GEOLOGIE EN MIJNBOUW VOLUME 49(1), p. 1-12 1970

RESEARCH ON VENTILATION AND SAFETY AND ITS APPLICATION AT DUTCH STATE MINES[1)]

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SUMMARY

Dutch Statemines conducted until 1965 research for underground operations in the *Centraal Proefstation.*

The present paper sketches the image formed on the occurrence of methane in the underground works, its release during mining operations, the method of safe dilution, and the removal in high concentrations.

It gives measures taken to prevent ignition possibilities and finally describes how using the results of this research the Inspectorate allowed to increase the methane percentage in the general body of the air from 1.5 to 2 %.

1. INTRODUCTION

"Mining is a chance", it has been said, but, when in the beginning of this century a liberal Minister decided to reserve the still unallotted parts of the Dutch coal deposits for exploitation by the State, and Staatsmijnen was founded, it did not seem as if the new company would stand a good chance.

Natural conditions in the north of the Limburg coalfield, which was opened up by Staatsmijnen after this decision, turned out less favourable than those in the south, for which concessions had been granted to private companies working with foreign capital. Whereas in the south the overburden measures at most 100 m, in the northern part it increases to 200 and 300 m, so that shaft building is much more expensive there. Since it was not known at the time if the whole Carboniferous was overlain by a clay layer, that would prevent penetration of water into the future workings, it was necessary to leave an extra thick safety roof between the workings and the top of the Carboniferous. In consequence, the first levels had to be laid out at a depth of 300-400 m.

The northern deposits are younger than those in the south and consist of coking coal. The rock is also younger and, conseqeuntly softer, which calls for more and heavier supports. Added to the greater depth of the first workings, this involves higher investments in both shafts and roadways.

Young coal being capable of propagating explosions, special measures have to be taken, like stonedusting and the use of stonedust-barriers and of safety explosives for firing in or close to the seams. All this means a constant burden on the economy of a coalmine.

Whereas hardly any methane had been found in the southern part of the coalfield, it appeared that in the north, where the coalification process had advanced less far, methane was present in much larger quantities, especially at greater depths. This created the need for bigger fans, more safety measures and more frequent inspection.

Finally, since the first levels had to be laid out at a comparatively great depth, the climatic conditions rather soon became a problem in this area.

To solve these additional difficulties, Staatsmijnen founded a research station (Centraal Proefstation, C.P.) at the end of the thirties. Its development was greatly hampered by the war, but after 1945 it got in full swing. The work to be reported here was executed at the C.P. between 1947 and 1965.

[1)] Staring lecture 17 October 1969.

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2. LIMITATIONS

The subject of climate, although bound up with ventilation and safety, will not be treated here; a thesis on this matter will appear by the end of the year. Anticipatory to its publication, however, two conclusions drawn in it must already be mentioned here.

To improve the climate it is necessary to increase the quantity of air as much as possible and to use descending ventilation – a practice which is unusual in W. Europe and even prohibited in some countries.

The mechanical aspects of shaft-building and roof-support, which can be regarded as part of the safety problem, will also be left undiscussed. The results achieved in solving the problems on these points have gained such wide international recognition that they deserve separate treatment.

Electrical problems were tackled by the electrical department; C.P. only did the actual testing of equipment in explosive atmospheres. However, these problems have so great an influence on safety that the solutions found for them cannot be left out of consideration here.

3. HISTORY

Three mines built on the horizon mining system were opened up in the northern part of the coalfield between 1914 and 1926 (Emma 1914; Hendrik 1918; Maurits 1926; total output in 1961: $6\frac{3}{4}$ mill. tons).

In 1947 these three mines were laying out new levels at depths varying from 660 to 730 m. Transport was by rail, except in gate and tail roads and at the faces, which were equipped with conveyor belts and chutes, respectively. The long-wall faces, dipping between 0° and 15°, were worked with pneumatic picks. The principal energy source was compressed air. Fresh air was drawn in by main fans installed on the surface.

4. EXPLOSION-PROOF INSPECTION EQUIPMENT

At that time research was in need of measuring instruments that could be used underground, also in areas classified as presenting an explosion hazard. As there was no testing station in Holland that could try out our instruments and issue certificates for them and as it was also difficult at the time to have this work done by foreign institutes, Centraal Proefstation decided to do its own experiments in explosive atmospheres. The Electrotechnical Department, which foresaw an extension of the use of electric power in the collieries, was having the same difficulties in getting their gear tested. In consequence, Staatsmijnen decided to set up a testing group of their own in C.P. Reports by this group testifying to the safety of instruments or electric gear for use in explosive atmospheres underground were sent to the Inspectorate, and the use of such gear was never forbidden. Later, the group also undertook the testing of equipments for Staatsmijnen' chemical works. Through national and international cooperation, i.a. in International Electrotechnical Commission 31 (I.E.C. 31), the work done by this group could be kept at a standard acceptable to national authorities.

Once certified by C.P., recording and direct-reading instruments (partly developed by Staatsmijnen), such as anemometers, thermometers, methanometers, movementmeters (shotfiring), etc., could be used underground wherever research needed them. The data obtained from them have highly contributed to our knowledge about the conditions in a mine, and have proved very useful in guiding and supporting laboratory research.

5. PHILOSOPHY OF RESEARCH IN COALMINES A.D. 1950

Once the necessary tools are available, work can be started. Before doing so, however, it is recommendable first to find out what other people are doing in the field.

Around 1950 coalmining research occupied itself almost exclusively with safety aspects, which were studied in governmental or semigovernmental institutes (speech Delft 1963). Fruitful interchange of ideas and results among these institutes is still taking place at bi-annual conferences (Conference of Directors of Mine-Safety Research Stations; "Directors"); in 1950, when we attended such a meeting for the first time, we were very cordially received and collaboration still continues.

The idea of research being done by a coalmining company was rather new at that time. Consequently, research programmes were still rather undefined and lines had to be set out which would open up the way towards cooperation between research workers and mining people, who sometimes even did not speak the same technical language.

Many research workers were commissioned underground for a few months to work in ventilation, mechanical or electrical departments, and mining men came to the laboratories to see how problems were tackled there.

The cordial relations thus developed sometimes encouraged the miners to ask questions touching subjects outside the scope of the existing research programme. In response to the help received from us in such cases, they were always willing to assist us even in our "highly scientific work", as they sometimes called it with a smile.

This policy, i.e. pushing ahead in a rather wide field of research and giving service to the mining people whenever they asked for it, has proved very effective. Knowing the mines, their problems and long-term planning, the research workers could adapt their research programme to the requirements, and they often had the pleasure of seeing the results of their research applied in practice, which is very inspiring.

6. PROGRAMME FOR TODAY

You will understand that the research done on the subject of this lecture cannot be dealt with at full length here. Today I shall sketch the image we have formed on the occurrence of methane in the northerly Statemines, its release during mining operations, the methods of safe dilution and its removal in high concentration.

We feel that the image we have developed applies to other coalfields as well.

Safety calls for more than a low methane concentration in the general body of the air alone. A second line of attack to prevent ignition is to avoid ignition by sparking and heating. Hence, this also forms a main subject of mine-safety research. The results achieved in this field will be dealt with after our discussion on methane. In the following part some aspects of the ventilation technique will be treated. I am proud to say that this research has led to a method of working that enables us to take full advantage of the possibilities offered by mechanized coal-getting; this method will be outlined at the end of this lecture.

7. METHANE

7.1. *Occurrence*

In our district a close correlation exists between the occurrence of methane and coal. If methane is found anywhere in a mine, there are always crevices or fissures linking up this place with a coal seam. In the laboratory we measured the adsorption of methane on coal as a function of temperature, CH_4-pressure and volatile matter content. (Arets et al., 1962, p. 43-44.) The results proved to be in good agreement with those of CH_4 pressure measurements in boreholes, driven in the coal, and of measurements of the methane quantity released by shotfiring plus the quantity still absorbed in the coal in the shotfall.

These results, in combination with other observations, produced the following image.

In our district methane is present only in coal seams, where it is adsorbed on the coal. The relation between coalquality (volatile matter content), temperature, quantity of methane adsorbed, and pressure, is given by the adsorption isotherms.

Going from upper to lower seams, generally an increase of the methane quantity is found, but beyond a certain stratigraphical depth it falls off rather quickly to zero. There is a second rule, saying: the quantity of methane adsorbed on the coal at the top of the Carboniferous is negligible. In the Car-

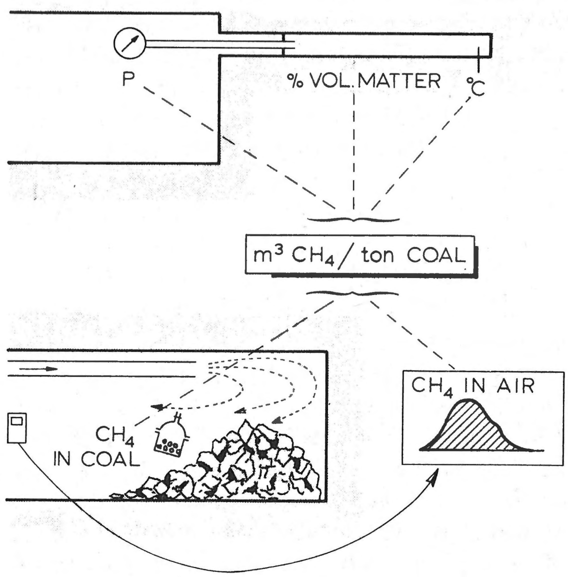

Fig. 1

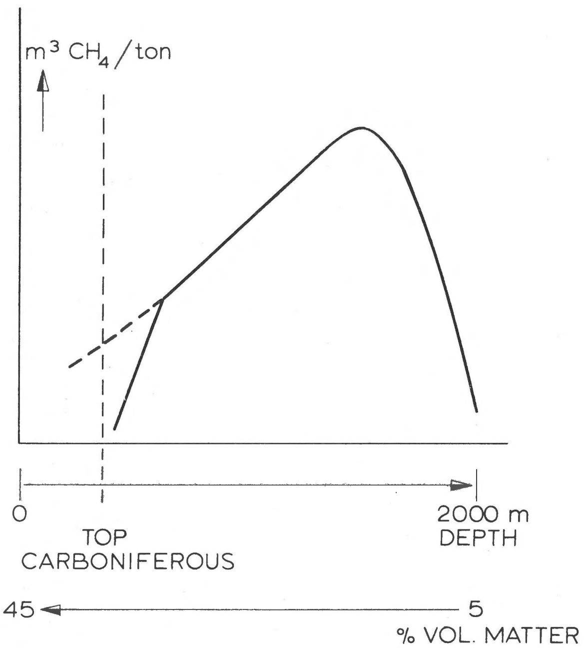

Fig. 2

boniferous, the methane content is found to increase with depth, reaching the maximum referred to in the first rule at about 300 m. The same trend has been observed in the Peel coalfield (not opened up). Measurements there have been made on coal cores from prospection drill holes. After their arrival on the surface, these cores were immediately brought into a closed steel shaking vessel containing steel balls. The methane desorbing in the crushing treatment, was pumped off and measured. Finally, the quantity of crushed coal was measured and its volatile matter content determined. This gave the quantity of CH_4 adsorbed per ton of these coal (m^3/ton).

7.2. *Release of methane*

7.2.1. *The first appearance of methane.* – In principle, the first release of methane in our system of horizon mining takes place when a shaft or crosscut is driven through a seam. In reality, the gas can begin to escape as soon as fissures in the rock reach up to a seam. The methane pressure will then drop and the equilibrium will shift towards lower quantities of adsorbed methane. If these fissures continue into the coal, or the coal itself already possesses a system of fissures, all the fissure walls will degasify.

The gas from further away in the coal must diffuse through the coal towards the fissures. In normal coal this is a very slow process. Coal, however, that has fully disintegrated or is fully fissured, allows a lot of gas to erupt through the first rock fissures reaching it. This phenomenon is known as a "gas outburst". If the gas pressure is strong enough to break up the rock, the methane will drag along the rock and part of the already broaken coal, and this is what is termed a "gas and coal outburst".

7.2.2. *Measures against coal outbursts.* – The first gas and coal outburst in our district took place in 1938, and a similar event occurred in 1949. After extensive studies the Chief Safety Engineer decided that the method of shockfiring widely used in Belgium and France could not be employed in our district, unless we took the same precautionary measure as was prescribed in those countries, viz. evacuation of all men from the return airway. In our extensive and

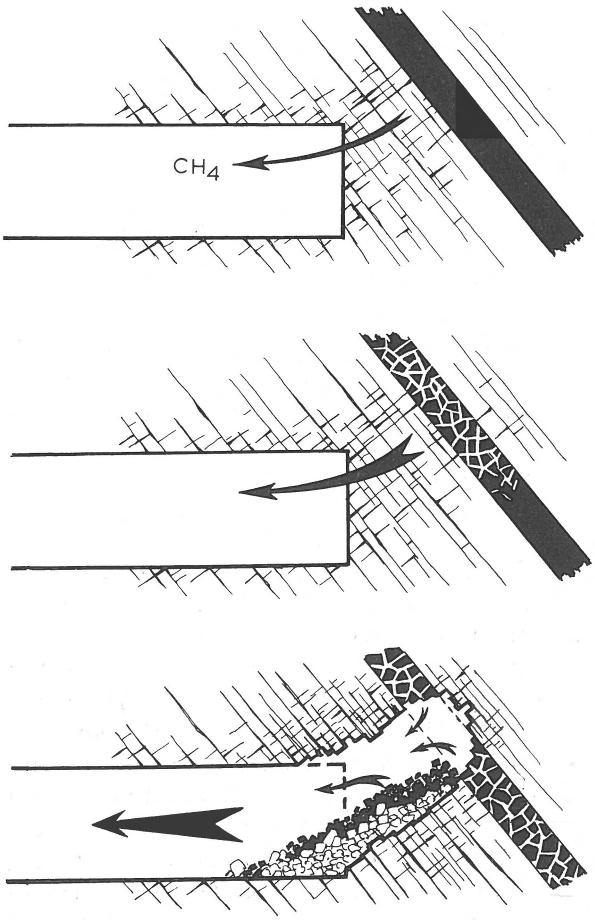

Fig. 3

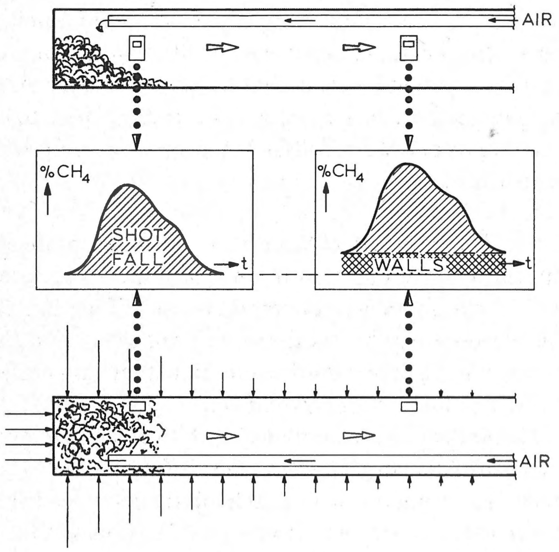

Fig. 4

complicated mines this would hardly have been feasibly, and it was therefore decided to take other safety precautions. These involved drilling holes at least 5 metres ahead of the face and allowing the face to advance only when the pressure in the holes is below 5 atmospheres, it being taken that this pressure is not strong enough to blow out the 5 m. thick safety wall. It was felt that with this method normal operations could be continued all through the mine and the face in question could be worked safely. The system has been used in opening-up and preparatory work on the lower levels, and never a gas and coal outburst has occurred if these measures were taken.

Faulted areas where the coal had been broken up, proved to be particularly apt to give rise to gas and coal outbursts. At the faces such zones are worked with special care.

7.2.3. *Gas release on shotfiring.* – If there are no geological irregularities, and drifts are made by hand, gas is released at a very steady rate as coalgetting advances. If, however, the roads are driven by shotfiring, large volumes of gas are released at the moment of shortfiring. (See: M a a s, 1963, p. 397).

The volume of gas contained in a shotfall approximately equals the quantity in equilibrium with an outside pressure of 1 atmosphere. During transport from the face to the shaft, the coal degasifies further to a certain extent; when it is broken or ground, an additional, not unsubstantial, quantity of gas is given off. This phenomenon makes the ventilation of bunkers for fines necessary.

7.2.4. *Gas release from fresh walls.* – When the air flows through a drift with fresh coalwalls on both sides, these walls also give off gas, the more slowly the older they are. This also adds to the methane content of the air. Equilibrium is reached in about one month's time. The total quantity of gas released by the walls is then approximately equal to the quantity that had to be given off to reduce the CH_4-pressure to 1 atmosphere absolute in a 20 m deep zone on either side of the gallery. After that time, diffusion is so slowly that the quantity of methane released is negligible in comparison with the quantity coming from the coalface.

7.2.5. *Gas release at a long wall face.* – The liberation of methane from a coalface is much more complicated. The amount of methane released by the coalface proper – which can be predicted by measuring the pressure and coal quality – is the same as that given off at a face in a drift. Here also the volume of gas contained in the coal on the conveyor approximately equals the quantity in equilibrium with 1 atmosphere absolute pressure. The breaking of the roof, especially at a face with total caving, produces crevices and fissures, which may go up 70-150 metres. Through these fissures methane present in adjacent seams can escape to the seam worked. The quantity actually given off depends on the width of the fissures – i.e. on the condition of the rock – and on the methane pressure in these adjacent seams. Analogously, the underlying seams can degasify, though to a less extent, when the floor heaves.

In predicting the quantity of gas to be expected at a face, one must also know the quantity still present in the adjacent seams both in roof and floor, and the rate of degasification as a function of the distance to the seam worked, which, in general, can only be learned from practice (L i n s e l, 1963, p. 388-390).

7.2.6. *Methane drainage.* – The amount of gas released by a face into the ventilation air can be decreased by the use of methane drainage from holes in roof and floor. The volume drawn off by this technique comes predominantly from the adjacent seams. The seam that is being worked gives off practically all of its gas to the ventilation air. The system of methane drainage has to be adapted to the type of rock (for hard rock: long holes in roof and floor; for soft rock: short holes). Water in floor holes makes drainage almost impossible.

7.2.7. *Influence of mechanical pressure.* – It has been shown that our coal swells upon adsorption of methane; according to van 't Hoff's law a rise of the mechanical pressure makes the equilibrium shift towards a lower methane content or a higher methane pressure. Between 3 and 10 metres ahead of a long-wall face a zone extends in which the mechanical pressure may reach up to about 1.7 times the normal value. This causes more gas to be forced out. If fissures are present, this gas will escape into the roof and there join the gas coming from the overlying seams. If there are no fissures, the CH_4-pressure in this zone will increase, while furthermore the heightened rock pressure will cause a decrease of the permeability of the coal. Both phenomena have been found to occur in our mines.

7.3. *Dilution*

7.3.1. *Mixing of gases with unequal densities.* – It has long been thought that to dilute a volume of 3 m^3 of methane to a concentration under 1%, it was sufficient to supply more than 300 m^3 of fresh air. It is not long since, however, when it became recognized that a really effective dilution may need extra energy. Owing to its specific density being about half that of air, methane issuing from a fissure in the roof will tend to float on the air. Mixing will then take place by diffusion only, and this takes a very long time (hours). To effect proper dilution in this case, the methane must be pressed down and the heavier air be lifted up. Therefore, the laminar flow has to be changed into a turbulent flow, which has a component perpendicular to the direction of flow.

On the basis of energy balances, Richardson developed his wellknown number which, if greater than unity, indicates that there is no turbulent interchange between the floating layer and the gas on which it floats. Bakke used Richardson's considerations to determine whether a methane layer floating on air will be diluted within a reasonable length of time. He found that depending on the rate of methane release, an airvelocity of at least 1 m/sec is needed to ensure a sufficiently quick dilution of a methane layer. Bakke's considerations provide an explanation for many firedamp ignitions in foreign mines. In our mines where airvelocities were too low according to Bakke, we occasionally have come across methane accumulations along the roof. Where Bakke's conditions were fulfilled, however, layering was never found.

7.3.2. *Longitudinal diffusion.* – Another problem studied was the question if a sudden and strong local rise of the methane concentration as a function of time, caused e.g. by shotfiring in coal, is lowered by forward and backward diffusion of methane on either side of the high-concentration area.

Theoretical considerations both for laminar and turbulent flow suggested that this diffusion effect was small. Experiments in a 1200 metres long roadway showed that there was no appreciable effect within a

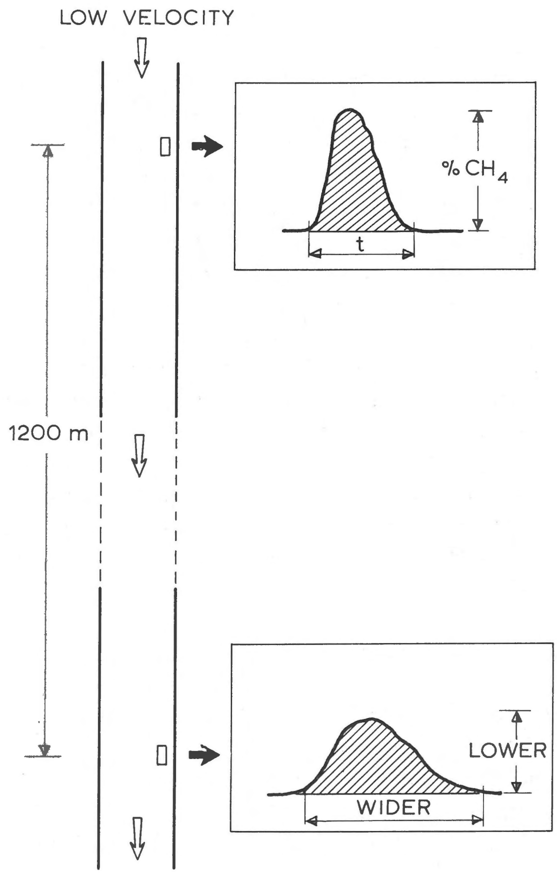

Fig. 5

quarter of an hour. The effect found could well be described by our formulas. In mines with methane problems there is always a high velocity of the air and consequently, diffusion in longitudinal direction does not promote safety at or near the coalface. ("Directors", Sheffield 1965.)

7.4. *Summary*

We have now a clear idea of how methane is present in the coal, and how the quantity of CH_4 present per ton of coal can be determined from CH_4-pressure measurements, combined with determinations of temperature and volatile matter content. Further, we can predict how much gas will be released in preparatory workings and at coalfaces, provided some experimental data are known about the influence of rock-conditions on the degasification of adjacent seams. On the basis of the same data, the efficiency of methane drainage from roof and floor can be foretold.

The occurrence of gas and coal outbursts remains difficult to predict. Work on this subject is still going on with financial aid from E.C.E., but prevention by drilling boreholes at least 5 m ahead of the face and allowing the pressure to drop below 5 atmosphere has shown to be effective.

Finally, Bakke's theory provides a means for determining the air velocity needed for a sufficiently quick dilution of the methane released.

8. PREVENTION OF IGNITION

The study of many mine disasters has shown that prevention of ignition is not less essential than control of the methane concentration. Some results of studies on potential ignition sources will be dealt with here.

8.1. *Fires*

8.1.1. *Lining and support.* – After a fire near a pit bottom in 1942, it was decided to make all pit bottoms fireproof over a distance of at least 100 m from the shaft. To this end use was made of concrete lining behind steel supports, or the roadways were fully concreted.

Another fire, in 1947, showed the danger caused by wooden lining in roadways and drifts. It was then decided that new stone drifts were to be fitted with steel lining and steel supports or with concrete blocks.

The less permanent drifts in the seams had always been supported in steel, but after this fire it was decided that machine rooms for belt drives, pumps for hydraulic supports, etc., should also be equipped with a steel lining, which was to be continued 10 m down wind.

Fire-fighting equipment is installed up wind of these machines.

8.1.2. *Conveyor belts, V-belts, etc.* – After a fire ignited by a slipping rubber belt, anti-slip devices were installed; still, it was felt necessary to replace the rubber belts as soon as possible by fireproof belting satisfying two requirements:

a) a stalled belt on a turning drum of normal make shall not catch fire, give off glowing particles, or get heated up beyond 150°C, below which temperature ignition of coal dust under the drive head is very unlikely,
b) after fierce heating over 50 cm in an air flow of 2 m/sec, a 2 m long test piece shall extinguish when the heating flame is removed, and the remaining part shall be undamaged over the full width at the end not directly heated ("Directors", Pittsburg 1959).

The industry developed belts which, giving economic performance, satisfied these requirements; these belts have been used to the exclusion of all others since 1956. Similar observations can be made for V-belts, driving belts, etc.

8.1.3. *Oil.* – For many applications, no non-flammable oils are available. However, the danger of oilfires can be reduced in many ways. Oil stores near the pitbottom, as well as the lining in roadways over a length of 10 m down wind, have been made flameproof.

Firefighting equipment is installed up wind.

In the districts the oil is stored in a safe place and in a safe way and there is never more oil in stock than is needed for daily use.

Oil-cooled transformers have been replaced by air-cooled ones, and oil couplings, which cannot be done without yet, are equipped with melting plugs giving way at a temperature 20°C below the flamepoint of the oil used.

Where possible, non-flammable oil is used, e.g. in hydraulic props.

Finally, 6 kV switch gear containing a limited quantity of oil has been developed by the industry apt to be used in class I areas, and tested under loads in conformity with I.E.C. standards.

8.2. *Shotfiring*

In a mine where methane and flammable coaldust are developed, shotfiring is a critical operation. On the one hand, it is profitable to use a strong explosive, while, on the other, safety demands the use of a weak one. As a compromise, the strength of the explosive is adapted to the chance that an explosive mixture will form. This may easily lead to five different methods of shotfiring being used within one mine. Within the limits of the legal regulations, it is for the management to decide which type of shotfiring shall be used at a given face.

Since the introduction of ion-exchange explosives in 1956, it has proved possible to restrict the choice to two shotfiring methods. The one uses dynamite for rock bursting and the other ion-exchange explosives – practically without any load limitation – in all places where a dangerous mixture of methane or coaldust with air may occur. The use of millisecond delay detonators – known since 1951 – made these

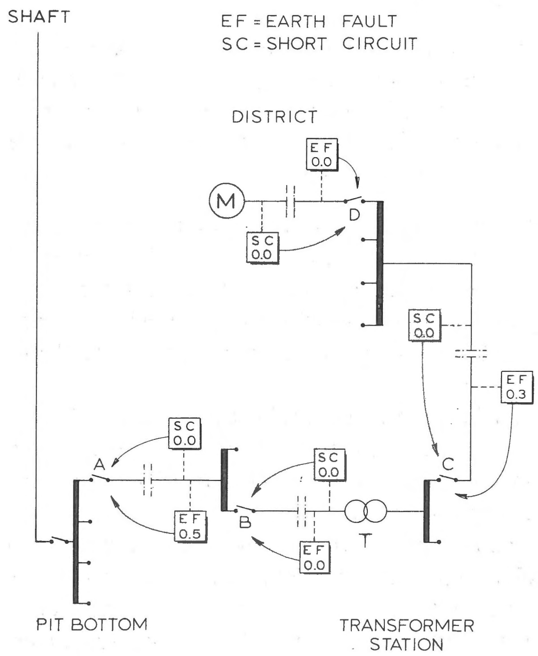

Fig. 6

methods all the more successful. In 1957, the introduction of "safe-in-methane" millisecond-delay detonators followed.

In shotfiring practice first the primer is placed in the borehole and, in order to prevent interruption of the detonation wave, the cartridge train of ion-exchanged explosives is slipped into a length of plastic tubing before being put in. With ion-exchanged explosive, coal and rock can be blasted in one round, on the condition that detonators bearing consecutive numbers shall be used in coal, and that in rock bursting not more than every other number shall be left out of the serie..

Nowadays, explosives are transported in regulation boxes on trains, on railbikes, conveyor-belts, sledges and by monorail under specified conditions. The shotfirer is reinstructed and his work inspected by a special overman at least once every six months.

The Inspectorate allows operation of this system of shotfiring in atmospheres containing up to 2% of methane.

8.3. *Static electricity*

The build-up of static electricity on conveyor-belts, V-belts, drivebelts, etc. is prevented by making them conductive. The conductivity should be higher as the belt runs faster. Conductivity is a requirement also for plastic air ducts. The use of plastics and other non-conductive materials is subject to authorisation by the Chief Safety Engineer. Pneumatic stemming with dry sand is regarded as dangerous, and therefore not allowed. Neither may compressed air from a hose be used for diluting a methane layer.

8.4. *Aluminium*

During rubbing contact with aluminium, rusty iron may give off incendiary sparks if the rubbing energy is over 20 kgm. The use of aluminium underground is therefore also subject to authorisation by the Chief Safety Engineer, who checks if the abovementioned energy can be reached during correct and faulty use of the aluminium part under consideration. Where necessary, precautions are taken if aluminium is to be used underground. For example, fans with aluminium blades and a steel housing must be fitted with a brass ring preventing the blades from touching the steel of the housing. Experiments have shown such a ring to warrant safe operation.

Aluminium friction pads are not used in props.

8.5. *Diesel locomotives*

70 H.P. locomotives had been in use in class II areas since 1937. In the course of time a need began to be felt for locomotives of 100 H.P. capacity for use in class I areas. To obtain the necessary permits, special safety measures had to be taken, such as the installation of

a) flametraps in intake and exhaust,
b) waterinjectors in the exhaust,
c) a thermal relay, cutting off the fuel-oil supply if the temperature of the exhaust gases surpasses 100°C (sentinel),
d) an explosion-proof dynamo and starting motor and explosion-proof lighting fixtures capable of withstanding heavy shocks,
e) an explosion-proof accumulator capable to start the loc.

The explosionproof accumulator was constructed in our laboratory and the other elements were tested there. ("Directors", Brussels, 1956).

8.6. *Electricity*

Not only electric appliances, but also electric cables, present an ignition hazard. Standards for electric appliances to be used in explosive atmospheres have been laid down nationally and internationally, but little has been specified so far about cables.

Our electrotechnical department has developed and introduced a system the main principles of which will be given here. 6 kV is fed through the shaft cables to the main switch (A), and distributed to the 6 kV oil switches in the districts (B). The oil switch protects the transformer (T) on the 6 kV side. On the low voltage side (865 or 500 V) there is the field switch (C), which feeds the motors (M) through motor switches (D).

Some provisions to decrease the ignition hazards are:

a) All underground cables have an earth shield around every core,
b) The neutral on the low-voltage side of the transformer is earthed via an impedance (29 Ohms for 500 V, and 50 Ohms for 865 V), limiting the earth current to 10 Amperes. The earth current on the high-voltage side is also limited to 10 Amperes.
c) An earth fault between motor and motorswitch on the low-voltage side immediately cuts out the motor switch. An earth fault between motor-switch and field switch cuts out the field switch after 0.3 sec. A relais on the impedance works as a back up safeguard. Similar effects are produced by earth faults between transformers and oil switch (direct cut-out) and between oil switch and main switch (cut-out after 0.5 sec.).
d) Every switch instantaneously cuts out if 2/3 of the calculated two-phase short-circuit current is surpassed.

These safeguards have the following consequences:

a) an earth fault is much more likely to occur than a short-circuit, and every short-circuit is at the same time an earth fault.
b) all earth faults are limited to 10 Amperes,
c) an earth fault causes an immediate or short-delay cut-out. The delay times of the relais are so selected that only the part in which the fault occurs is dead. Consequently, the fault can easily be found and a spare cable makes a quick replacement of the faulty cable possible.

This system has been thoroughly tested in the laboratory, where, in an explosive methane-air atmosphere, cables were pierced with conductive objects, e.g. picks, at various speeds ("Directors", Aix les Bains, 1963). In no case did this piercing produce an explosion. When the pick was taken out and the damaged cable energized again, a few explosions did occur. It has therefore been made a requirement that after a switch has cut off part of the electric system in consequence of an earth fault or short circuit, the fault shall be located before the part in question is re-energized. If the fault cannot be found, re-energizing is not allowed except with the consent of the ventilation department, which knows whether methane might be present or checks if it could be present.

The Inspectorate allows actual operation of this system in atmospheres containing up to 2% methane, and permits the cables to be kept energized in up to 3% methane.

9. VENTILATION

9.1. *Ventilationmodel*

The quantities of air needed for controlling the climate and diluting the methane concentration to a safe value being known, the ventilation scheme can be set up. First of all, a mine ventilation model was built. For this purpose we needed an element in which the pressure-drop producing flow is proportional to the square of this flow. It proved possible to use normal gas-filled lighting bulbs with spiral tungsten filements at loads from 30 to 100% of the normal rating. This model, which took quite some time to build, because every resistance had to be produced by connecting bulbs in series and parallel, gave excellent results, until the day when the computer took over.

9.2. *Natural ventilation*

Another problem in gassy mines is the question of what happens if the main fan suddenly stops. Determination of the natural ventilation by plotting in a PV-diagram the pressure and density measured at various points along the circuit considered, showed the natural ventilation in a district to be the same before and after stoppage of the fan. This makes it possible to measure the natural ventilation while the fan is running, and to calculate the flowrate when the fan has stopped. (M a a s, 1950, p. 237-240.)

9.3. *Time to evacuate after stoppage of fan*

Surface-installed sucking fans operating at 300-600 mm W.G. normally produce an underpressure of between 150 and 300 mm W.G. in the mine. Upon stoppage of the fan, this partial vacuum is filled by fresh air from the surface. This air enters the roads and forces the methane back into the old workings, thus delaying the moment when a dangerous methane concentration can occur. A diagram showing the order in which the faces in our gassy mines shall be evacuated by the men in an emergency has been drawn up on the basis of this knowledge and is always kept up to date.

9.4. *Volume of a mine*

Measurements on the air inflow after stoppage of the fan showed the volume of our big mines to be approximately 10 million m^3; only 5-10% of this volume is accounted for by accessible workings, such as shafts, roadways, drifts and faces, and 90% or over by inaccessible fissures and crevices.

10. APPLICATION OF THIS RESEARCH

While this research on methane and safety was in progress, research was also performed on mechanisation of coalgetting and later on, on hydraulic support.

Mechanisation not only made it possible to get more coal per face and per shift but also to increase the number of coalgetting shifts per 24 hours. This increase of coal production and the increase of depth both led to an increase of methane liberated per minute and this increase of methane put a stop to further concentration of production.

In view of the more accurate prediction of degasification at a face, the use of methane drainage and the improved knowledge of the dilution process, on the one hand and in view of the measures taken to reduce the hazards due to ignition sources on the other, the Inspectorate has raised the maximum allowable concentration of methane in the mine air from 1.5 to 2% for certain districts. In doing so, however, the Inspectorate stipulated that certain special requirements should be met ("Directors", Dortmund 1967).

The principals of these requirements are:

a) Maximum use shall be made of methane drainage.
b) The dilution of methane has to be effected with due observance of Bakke's theory. For simplicity, 2 m/sec air velocity has been prescribed in return airways because the highest quantity of methane is liberated there.
c) Close inspection of the methane concentration in the air, especially in the return airway has to be made. The concentration at the end of the return airway shall be recorded.
d) Strict adherence to the safeguarding system for electric cables.

Since 1960, when the first experimental permission was granted, the number of so-called 2%-faces increased, to reach a maximum of 25 in 1965. The last 2%-face – no. 63 – was stopped this year. In the nine years since 1960, these faces produced 8.5 million tons of coal. Calculations have shown that under the circumstances prevailing in our mines, the increase in production per shift made possible by the rise from 1.5% to 2% methane concentration, reduces the cost of coalgetting by about fls 3.50 per ton. The gain achieved by this special permission thus amounts to a total of about fls. 30 million.

Methane drainage in the same period required an expenditure of 5 million guilders, but this was offset by the recovery of a quantity of methane equal to 250 million m^3 of 100% CH_4 yielding fls. 10 million and giving a net profit of fls. 5 million.

EPILOGUE

The results of C.P.-research from which I had the honour to give you an impression to-night have not been realized by research alone but by close cooperation between many, among whom I want to single out the following groups:

a) A managerial board which, at a time when research and science in mines were still regarded as hobbies of the management, was far-sighted enough to raise the cost of coal-getting by 1% on behalf of research.
b) An Inspectorate which valued and accepted the results achieved by enthusiastic research workers.
c) Mine managements which gave the research workers ample opportunity to do experiments in their mines and kept themselves informed of the results, ready to use them.
d) Enthusiastic research workers who, educated in other branches and used to working under much cleaner conditions, had an open eye for the interesting problems of coalmining.

"Mining is a chance". At the outset it did not look as if the mines in the north of the Limburg coalfield would stand a very fair chance, but thanks to the vision of their managers, and to enthusiastic cooperation, the work done in this district has brought forth results which permit us to say: "Mining is a science".

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