of the size consistency of the dust being studied, while maintaining the facility for quantitative determination of the various forms of silica—even amorphous silica. This considerably widens the field of investigations which can be carried out in the study of the mineralogical composition of different siliceous rocks.

The results obtained from routine analyses by X-ray diffractometry and by infrared spectroscopy are comparable.

(1) Research carried out by the Steinkohlenbergbauverein, Essen, Volume II, Appendix 25.

6. It is well known that particle counts under the microscope as a means of quantitative examination or qualitative analysis of mine dusts give very useful and informative data, but that, on the other hand, they take up a great deal of time and require great care (1).

Research work (2) was carried out with the intention of automating the operations of determining size distribution and even the mineralogical constituents of dusts. The automatic or semi-automatic methods known hitherto are not immediately applicable to the case of dust samples taken in pits.

The experiments principally dealt with quartz and anthracite dusts prepared in the laboratory for animal experiments.

The size analysis of the particles was carried out by previously photographing them under an electronic or optical microscope and the particle images compared with a set of circular reference images of different diameters, and connected to the apparatus, which is known as "a size-consistency analyser". Each circular reference image is associated with a counter which automatically records the particles once they have been measured.

This Endter counter makes it possible to obtain size-distribution curves and cumulative curves of satisfactory reliability, provided that the photographs taken under the electronic or optical microscope are perfect and contain no images of aggregates of particles.

The saving in time in the counting operation is said to be of the order of 75%.

7. The most refined research has been carried out in efforts to explore the size fractions lying below the threshold of resolution of the optical microscope (3). Thus, studies were made of samples of dusts, with respect not only to size consistency and size distribution, but also to the composition, mineral content, coal content, soot content etc.

It was necessary to find for this purpose new methods of preparing dust samples for examination under the electronic microscope, suitable for use with underground suts and to the methods by which they are sampled.

It was, however, not possible to distinguish by this method the various clay minerals, but it was possible to demonstrate the presence of extremely small particles of soot originating in the exhaust fumes of diesel engines, these particles being the cause of certain differences which are sometimes found to exist between the various measurement methods.

The studies of mine dust by the interference technique of microscopy have been finished. This method of analysis of mineral dusts in a very fine state

(1) An experienced laboratory system needs more than an hour to count about 1,000 particles between 0.5 and 5 um. under the microscope.

(2) Research carried out by the Steinkohlenbergbauverein, Essen, Volume II, Appendix 26.

(3) Research carried out by the Steinkohlenbergbauverein, Essen, Volume II, Appendix 27.

gives basically the same results as the method producing coloration by the use of immersed objectives, with phase contrast and dark-ground illumination.

8. In the field of dust measurement two opposing trends have become evident in recent years. Firstly, it was found desirable to standardise the methods used and to achieve easy interpretation of the data recorded by various methods. Secondly, each institute or organization has its own ideas in this field and directs its work along the lines suggested by its own particular preoccupations or its position with regard to other dust-prevention problems. It should also be pointed out that any modification in the procedure or method used by an institute in carrying out dust measurements causes that institute to lose the benefit of its previous records.

To meet the first of these two wishes, while keeping practical realities firmly in view, the institutes hit upon the idea of attempting to make joint dust measurements.

The aim laid down for these measurements was the comparison of the sampling apparatus, analysis methods and results, and to compare closely the criteria of assessment of dustiness which had been either adopted or put forward.

The first part of this work was begun in tests which were executed in the experimental roadways at Sterkrade (Ruhr) and Hohenpeissenberg (Bavaria), where the representatives of each country—joined by delegates from Great Britain and from Austria—carried out measurements with their apparatus, in accordance with their own working methods, this being followed by entrusting the interpretation of the samples to other laboratories, thus multiplying the possibilities of comparison.

The claims of the various types of instrument became more clearly defined when certain differences were more clearly explained. The experience gained made it possible to establish and carry out detailed programmes of comparative studies, each more exhaustive than the preceding one.

Meanwhile, work had commenced in the Netherlands [1] on a research project of the same kind, which however was to deal with a smaller number of instruments—only four types. When comparing the results of determinations of the degree of dustiness in the air in different underground workings in the same deposits, it was observed that the gravimetric "limit dustiness levels" put forward by this organization corresponded with a satisfactory degree of approximation to the American "standards" when the quartz content of the coal dusts lies between 10 and 15% of the ash content (by weight) of these dusts.

9. It would be impossible to close a chapter dealing with the measurement and analysis of dust without indicating the lines of advance opened up by past work, and stating what remains to be done.

(1) Research carried out by the Stofinstituut, Heerlen, Volume II, Appendix 28.

The following problems are among others still awaiting attention:

(a) perfecting the existing instruments, making them independent, simpler, more robust and more accurate;

(b) developing a continuous sampling apparatus which is simple, portable, and independent, and which would allow of establishing the quantity of dust inhaled by a miner during a working shift;

(c) developing an immediate-reading dust-level indicator which would allow of carrying out instantaneous adjustments in the dust-suppression systems in use;

(d) developing a remote dust-level indicator, which would transmit the measurement, e.g., to a pit control centre.

In fact, the same problems arise here as those which were observed in connection with measurements of mine gas.

Physical properties of the dust

During this first programme of research, work with regard to the physical properties of the dust was not pushed very far. The relatively restricted funds supporting the programme did not permit of any wider extension of these techniques, since priority was necessarily given to research of an immediate practical character.

It is appropriate however, to recall that many of these research projects will ultimately be introduced into practice and will be very useful because they will make possible a better understanding of the phenomena and will contribute to improvements in the technical preventive measures.

Thus, thanks to the study of the optical properties of heterogeneous dust clouds, it is hoped that an immediate-reading and directly interpretable measuring instrument will be available in the near future. The coagulation properties of dust, whether natural or artificially-induced, clearly defined and capable of modification as desired, will be used in the different dedusting techniques.

The relationship existing between the dust and the nature or the texture of the rocks from which they are formed will probably allow of a better direction of effort in the establishment of a rational plan of dust suppression.

1. In order to study the coagulation effect caused when electrically-charged dust particles meet, laboratory determinations were first made of the magnitude and sign of the electrostatic charge on particles of differing nature, origin and size [1]. For this purpose it was necessary to perfect and adapt the instruments which would be used to measure and weigh these particles and to determine separately and independently the electrical charges of opposite sign.

(1) Research carried out by the Silikose-Forschungsinstitut der Bergbau-Berufsgenossenschaft, Bochum, Volume II, Appendix 29.

Particular attention was paid to examining how the dust becomes charged as early as during the crushing and pulverisation of the rocks, and how various materials behave in identical conditions.

In the case of certain of these materials, charges of one sign tend to predominate. It has been noticed that the magnitude of the charge is a function of the size distribution and the concentration of the cloud of dust being tested.

Nevertheless, the behaviour of the same dust when charged with opposite polarities is still unexplained.

In order to make progress in these investigations, the research workers set out to determine the charge of the isolated particles, as a function of their dimensions. This technique employs a recording on cinematographic films and the dark-ground illumination technique. This makes it possible to follow the trajectory of particles falling in free fall in a sedimentation chamber—which is both insulated and air-conditioned—subjected to the effect of a horizontal electrical field.

2. In contrast with the preceding research work, the coagulation tests were carried out in underground workings, making use of the natural electrostatic charge of the dust particles. To do this, it was necessary to know the polarity of the different mineral constituents present in the dust. It was observed that quartz and silicates generally carried negative charges, while coal and limestone preferentially became positively charged. Clay minerals show no preference. The intensity of the charge on the particles depend on their surface area, and up to a certain limit on the cause which produced the suspension of the aerosol.

Thus, where minerals are violently broken up, e.g. by shotfiring, the particles have high charges, whereas a gentler means of bringing particles into suspension causes weaker charges.

No relationship has been discovered between polarity and size.

If it were desired to use the natural charging phenomena to bring about precipitation of the dust particles, i.e. by causing coagulation, it would seem necessary to bring together dust particles of opposite polarity.

As quartz is the mineral which is considered to be most dangerous with respect to silicosis, it was decided to use, as a bonding material for quartz, dusts which involve no health risk and are of opposite polarity.

In this way salts and limestone dusts, in various size consistency, were employed. In the laboratory tests, salts were used predominantly.

It thus became clear that it was necessary to use concentrations of up to several grams per cu.m to achieve a satisfactory reduction in dustiness. A relationship was then found between the coagulation effect and the relative humidity. If the latter increases, the formation of aggregates is reduced. However, this reduction is observed only for relative humidity values in excess of 75%.

The relationships found in laboratory tests could not be transferred to underground conditions, since there are modifications due to the presence of turbulence spots in the ventilation current. In fact, it was possible to show that in these workings the process of coagulation is already triggered off at relatively low dust concentrations, and that it increases with increasing concentration.

The tests were continued under the most widely differing conditions of working, both from the point of view of total dust concentration and that of the mineral composition of the dust. This made it possible to achieve appreciable—although only partial—improvements in the dustiness conditions with respect both to the concentration of dust to be brought down and the selective formation of aggregates (1).

3. The knowledge of the properties of other dusts, such as those which are found in workings in metalliferous mines, has also contributed towards improvements in the dust-prevention methods in those pits (2).

The mineralogical constitution of the respirable fraction of the freed dust does not correspond exactly with that of the rocks from which it originated. The quartz content of these dusts is nearly always lower than that of the original rock. In addition, it is well known what importance in the assessment of the silicogenetic action of quartz is attributed by certain research workers to the "amorphous layer" which surrounds the silica crystal.

In the same way, measurements were made of the thickness of the layer on the surface of the fine particles which was damaged as a consequence of the crushing which produced these dust particles. It was observed that this thickness varied in certain cases according to whether the crushed rock had been subjected to shear or percussion forces.

Another investigation was directed to the study of the electric and physicochemical properties of mineral particles below 1 micron.

The method employed consisted of examining the similarities which existed between the surface properties which are used for the flotation of minerals and those which act on the precipitation of the dust particles in the presence of water to which a wetting agent has been added.

Quantitatively, there is the fact that the fresh break surfaces of quartz crystals react 5 to 10 times more intensely to the fixation forces exerted by flotation reagents than naturally "aged" surfaces.

4. These few research projects fields indicate that the field of physical properties of dust is an entirely new field, which is still almost unexplored, and where numerous discoveries are still waiting to be made.

(1) Research carried out by the Silikose-Forschungsinstitut der Bergbau-Berufsgenossenschaft, Bochum, Volume II, Appendix 30.

(2) Research carried out by the Clinica del Lavoro, Milan, Volume II, Appendix 31.

Personnel protection

It is very clear that dust measurements cannot by themselves guarantee that the miners are protected from risks to their health. The technique offers only quantitative indications of the degree of dustiness resulting from the working conditions and from mining operations. There is nothing which proves that a reduction in the dustiness level, even if technically remarkable, indicates working conditions which are acceptable from the medical point of view.

We must be able to judge whether the means applied to combat dust are in the last analysis effective in protecting the health of mining personnel; in other words, we have to demonstrate the extent to which these means ensure that the workers are protected against pneumoconioses. In actual fact we do not yet completely know the limits of dustiness in the air in mine workings below which the worker's health will not be endangered.

In the entire range of work in the first programme of research into dust suppression in mines, two statistical projects were supported by the High Authority. Their aim was to determine the relationship which might exist between the working conditions underground in the mine on the one hand, and the appearance and development of pneumoconiotic diseases on the other hand, with a view to establishing the fundamental principles which should be applied in organizing efficient protection of personnel.

The means applied to bring researches of this type to a successful conclusion are the recording and classifying of the "environmental factors", in particular, the type of work carried out, the dustiness level, the duration of working periods etc., followed by a comparison of these series of technical values with the medical statistics which in particular record the results of X-ray examinations made when men were set on, and at subsequent periods, to determine the course of development of pneumoconiotic diseases. These are research studies whose duration is governed by the development of pneumoconioses, a process which cannot be studied except by periodical medical examinations (one to three years).

However, in spite of having to wait for long-term statistical confirmation, the research undertaken has already furnished very useful interim information, by reason of the large number of practical observations which can be carried out in these studies.

German research (1)

The card index of "Work in the Pit and Dust Exposure of Working Shifts", introduced in the West German mines has placed a good deal of information at the disposal of the researchers. This system contains monthly reports on the nature, place and duration of the miner's work and on the dustiness level obtaining in his working place.

This card index has made it possible to compare for the first time information resulting from measured dust levels and data from X-ray examinations.

At the end of a period of research extending over four years, a mass of information is now available concerning 9,200 miners working in 11 pits for the last seven years.

These 9,200 miners met the following requirements:

1. They had been employed at the same pits at least since the first quarter and up to the last quarter of the observation period of seven years.
2. The information in their card index for that period was complete and usable.
3. Medical records with regard to lung were available for the beginning and the end of the observation periods.

The men so selected represented half the total personnel.

Dustiness levels were calculated as follows:

the concentration of fine coal and rock dust (k) and of rock dust (k_b) (2) give estimated values for the dustiness of the air.

To calculate the dust exposure, it is necessary to multiply these values by a factor which represents working time S (No. of shifts).

As the card reports are made up monthly, the following figures are obtained each month.

$$k \times S \text{ and}$$
$$k_b \times S$$

If these values are added together over a period, (in the present case seven years) we obtain for each individual:

the total dust exposure Σ ($k \times S$) and

the total exposure to inert dust Σ ($k_b \times S$)

The development of the pneumoconiotic affections has been studied as a function of these values.

It has been observed that in mines where the proportion of inert material in

(1) Research carried out by the Steinkohlenbergbauverein, Essen, Volume II, Appendix 32.

(2) Values obtained by the normal methods using the tyndalloscope and the "Bergbaukonimeter".

the suspended dust is on average relatively low but where, on the other hand, the total concentration of fine dust (coal and rock) is high, there is a correlation between the frequency of lung tissue changes and the total figure representing dust exposure defined above.

This relationship is less clear if inert dusts are left out of account.

In workings where the inert content of the dust is fairly high but where the total dustiness level is low on average, this relationship is no longer so apparent. It is probable that a seven-year observation period is not sufficient for a valid statistical investigation. It would seem that it is necessary to include factors other than the total concentration and the concentration of rock dust to express more accurately the effect of exposure to dusty mining conditions.

One such factor might be the quartz content, for it is not necessarily the case that the quantity of rock dust and the quartz content are proportional in every instance.

However this may be, in certain of the pits where this research is being carried on, dustiness values have been found for which no associated changes in the lung image can be detected after seven years of work. It might thus theoretically be possible to deduce from this fact limit dustiness values, if the influence of the quartz contents in the dustiness values under consideration were better known.

It would, however, be advisable to check this information in a wider range of pits with respect to the type of coal won and the composition of the dusts.

To sum up, it can be pointed out that research carried out in the pits which have been studied up till now have clearly shown the effect of the total concentration of dust on the appearance and course of pneumoconiotic affections. No particular importance is to be attributed to rock dust alone, in respect of assessing the health hazard of the dustiness levels in the workings. On the other hand, from this point of view, it does seem necessary to pay particular attention to the quartz content.

Belgian research (1)

(a) An investigation of the same type is being carried on at the Houthalen pit in the Campine coalfield, which maintains a card index of medical and working histories of the personnel (about 2,500 workers).

The purpose of this investigation is in the first place to study the development of pneumoconioses in the workers in the pit. But in addition attention has been paid to determining the dustiness levels specifically associated with

(1) Research carried out by the Institut d'Hygiène des Mines, Hasselt, Volume II, Appendix 33.

various phases of mining operations. Research has also been carried out on the dustiness levels which can be considered as unavoidable, i.e. those which it is not possible to reduce in the present state of winning techniques and with correctly-applied methods of prevention.

(b) The dustiness levels are measured by means of the thermal precipitator; the dust sampling and analysis methods are those chosen by the Institut d'Hygiène des Mines.

The results of these measurements, expressed in numbers of particles between 5 and 0.5 microns, with an indication of the quartz content, are recorded every fortnight in the medical-history card for each worker. The card index makes it possible to know the identity, speciality, and exact functions of the worker; in addition, suitable codes are used to record medical information concerning X-ray records, clinical information, pulmonary function tests.

Starting with this information, the levels of dust exposure undergone on average each year by each of the underground workers are calculated. These dust exposures are expressed in terms of average concentrations (Number of particles from 5 to 0.5 microns per cm^3) and of average content of quartz in the inhaled air.

(c) To assess the health risk of these dust levels, a "hazard index" for the air has been proposed, derived from the French koniotic index, but modified to suit the sampling and analysis methods employed by the institute commissioned to perform the measurements. This index takes into account the concentration of dust expressed in particles from 5 to 0.5 microns per cm^3 and the quartz content. Since these values are inserted in a logarithmic formula, it is possible to express the health hazard by a simple number: the higher the number, the more dangerous is the atmosphere to which it refers.

Dustiness levels with a hazard index below 5 have provisionally been considered acceptable. This rule will need to be checked during subsequent work.

(d) The statistical studies undertaken have shown that, provided that the turnround of personnel employed at the pit being examined is maintained at the same level, the study of the development of pneumoconiotic affections calls for systematic recording of the dustiness of the air for at least ten years—which corresponds to one conclusion drawn from the German research work.

If it is required to study the development of the pneumoconiotic affections passing through several successive X-ray picture stages, and not simply the development of one phase independently of the preceding one, the time required for the research will be longer the more intensive the dust-suppression measures have been.

(e) Research has shwon that a relationship exists between *the appearance* of the first X-ray picture stage and the hazard index as defined above.

It was observed that 92.3% of the hewers, who were free of any affection when set on, and who had not yet reached the sub-normal X-ray stage (O-Z) after eight years at work, had worked for at least four years in workings with a hazard index below 4.9; 50% of the hewers who had reached the same benign stage after eight years had worked for at least four years in dusty conditions with a hazard index above or equal to 4.9. This is the reason for which dustiness levels with a hazard index below 5 have provisionally been considered to be acceptable.

These observations coincide with one conclusion from the German work: there does exist a possibility of establishing limit dustiness levels.

It is however, possible that one might also have to take into account the age of the workman at the moment when he first began work underground. In actual fact, the present enquiry shows that development of the pneumoconioses is more rapid in older workers at the moment when they are first set on in the mine. This fact must also be checked, since the dust exposures are not always known, any more than the work carried out by these workers in the years prior to the investigation period.

(f) One of the first general conclusions from this enquiry is that, for each category of underground workers allocated to coal deposits worked in a similar manner to that of the pit where the enquiry was carried out, it is possible to consider the unavoidable dustiness levels as acceptable provided there is a rational and sustained programme of dust suppression.

One exception which has, however, been found concerns those workings where shearer-loaders are used or where, up to 1964, dust prevention measures had not been applied completely satisfactorily.

(g) The continuation of this work—in association with similar projects in other countries—will make it possible *to establish the limit dustiness levels which can, on the one hand, eliminate the appearance of the X-ray picture stage which qualifies a man as an invalid and, on the other hand, to ensure that miners affected by the very first pneumoconiotic lesions can be kept at work in satisfactory conditions.*

It goes without saying that the result is of the very highest importance; it does in fact lay down the aims of a policy of protection for all mining personnel. But this protection is in fact based on sustained dust-suppression efforts, applied systematically and suitably adapted to developments in mining techniques.

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