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An Outline of a Hybrid Intelligent System for Mine Safety Analysis

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ABSTRACT: The analysis of safety in coal mines is a very complex process based on the estimation of numerous interdependent parameters. The complexity of the subject matter requires a high level of expert knowledge and great experience. This paper discusses one of the possible approaches to solving this problem by a hybrid intelligent system for surface mine safety analysis (PROTECTOR).

1 INTRODUCTION

One of the most significant and also most complex problems encountered in surface coal mines is safety analysis. An appropriate and reliable solution to this problem is vital for the working process in mines with surface exploitation. Contemporary mining theory already operates with a number of mathematical methods which can be used to solve mine safety problems. These methods are used in current engineering practice with the help of appropriate software products.

Numerical software products in mine safety need expert knowledge and experience to be fully exploited. This knowledge consists of rules which heuristics experts use when they apply numerical methods. The knowledge-based approach developed by artificial intelligence (AI) offers the possibility of incorporating knowledge in software systems. Proponents of AI have devoted a major part of their efforts to the formalisation of knowledge representation and the development of mechanisms for using this knowledge, which has finally resulted in knowledge-based or intelligent systems. The so-called expert systems (ES), whose main purpose is to emulate the behaviour of an expert in a specific domain, are the most popular of these. This is due to the fact that they have been successfully implemented in different areas, ranging from medical diagnosis to complex computer network design, where they have produced very good results (Durkin, 1994).

Artificial intelligence has developed a number of methods and tools for solving complex problems. However, the complexity of some problems exceeds the potentials of single methods. A possible solution is to combine two or more AI methods into a hybrid

intelligent system. This approach has been adopted in the case of PROTECTOR.

This paper describes the salient features of PROTECTOR, a hybrid system for the analysis and estimation of the mine environment, developed at the Faculty of Mining and Geology at the University of Belgrade. PROTECTOR was developed by combining neural networks and expert system technology. While the mine environment estimation methodology is implemented through an expert system, some of the related estimation parameters are determined by neural networks.

Section 2 of this paper outlines the global problem-solving strategy through a hierarchical decomposition of the main goal, the evaluation of the mine environment, and the formalisation of this strategy by means of a modified object-oriented analysis (OOA) model. The system structure and the main architectural components of the PROTECTOR system are described in Section 3. The implementation of the system in the KAPPA-PC expert systems shell is discussed in Section 4, followed by the conclusions in the last section.

2 A FORMALISATION OF MINE ENVIRONMENT EVALUATION PROBLEM SOLVING

The analysis of safety in coal mines is a very complex process based on the estimation of numerous interdependent parameters that are classified by means of several basic criteria for the estimation of the mine environment. These criteria are related to the following conditions: gas, dust, climate, noise, vibration and illumination.

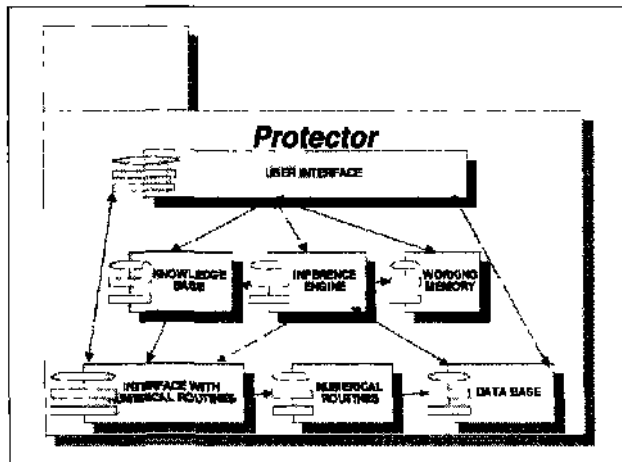


Figure 2 Architecture of the hybrid intelligent system PROTECTOR

The main purpose of the *user interface* is to provide means for a successful dialogue, i.e., an exchange of information between the user and the system. It is the user interface that enables PROTECTOR to obtain all the necessary information from the user, and that then transforms the system's results and conclusions into information the user can understand.

The PROTECTOR *knowledge base* is a formalisation of the mine safety expert's knowledge. Knowledge in expert systems basically consists of facts and heuristics which can be represented by means of rules, frames, semantic networks and other formalisms. Since knowledge is the key factor in problem solution and decision making, the quality and usability of an expert system is basically determined by the accuracy and completeness of its knowledge base. The selection of the representation formalism is very important and plays a significant role in knowledge-based design.

The problem-solving strategy is realised by the expert system's *inference engine*. This reasoning mechanism infers conclusions based on knowledge from the knowledge base and the available information pertaining to the safety problem at hand. The inference engine stores intermediate results in the *working memory*.

The PROTECTOR system was developed as a knowledge-based (symbolic) upgrade of the numerical package for relevant safety parameter determination, and it thus belongs to the category of *coupled numerical and symbolic systems* (Kowalik, 1986). The numerical part consists of routines for the determination of relevant safety parameters using neural networks and for the analysis of degree of importance. The symbolic part formalises the mine safety expert's knowledge.

Successful implementation of a coupled system requires the solving of a number of complex problems. In order to obtain efficient communication between the symbolic and the numerical part of the system. In order to cope with this problem, a separation of the processes in coupled systems into independent modules is suggested. Furthermore, information interchange, i.e., communication among modules, is strictly defined and reduced to the lowest possible degree. Communication between two modules is allowed only through previously defined external links, while all implementation details remain "hidden" within the module itself. These requirements can be met successfully through the modified object-oriented approach proposed in this paper with the object as the modular unit of the system. Objects consist of attributes (structures representing their internal data), methods (procedural components), and rules (declarative components).

The object/attribute approach is often mapped into the frame/slot paradigm, which can be successfully used for its implementation (Rich, 1983). In the same way, the characteristics of an object are represented by its attributes, and the frame characteristics are represented by its slots. Slot values describe attributes of the object represented by the frame and its relations to other frames (objects) in the system. The object-oriented approach implemented as a system of frames offers a suitable formalism for the proposed decomposition of the general mine safety state evaluation problem, since they both possess a hierarchical structure. The outlined features of the knowledge base facilitate both the coordination of knowledge within the knowledge base and the communication between the symbolic and the numerical part of the PROTECTOR system.

4 IMPLEMENTATION ISSUES

PROTECTOR was developed using an expert systems shell, the KAPPA-PC applications development system. KAPPA-PC is a MS Windows application which provides a wide range of tools for constructing and using applications by means of a high-level graphical environment which generates standard C code. In the KAPPA-PC system, the components of the domain are represented by objects that can be either classes or instances within classes. The relationships among the objects in a model can be represented by linking them together into a hierarchical structure. Thus, the modified OOA model based on the strategy for evaluation of the general state of safety of the surface coal mine could be easily mapped onto the appropriate elements of KAPPA-PC.

Object-oriented programming tools within KAPPA-PC were used to provide PROTECTOR objects with methods which specify what objects can do. First, the objects and methods for the knowledge base were constructed. Then, mechanisms were built that both specify how objects should behave and reason about the objects by using rules. Each rule specifies a set of conditions and a set of conclusions to be made if the conditions are true. The conclusions may represent logical deductions about the knowledge base or specifications of how it changes over time. Each rule is a relatively independent module, which made it possible to build the reasoning systems gradually, rule by rule.

Since applications written in KAPPA-PC are intended to perform very complex tasks, a variety of graphic images in building the user interface can be used in order to observe and control the operation of an application. An important feature of KAPPA-PC is its usability for enhancing existing systems. For example, it can link into existing programs written in standard languages. Therefore, KAPPA-PC was a powerful tool for integrating the existing numerical routines into the PROTECTOR hybrid system.

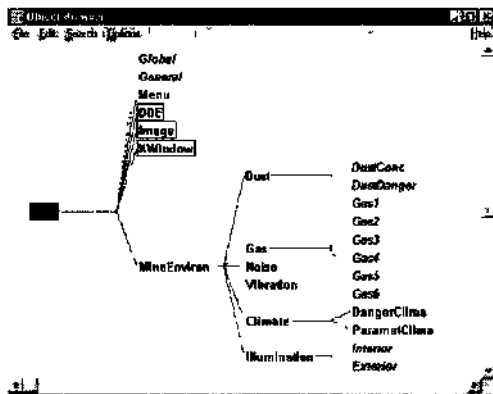


Figure 3. The ICAPPA-PC Object Browser for PROTECTOR

The classes and objects of the modified OOA model were transformed to classes and instances in the KAPPA-PC system as shown in the system's object browser (Fig. 3). The object browser also shows the classes that KAPPA-PC generates for each application, such as Root, Image and Kwindow

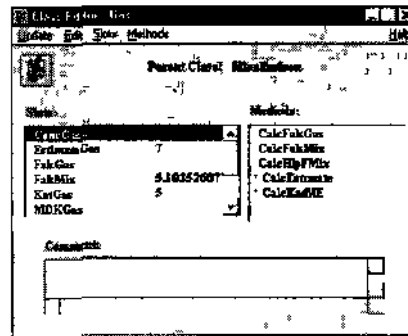


Figure 4 The Gas Class

Classes/instances are described using the class/instance editor, while slot facets are defined by means of the slot editor. Slots represent class attributes, while methods in the class/instance editor account for both methods and IF-THEN rules related to a class in the modified OOA model. For example, consider the Gas class given in Fig. 4. The class has a parent class MineEnviron and six slots. Five methods are listed. The first three are numerical procedures (CalcFakGas, CalcFakMix, CalcHipFMix) used for calculating the value of attributes FakGasa and FakMix, and the remaining (CalcKatME, CalcEstimate) contain rules for the evaluation of the mine environment on the basis of several parameters and their mutual relationships.

The methods are described by the method editor. The method editor for the CalcFakMix method is given in Fig. 5.

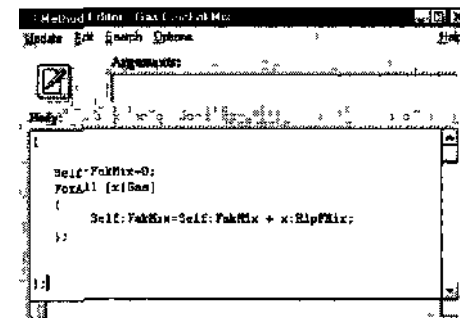


Figure 5 The CakFakMix

Since all rules in the system do not have to be related to particular objects, KAPPA-PC offers the possibility of specifying rules independently, using a rule editor as shown in Fig 6

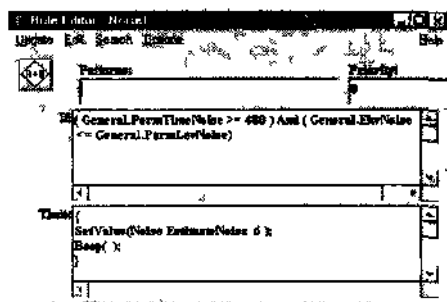


Figure 6 Noise 1

The problem-solving process in PROTECTOR unfolds by means of the KAPPA-PC backward-chaining inference engine. Goals to be satisfied by backward chaining are defined by means of the goal editor. The goals in PROTECTOR pertain to the estimation of different parameter values. A decomposition of the goal ParametCluna into subgoals is illustrated in Fig 7

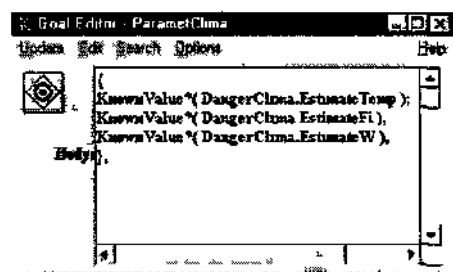


Figure 7 The ParametCluna Goal

Goals can also be generated and modified within methods. This feature enables the creation of new rules and the modification of existing ones dynamically during system operation.

The interface developed for PROTECTOR in KAPPA-PC fully exploits the GUI (graphical user interface) technology available for MS Windows applications (Fig 8). It enables straightforward and easy manipulation of input data and control over parts of the problem-solving process. It also offers suggestions and recommendations to the user which can contribute to the improvement of the overall performance of the mme system.

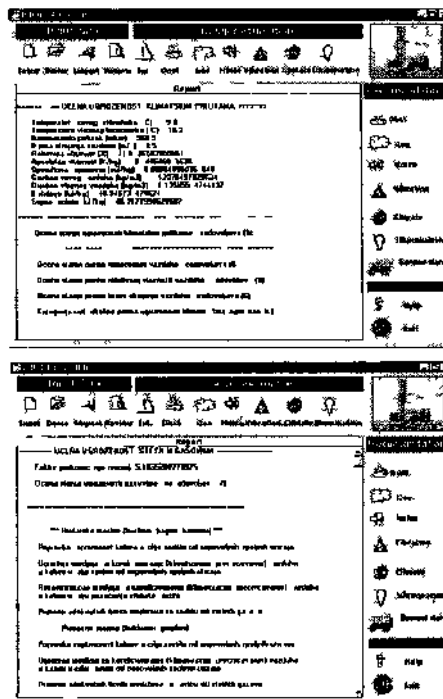


Figure 8 The PROTECTOR interface, with explanation and suggestions for improvements

5 CONCLUSION

In this paper, first, a hierarchical decomposition of the safety state evaluation analysis problem was proposed. As a consequence, the solution of this complex problem, which is based on the estimation of a number of mutually dependent parameters, is greatly facilitated. Then, a possible approach to the solution of this problem through the development of an expert system was outlined. The aim of such a system is to generate an overall evaluation of the general state of safety of the mine as well as suggestions for the improvement of particular characteristics of the mine system.

The approach to the realisation of the hybrid system was based on a symbolic upgrading of existing numerical routines. It has been argued that the object-oriented frame structure represents a natural approach, considering the coupled numerical-symbolic nature of the system and the hierarchical decomposition of the problem. PROTECTOR was developed by integrating neural networks and expert system technology. While the mme environment estimation methodology is implemented through an expert system, some of the

related estimation parameters are determined by neural networks. The conceived system structure was realised in the KAPPA-PC expert system shell, resulting in PROTECTOR.

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New Acoustic Anemometers for the Mining Industry

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ABSTRACT: The selection of the measurement base for the control of ventilation regimes in underground mines involves the choice of devices for measuring velocities and air/gas flow rates. The resolution of this task is rather difficult. Tachometric sensors (the great Leonardo's invention) traditionally used in many countries have a variety of disadvantages: low sensitivity, high inertia, inability to cover necessary measurement ranges with one device, presence of movable accumulating error parts, vulnerability to the effects of dust, etc. For about a hundred years, attempts to create thermoanemometers have continued, successfully in some areas, but not so in mining. The present report deals with a number of new acoustic devices developed in Moscow State Mining University. Acoustic anemometers are free of all the disadvantages listed above: they have unsurpassed sensitivity, time lag freedom and a wide range for velocity and flow rate measurements. They do not contain movable parts, are sensitive to the direction of the stream and are not sensitive to coal dust

I INTRODUCTION

The solution of mine safety delivery problems necessitates the creation of modern and reliable technical methods and tools for ventilation control in mine workings. The increasing demand for monitoring of the quality of the air/gas dynamics process means that more and more advanced devices must be used for air/gas flow and velocity measurement.

Anemometers which are used now for occasional measurements of air/gas flow characteristics, as well as anemometer sensors involved in systems of mine ventilation monitoring and metrology support, are not capable of ensuring modern safety and metrology demands or regulations, or of providing an appropriate level of mine atmosphere control.

The main way of measuring air/gas velocity in coal mines in Russia is still the use of tachometric anemometers, some of which were developed more than 40 years ago, the ASO-3 and MS-13, and some of which are the latest developments, the AP-1 and APR-2.

As mentioned above, tachometric devices such as the ASO-3 wind-wheeled anemometer, the MS-13 cup anemometer and the new APR-1 tachometer (all Russian) are the most widely used devices for measurement of gas and air consumption at mining enterprises. They operate on the principle of turbine-type anemometers (with a small rotating turbine). Under the dynamic thrust of the flow, the small turbine de-

velops torque, the quantity of which is a function of the speed of flow. The value of the rotation frequency of the small turbine can be used as a basis for assessing the speed of the monitored flow. The ASO-3 anemometer is used to measure the speed of air flow ranging from 0.3 to 5 m per sec.

The air flow acts on the blades, causing rotation through the stringed axis. In the MS-13 cup anemometer, unlike the ASO-3 anemometer, speedy air flow puts pressure on the inside surface of four hemispheric cups placed symmetrically in a circle. A cup anemometer is used to measure the speed of the air flow ranging from 1 to 20 m per sec.

A stopwatch is needed to time the number of rotations of the impeller and then, in order to calculate the frequency value, the speed of the air flow is determined through grade characteristics (data) given in the anemometer manual. The period of measurement required, using the ASO-3 anemometer, to identify the average speed of the air flow in a mine working must not be less than 100 sec. with no less than three measurements taken. Thus, one measurement, including preparation, takes about 8-10 minutes. Tachometric anemometers have their disadvantages, which affect measurement error. On the one hand, the impeller has to be as light as possible so as to make sure that the friction threshold and its sensitivity are adequate; on the other hand, it has to be as rigid as possible so that it is not deformed by turbulence flow. The axis has to have the smallest

possible diameter, yet this axis wears more quickly, accumulates error and is subjected to dust. The impeller axis deviation from a vector parallel or perpendicular to the flow is also caused by the occurrence of a turbulent inlet vortex. Sensitive mechanical parts in the devices are subjected to unfavorable mining environments, particularly in terms of dust subsidence and penetration. At the same time, for a number of reasons, the metrological support is not adequate (in fact, of all anemometers used in mines, not more than 15% are tested annually).

Most mining anemometers designed and produced today are devices with a small movable turbine, the rotation speed of which is measured not by mechanical meters but with the help of inductive AE-2, optic AFA-1, electromagnetic ESNV-1, and capacitive and other means. They have the same disadvantages in that they have an impeller and movable axis. Apart from that, the level of error for induction converters of the rotation speed of the impeller increases due to the permanent magnet on the blades creating antitorque. Mine dust with magnetic properties that exists in the flow monitored also contributes to the increase in measurement error. One disadvantage of the photoelectric converter is an increase in error as a result of less detectable light flow in dusty mine environments. Turbine-type anemometers, because of their design characteristics, are more suitable for measurement of high speeds and as far as low speeds are concerned, these devices have nonlinear characteristics determined by the considerable influence of force moments of viscous and mechanical friction as compared to the torque.

In order to reduce the friction threshold (friction between the axis of the impeller and the bearings), special devices are used. For instance, the ESNV-1 employs an impeller mounted on a special vibrating frame. The APR uses axes fixed by means of hard stones. However, this complicates the design and makes it more costly. Modern designs of portable turbine-type anemometers allow for temporary automatic averaging of measurement results. They also allow for digital indicators and for the sensor element to be fixed to a telescopic rod. However, neither this anemometer nor any other tachometric devices that have been developed recently, including those built with the modern technology of watch-making factories, can meet the challenge of measuring speeds starting at 0.05 m per. sec. This has been confirmed by aerodynamic tube tests performed at Moscow Mining University.

Another method of measuring the speed of the air (low is the thermo type. Here, two main varieties exist: thermoanemometric and thermocatalytic. Devices where the signal to be measured is a function of the heat dissipated throughout the monitored environment by the electrically heated body as the

source of energy are known as thermoanemometers. There are two methods of measuring the speed of flow by thermoanemometers. The first is based on maintaining a constant current heating thermoelement, and the measurement of the speed of the flow is associated with the measurement of the temperature of the thermoelement.

The other method presupposes that the heating current keeps the temperature of the filament constant; as a result, the measurement of the speed of flow is associated with the measurement of the compensating electric current. Most thermoanemometers operate on the principle that the filament heated by an electric current is contained in a Wheatstone bridge circuit. The passing flow cools the filament, its temperature decreases, and as a result, its electrical resistance also decreases. This causes an imbalance of the bridge and it is monitored by an electric device. The TA-8 thermoanemometer of the same type measures the speed of flow in the range of 0.1-5 m per sec. The advantages of thermoanemometers include their capacity to measure low speeds (0.1-0.5 m per sec), while their main disadvantage is thermal lag. However, unstable graduation results, dependence of the readings on temperature flow, construction fragility and the influence of subsiding coal dust during the taking of readings limit their range of application. Thermoanemometers have not found any widespread application in mines. Devices in which heat is transferred from a heater to a measuring-converting element with the aid of controlled gas flow belong to the constant-type colorimetric anemometers. The greater the speed of the controlled flow, the lower the sensitivity of the devices become, which is why they are suitable for speed measurement. The ATA-2 thermoelectric anemometer ensures the desired accuracy of measurement with a flow speed of 0.5 m per sec. As the air within the thermoelectric anemometer moves, the heat from the thermofilament is transferred to a number of thermocouples, which is registered by a millivoltmeter. In this way, the speed and direction of the flow are determined. The sensitivity of the thermofilament to environmental temperature and pressure is a disadvantage in any thermoanemometer. The sensitive element of a thermoanemometer is made of platinum or sometimes nickel filament with a diameter of several micrometers and a length of 2-10 mm. The smaller the diameter of the thermofilament, the less durable and more susceptible to wear it becomes. The thermofilament is also subject to aerodynamic stress. As a result of pulsation while measurements are taken in turbulent flows, vibrations occur in the thermofilament, and these can either cause damage to it or cause fluctuations of resistance, which bring about considerable error in measurements. One disadvantage of colorimetric flow meters is the negative influence of moisture

and corrosive admixtures of gassy environments on the work of the thermoconverter and the heater, which are in immediate contact with the environment.

The way to widen the upper limit of the speed measurement range in colorimetric anemometers is to slow down part of the flow so that its speed does not exceed the maximum speed for the given thermoconverter. The colorimetric sensor of the speed of the DBT air flow meter as part of the complex system for continuous automatic air monitoring in mine workings provides measurement in the ranges of 0-2.5, 0-5, and 0-10 m per sec. The change from one range limit to another is carried out by changing diaphragms placed in conical extensions of the sensor. At this point, it should be mentioned that the noted range beginning from zero is nonsense - no meter can measure zero due to quite definite sensitivity.

There is a tendency outside Russia to combine a colorimetric converter and a pressure mechanism, creating a pressure differential depending on the dynamic pressure of the flow. Ventor, made by the Maichak company (Germany), is a mechanism for monitoring the speed of flow in mine workings. It has a speed sensor consisting of a differential Pitot tube and colorimetric speed converter. Within the sensor, the flow passing through the channels of the colorimetric converter is formed as a result of the impact and static pressure difference at various points of the monitored flow. The sensor is capable of measurements ranging from 0.15-0.75, 0.5-2.5, and 1.5-7.5 m per sec.; the sensitivity of the mechanism to speed can be regulated in the range of 15% of the upper measurement limit.

The difference in the range of speeds measured by turbine-type anemometers and thermoanemometers suggests the idea of combining the two sensors based on different principles into a single device. The UBM-1 is a domestic device designed for methane concentration and air flow measurements during mine air and gas dynamics research, and in solving engineering problems of coal mine ventilation with dust and gas hazards, it has a unit responsible for speed of flow measurements which combines thermoanemometric and tachometric primary converters. The thermoanemometer is responsible for measurements of low speeds of flow ranging from 0.05-0.5 m per sec., while with speeds of flow which are within the range of 0.5-10 m per sec., measurements are taken by the tachometric sensor. However, such an engineering solution is apparently possible only for laboratory research instruments as devices combining two different sensors are twice as expensive, bulky and the whole structure turns out to be too complicated.

From all the facts mentioned above, one can conclude that mining enterprises in Russia have no anemometers based on principles other than those

employed in turbine-type and thermo-type anemometers.

However, as we can see, commercially available turbine-type and thermoanemometers and sensors for controlling the speed of gas and air flows in mine workings have a host of disadvantages as mentioned above. In particular, they cannot ensure the speed range defined by safety regulations, they are bulky, and they are neither reliable nor cheap. As things stand now, there is no hope that further improvements of engineering solutions based on traditional principles of thermo and tachometric anemometry used to measure speeds of flow in mines will lead to the creation of a device with the desired characteristics. As the analysis of modern anemometric sensors shows, further improvement in the quality of measurements is related to the application of more expensive materials and more complex technologies. One can say that thermo- and turbine-type methods for the measurement of flow speed have reached their limit in as far as being a basis for the creation of mine speed monitoring devices. Moreover, they still cannot meet the needs of mining anemometry.

Evidently, the solution to this problem should be found not by improving traditional principles used in these constructions, but by employing new methods of anemometry.

Complicated modern mining technology comprises the use of appropriate means of automation, hardware and software for mine ventilation control. Such apparatus and software would make it possible to increase the permissible level of methane concentration, i.e., to increase mining. The effectiveness of the operation of such systems depends very much on the reliability and quality of the anemometers involved, and on their sensitivity, precision and inertia.

2 ACOUSTIC METHOD OF FLOW RATE MEASUREMENT

Careful analysis of published work and preliminary laboratory investigations has shown that on the one hand, acoustic methods in flow measurement have not realized their potential, and on the other hand, none of the existing acoustic methods of flow measurement allows the creation of an anemometer able to:

- measure speeds of flow in the range of 0.05-30 m/s;
- be free of moving parts;
- measure high frequency pulsations;
- measure average flow speed in the working cross-section;
- have stable characteristics, making it possible to decrease error.

The suggested measurement method satisfies all the requirements mentioned here (Shkundin et. al., 1991). The method is based on air-acoustics interaction and involves excitation of vibrations in the cylindrical wave guide air duct, reception of these at some distance from the excitation point, and a comparative analysis of radiated and received vibrations as a result of which an informative signal (e.g., vibration phase or time difference) is singled out and serves as a flow rate measure. It differs from other known methods in that definite mode waves are radiated and received by excitement of the air conduit elements acoustically isolated from each other. This method provides accuracy and exception of the air conduit effect upon the aerodynamic field of air/gas flow.

A description of the wave propagation process in tubes without flow was given by Scuchic (1976) From this description, we concluded which waves can spread in the round channel of the given diameter. The spread rate of the zero mode wave fronts of these vibrations is equal to that of sound velocity in open space with the same medium

For an analytic description of air-acoustic interaction, which is the basis of acoustic anemometry, it is necessary to solve the boundary problem for the equation with partial derivatives. For the first approach, the anemometer channel may be realised for unlimited length. For better correspondence with real physical phenomena, in the mathematics model it is necessary to take into consideration the error caused by acoustic wave reflection from the open ends of the anemometer (Kremleva & Shkundin, 1998).

The method of correction determination corresponding to the reflected waves field by means of normal mode reflection coefficient calculation is proposed. The analytic dependencies of the velocities upon the dimensions, channel wall material and air/gas medium characteristics were obtained using the work of Gohnson and Ogimoto (1980).

3 OPERATING THE ANEMOMETER

The measuring channel of the anemometer constitutes a cylindrical air conduit containing two semi-channels (Figure 1).

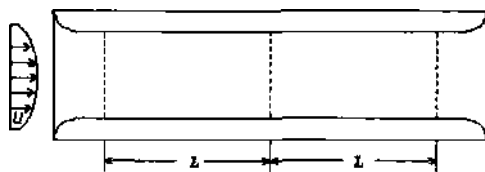


Figure 1. Scheme of anemometric channel

There is a radiating element in the center of the air conduit, on each side of which receiving elements are found at a distance L. The difference of phases in the right semi-channel $\Delta\varphi_1$

(down the flow) is expressed:

$$\Delta\varphi_1 = \frac{2\pi fL}{C+U} + \varphi_1 \quad (1)$$

where:

C = sound velocity;

U = flow velocity;

φ_1 = initial phase difference;

Analogous for the second, left semi-channel (against the flow):

$$\Delta\varphi_2 = \frac{2\pi fL}{C-U} + \varphi_2 \quad (2)$$

where:

φ_2 = initial phase difference in the second semi-channel.

The anemometer has to operate in accordance with technical tasks at temperatures of 5 to 25°C that correspond to the regime of metrological tests. In this range of temperature changes, as it is easy to see, the sound speed does not exceed 345 m/s.

In the right semi-channel, the minimum value of the phase difference corresponds to the maximum of $(C + U)$, i.e., $C = 345$ m/s and $U = 20$ m/s, that is, assuming $\varphi_1 = 0$:

$$\Delta\varphi_{1min} = \frac{2\pi fL}{365} \quad (3)$$

In the left semi-channel, $\Delta\varphi_{2min}$ corresponds to the case when $C = 345$ m/s and $U = 0$. That is, assuming $\varphi_2 = 0$:

$$\Delta\varphi_{2min} = \frac{2\pi fL}{345} \quad (4)$$

Now formulas (2) and (3) will give the following:

$$\Delta\varphi_1 - \Delta\varphi_{1min} = 2\pi fL \left(\frac{1}{C+U} - \frac{1}{365} \right) \quad (5)$$

$$\Delta\varphi_2 - \Delta\varphi_{2min} = 2\pi fL \left(\frac{1}{C-U} - \frac{1}{345} \right) \quad (6)$$

Before measurement, phase zero in the right semi-channel is adjusted to $C + U = 365$ m/s; in the left semi-channel, phase zero corresponds to $C - U = 345$ m/s. Phase zero may be schematically fixed precisely, and, therefore, anemometer phasing does not generate measurement error. We can describe different basic phases of the measurement algorithm from the formulas above as follows:

1. Automatic amplification and adjustment of the received vibrations.
2. Transformation of sinusoidal vibrations into meander.
3. Correcting phase change.
4. Forming of binary codes of the analog signals in each semi-channel.
5. Time averaging of binary codes.
6. Calculation of binary codes corresponding to the flow speed.

4 ANEMOMETER ELECTRO-ACOUSTIC CONVERTERS

For the implementation of different variants of the anemometric control studied, cylindrical channels with piezoceramic rings of different standard sizes were utilized. The material of the rings CTP-19, CTP-23, CTBP (CTP - circonate-titanate of plumbum; CTBP - circonate-titanate of barium and plumbum), a wide spectrum of imported piezoelectric ceramics, was also produced by such companies as: PI Ceramic (PIC131 ... 163), Sensor Technology (BM400 type I, BM300 ... 940), TRS Ceramics (TRS100... 600), etc.

Table 1. Piezoceramic rings of different standard sizes used in anemometric converters.

Geometrical characteristics, mm	2		3		
External diameter	27.5	30	17 J	17.3	112
Internal diameter	22	27	15.8	15.8	100
Height	8	4	5	3	26
Wall thickness	2	1.8	0.75	0.75	6

The piezoceramic ring represents the cylinder, on each surface (external and internal) of which the silver covering as electrodes is fixed. With supply to the electrodes of an alternating voltage, the return piezoeffect causes alternately, in phase with the applied stress, compression and relaxation of the piezoceramic cylinder, in the direction of its imaginary axis and from it. These oscillations happen near the non-movable imaginary average surface driving through average at the end faces of the cylinder lengths of circles. These oscillations are also accompanied by oscillations lengthwise of the cylinder, which are not used. From the influence of the circumscribed radial oscillations, the acoustic waves spread along the cylindrical channel. These waves come to the receiving ring, in which the piezoeffect causes a polarization of charges, and the potential difference emerges on the ring facing. The basic characteristics of acousto-electric piezoceramic converters are:

1. Acoustic power.
2. Electro-acoustic efficiency.
3. Electrical impedance.
4. Resonance frequency.

The electro-acoustic converter can be represented by the equivalent circuit, which contains two parts - electrical and mechanical. The electrical part contains units representing generating properties in a radiation mode, resistance, as a resistance of dielectric losses and capacity, connected in parallel. The mechanical part of the equivalent circuit contains a resistance of mechanical losses, the reactance of the converter and load. With the growth of frequency, the resistance of a converter diminishes (because of the capacity presence in the equivalent circuit) and on the resonance frequency it reaches a minimum value. Furthermore, with the frequency increase, the resistance rises again and reaches a maximum at the so-called anti-resonance frequency.

Because of this, the source has a resonance-frequency behavior, with a particular radius; usually it is reasonable to work only in a rather narrow frequency band close to the resonance. The resonance frequency strongly depends on the radius of the ring: the smaller the radius is, the greater the resonance frequency.

In practice, the radiated frequency and diameter of the channel are completely determined by the resonance-frequency behavior of the piezoceramic rings used as the sources and receivers of a sound. The amplitude-frequency curve (AFC) of the anemometric channel is a superposition of the AFC of the rings and the AFC of the appropriate wave guide at a stationary value of the radiation amplitude.

Experiments were conducted on the analysis of AFC converters. On this basis, it is possible to conclude that the resonance frequencies of the one type ring are essentially varied (within limits of 10 %). From the facts mentioned above, it is possible to conclude that to maximize the transferred power in the anemometric channel, it is necessary to use a couple of similar rings. At the same time, amplitude-frequency research has made it possible to state the AFC stability under a feed voltage not increasing 10 V, and also recurrence of the characteristics with repeated turning on and off. The schemes for obtaining AFCs separately for the converter and for the whole channel are represented in Figure 2.

As the experimental data and theoretical calculations have shown that the pressure on receiving rings depends on a radiated frequency, the radius of the channel, the height of the radiating ring, the length of the sound through base, and also upon the sound speed in the media. The dependence of the acoustic pressure on the height of the radiating ring is particularly interesting to us.

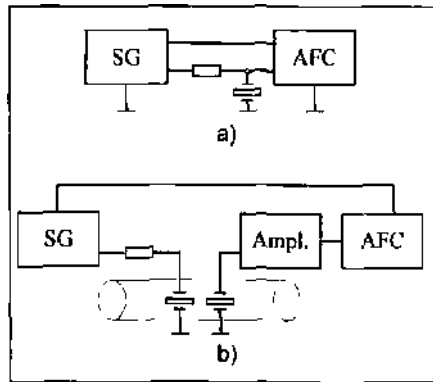


Figure 2. Block diagram for obtaining amplitude frequency characteristics', (a) for piezoceramic rings, (b) for anemometric channel.

One of the particular features of mine anemometry is the variation in temperature over a wide range, and though the Curie temperature (temperature at which piezoelectric loss in properties occurs) for ceramics is much higher, the change of temperature strongly affects the characteristics of piezoelectric converters and the whole system. Thus, it was necessary to determine the dependences of the most important characteristics of piezoelectric ceramics on temperature.

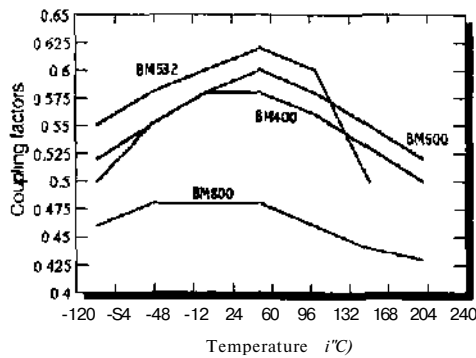


Figure 3. Dependence of coupling factors on temperature.

It can be seen that even at small changes of temperature, the resonance frequency varies, inevitably reducing the acoustic power, which should be compensated for by certain means. The electro-acoustic efficiency factor, one of the most important indicators, depends upon the electromechanical bound factor, which depends on temperature.

Thus, it is possible to conclude that the particular service conditions of mine anemometers strongly influence both the characteristics of primary converters and the choice of the type of ceramics.

In addition, the choice of a certain type of piezoelectric transducer is determined by the dielectric penetration, dielectric loss angle, piezoelectric modulus, and also such important parameters as the O-factor, and, as already noted, the electromechanical bound factor.

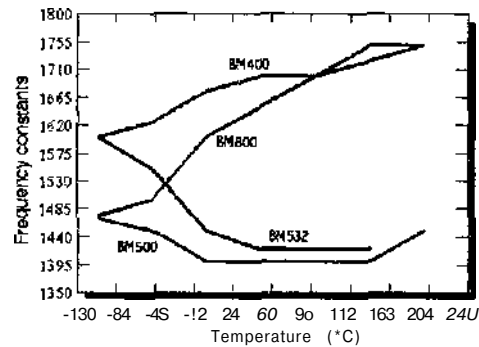


Figure 4. Dependence of frequency constants on temperature.

5 CONCLUSIONS

Acoustics is the most probable way for progress in the area of mine ventilation control devices.

As has been proved at Moscow State Mining University, on the basis of acoustics, it is possible to develop different types of acoustic control hardware: portable anemometers for episodic control, stationary devices for permanent monitoring and also methods of metrology support for ventilation measurements. The Plant of Measurement Apparatus, a partner of MSMU, is ready to meet any request.

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Opportunities of Improving the Microclimate in Underground Mines by Heat- and Hydro-Isolation

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ABSTRACT: This paper shows the results of large-scale testing of the heat-isolation of mine opening walls with high rock temperature. A technology for heat- and hydro-isolation is developed on the basis of Bulgarian and foreign experience in tunnel construction for mine openings with thermal water and passing highly water bearing zones. The properties of Bulgarian heat- and hydro-isolating materials as well as the technology of their placement and fastening onto the walls of mine openings are presented. The efficiency criterion of the use of heat isolation with respect to specific heat flow in a certain mine opening with and without heat isolation is shown. The values of the coefficient of non-stationary heat exchange are determined depending on the thickness of the heat-isolating layer and time for ventilation of the mine openings. The experience gained through these research activities can be applied successfully to other mines with similar conditions.

I INTRODUCTION

Recent investigation and experience from industry show that a reduction of thermal flow can be achieved in mines with ambient rock temperatures of more than 40-45° C by means of thermal isolation of the walls of mine openings. The efficiency of the applied thermal isolation is increased with the increase in temperature of the rock massif.

There are many examples of thermal isolation of mine openings in specialized literature (Voropaev, 1979, Shterban et. al., 1977, Baratov & Chemiaki, 1968, Voloshtuk et. al., 1975, Voloshruk & Andreev, 1972, Avksentiev & Skuba, 1984, Kara et al., 1975, Krasovitskii et al., 1977, Field, 1963, Psota, 1959). Investigations of suitable thermal-isolating materials have been directed towards froth polyurethane. A number of researchers consider that solid froth polyurethane has a broad potential to be used in mining. This is confirmed by different experimental works carried out in the United States and the Republic of South Africa on froth polyurethane covers (Baratov & Cherniak, 1968, Field, 1963, Niproruda, 1969).

In spite of the results achieved, however, the results presented in the literature on the reduction of thermal flow do not provide a quantitative estimation of mass exchange, even though it is an important element of the thermal regime. Moisture isolation of the walls of mine openings and* the reduction of relative moisture content in mines with

an overheating climate deserve special importance. Deciding topics in this direction contributes to the significant reduction of total refrigerating capacity as part of it used for the condensing of water vapors at a high relative moisture content (95-98%) varies within the range of 60 to 70 % or even more.

In Bulgaria, the topic of functions of froth polyurethane as thermal-isolation cover is especially relevant in relation to the development of the Erma Reka ore region, known for its unique geothermal conditions and particularly complicated mining and thermal-hydrogeological conditions. The mining of ore bodies of temperatures between 0 and 95° takes place there. Considering that most of the ore bodies are hosted in porous-quartz zone with accumulated thermal water, topics of predicted complicated heat- and mass exchange are of major importance for implementation of the project for excavation of the ore reserves. In this respect, particular attention is given to opportunities for heat isolation of mining openings as a means of dealing with high temperatures in mines in parallel to efficient heat ventilation and cooling of the air with cold-producing machines.

2 DETERMINING THE EFFICIENCY OF HEAT-ISOLATING COVER

Continuing investigations in this direction for estimating the efficiency of heat-isolation, we

considered the main heat-technical characteristics of the mine heat exchange.

For calculating the heat transfer coefficient, we used the following more important dependencies (Shterban et. al., 1977, Baratov & Cherniak, 1968, Donbas, 1979):

In the case of no isolation,

$$\alpha = 2.67 \frac{\epsilon(\rho v_a)^{0.8}}{R_0^{0.2}}, W/(m^2.K) \quad (1)$$

where:

ϵ is the coefficient of relative roughness, depending on the support of the mine opening;

ρ - density of the air, Kg/m³,

v_a - speed of the air, m/s,

R_0 - equivalent radius of the mine opening, m.

The reduced coefficient of heat transmission α^* is used instead of α in cases of evaporation from the walls of the mine opening. The dependence is:

$$\alpha^* = \alpha + \beta \frac{(\rho_{wall} - \rho_a) r}{\theta_{wall} - t_a} \quad (2)$$

where, P is the coefficient of mass exchange, kg/(s.m".Pa);

P_{wall} Pa " the partial pressures of water vapour for temperatures of opening walls and the air in them, respectively, Pa;

θ_{wall} , t_a - temperatures in opening walls and the air in them, °C;

r - specific heat of vapour formation, J/kg; $r = 2500$ J/kg.

In the case of the existence of isolation,

$$\alpha_{is} = \frac{1}{\frac{1}{\alpha} + \frac{\delta}{\lambda_{is}}}, W/(m^2.K) \quad (3)$$

where:

λ_{is} - coefficient of heat transmission of the heat-insulating material, W/(m.K);

δ - thickness of the heat isolation layer, m.

The characteristic K^* is the criterion for efficiency of the heat isolation cover - ratio of specific heat flow from the rock massif towards the air in a certain opening without isolation q_0 and flow in the presence of isolation q_{0is} , i.e.,

$$K_{ef} = \frac{q_0}{q_{0is}} = \frac{K_{\tau}}{K_{\tau is}} \quad (4)$$

where specific heat flow without isolation is

$$q_0 = K_i (t_0 - \tau t_a) \quad (5)$$

and in the case of heat isolation,

$$q_{0is} = K_{\tau is} (t_0 - t_a) \quad (6)$$

t_0 - ambient rock temperature, °K;

t_a - temperature of the air in the opening, °K.

Here, K_i and $K_{\tau is}$ are the coefficients of non-stationary heat exchange $W(m^2.k)$, calculated respectively for values of the coefficient of heat transmission without isolation ede and with isolation a_s between the air and walls of the mine openings (Shterban et. al., 1977).

Calculations are carried out for a thickness of the heat isolation layer of $\delta = 0.05m$ and initial ambient rock temperature of the Erma Reka mine $t_{m} = 348^{\circ}K$ and cross-section of the openings $S = 9.0 m^2$.

Results for K_{ef} are shown in Table 1.

Table 1. Results for K_{ef} .

Time for ventilation- τ, h	Specific heat flow at a speed of the ventilation stream $V=0.5 m/s$			Specific heat flow at a speed of the ventilation stream $V=1.0 m/s$		
	Non-isolated surface $q_0, (W/m^2.K)$	Isolated surface $q_{0is}, (W/m^2.K)$	K_{ef}	Non-isolated surface $q_0, (W/m^2.K)$	Isolated surface $q_{0is}, (W/m^2.K)$	K_{ef}
8	207.7	13.6	15.05	276.8	13.8	20.05
16	197.5	13.5	14.63	232.8	13.7	17.0
32	155.0	13.3	11.65	131.2	13.5	14.16
100	116.0	13.0	8.90	138.4	13.0	10.6
400	79.0	12.4	6.30	88.0	12.5	7.04
1000	64.0	12.2	5.24	68.2	12.3	5.54

Analysis of the results in Table 1 shows that q_0 of a non-isolated surface is significantly influenced by the time for ventilation of the opening, while an

isolated surface q_{0is} maintains almost constant values depending on T .

- the effect of heat-insulating cover can give the

highest values for a minimum time of ventilation T ;
 - the specific heat flow for a heat-isolated surface is slightly affected by the speed of ventilation in a certain opening.

Data for change of the coefficient of heat transmission a_{s1} , depending on the reduced coefficient of heat transmission α_{re} and the characteristic for perfection of the isolation S/A_{α} ($m^2 \cdot K$)/W, are presented in Table 2. Their analysis shows:

- at one and the same value of α_{re} with the increase of $0.7X_{\alpha}$ values of α_{re} sharply decrease, from 3.4 to 4.5 times;

- the change of a_{s1} in dependence on α_{re} at one and the same value of b/h_s is not significant and reduces to insignificance with the increase of $8/AH_s$; when S/X_{α} is equal to 3.3 then a_{s1} has approximately equal values. Therefore, the interval from 2.7 to 3.3, where α_{re} is lower, is interesting for practical needs.

Table 2. Change of the coefficient of heat transmission a_{s1} , and the characteristics for perfection of the isolation S/A_{α} .

Coefficient of heat transmission a_{s1} , W/($m^2 \cdot K$)	Coefficient of heat transmission for heat-isolated walls of the openings a_{s1} , W/($m^2 \cdot K$)							
	For a characteristic of perfection of heat isolation							
	0.67	1.0	1.3	1.7	2.0	2.3	2.7	3.3
2	0.85	0.67	0.56	0.45	0.4	0.36	0.31	0.26
3	1.0	0.75	0.62	0.49	0.43	0.38	0.33	0.27
4	1.08	0.8	0.65	0.51	0.44	0.39	0.34	0.28
5	1.15	0.86	0.67	0.53	0.45	0.40	0.34	0.28
6	1.20	0.88	0.68	0.54	0.46	0.41	0.35	0.29
8	1.27	0.89	0.70	0.55	0.47	0.41	0.35	0.29
10	1.29	0.90	0.71	0.55	0.47	0.42	0.37	0.29
15	1.36	0.94	0.73	0.56	0.48	0.42	0.36	0.30
20	1.38	0.95	0.74	0.57	0.487	0.42	0.36	0.30
25	1.40	0.96	0.74	0.57	0.49	0.43	0.36	0.30
30	1.42	0.96	0.75	0.57	0.49	0.43	0.36	0.30
40	1.43	0.97	0.75	0.57	0.49	0.43	0.37	0.30

Table 3. Required thickness of heat-insulating layer for different values of the coefficient of heat transfer A_{s1} .

Coefficient of heat transmission for isolation A_{s1} , W/($m^2 \cdot K$)	Thickness of isolation S						
	For a characteristic of perfection of isolation S/A_{α} , ($m^2 \cdot K$)/W						
	1.0	1.3	1.7	2.0	2.3	2.7	3.3
0.03	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.05	0.05	0.06	0.08	0.10	0.11	0.13	0.16
0.08	0.08	0.10	0.13	0.16	0.18	0.22	0.26
0.10	0.10	0.13	0.17	0.20	0.23	0.27	0.33
0.15	0.15	0.19	0.25	0.30	0.34	0.40	0.49
0.20	0.20	0.26	0.34	0.40	0.46	0.54	0.66
0.25	0.25	0.32	0.42	0.50	0.57	0.67	0.82
0.30	0.30	0.39	0.51	0.60	0.69	0.81	0.99
0.35	0.35	0.45	0.59	0.70	0.80	0.94	1.15
0.40	0.40	0.52	0.68	0.80	0.92	1.08	1.32

The data shown in Table 3 allow the selection of the required thickness of the heat-insulating layer for different values of the coefficient of heat transfer A_{s1} and coefficient of perfection S/A_{α} . They show that in the case of the characteristic of perfection $S/A_{\alpha} = 3.3$, achieved for material with $XH_{\alpha} = 0.03$ W/($m \cdot K$), a layer of thickness of only 0.09 m is necessary, while

for material of XH_{α} more than 0.30 W/($m \cdot K$), it has to be more than 1.0 m, which is obviously not rational from a technical and economic point of view.

In the case of high rock temperatures, within the boundaries of 70-80°C, like temperatures in the area of Erma Reka, the characteristic S/A_{α} must be selected near to 3.0, which means that the heat

transmission coefficient should not have a coefficient of heat transmission X_s of more than 0.1 W/(m.K).

In respect of the determination of the reduced coefficient of heat transmission ov , it should be mentioned that only experimental measurements can be used for obtaining precise values. In a rather wide interval of $6 < a_{rc} < 30$, given in Voropaev (1979) and Shterban et. al. (1977). This is extremely important for the slope of mine openings.

3 RESULTS OF EXPERIMENTAL INVESTIGATIONS

Experimental investigations with polyurethane Elastopor H-206, corresponding to the requirements of class B-2 of DIN A 102/1984, were carried out in the Erma Reka area for small-scale drying of a horizontal opening at a level of 300m.

The same has a coefficient of heat transmission of $X = 0.03 \text{ W/(m}^2\text{K)}$ and density of $p = 60 \text{ kg/m}^3$ (Niproruda, 1984). A polyurethane cover with thickness of about 0.05 m was injected by means of a small-dimension machine of the GRACO type with high pressure of the mixing chamber. In the case of an initial rock temperature of 46.4°C, with the temperature of the non-isolated wall of 41°C and air in the opening of 30.4°C, a decrease in the temperature of the isolated wall of 7°C was achieved (to 34°C). Then, borehole chamber No. 2003 of area 500 m² in the same section was thermally isolated. It was established that for an initial temperature of 60°C and thickness of the polyurethane layer of 0.05 m, the specific heat flow from the massif was reduced 5 times. As a result, drilling works became possible.

In this case, the efficiency of isolation was assessed in the alternation of local heat flow from die walls of the rooms towards the air in diem. Meanwhile, it is important to consider that the main obstacle to good adhesion of polyurethane during its distribution is moisture covering the non-isolated surface as a condensing agent or water film. With the aim of overcoming such difficulties, investigations are continuing in the search for a solution for hydro- and heat- isolation on die walls of mine openings, as the coefficient of non-stationary heat-exchange for moisture-containing and wet rocks is about 15-20 W/m².K.

A technology for heat- and hydro-isolation was successfully developed and tested on the basis of Bulgarian and foreign experience in the use of rolls of materials for hydro-isolation of underground workings. Materials like polyvinyl chloride (PVC) folio and geotextile were used for trial drying of a part of the 300-m level in Erma Reka mine mentioned in the section above. It basically consists

of fastening to the walls and roof of the opening a canvas of "sandwich"-type elements of PVC and geotextile, prepared in advance. The polyvinyl chloride folio "Plastifol A" is manufactured in Bulgaria especially for the needs of tunnel construction. It presents a mixture of suspended polyvinyl chloride with appropriate additions such as plastifiers, stabilizers, anti-aging agents, etc. Its main technical data are: thickness of 1.4 mm; width of 1300 and 2000 m; tensile strength of 18-20 MPa; and a relative elongation of 260-300 %.

The geotextile, called geo-filts, type TX 0685-75, is produced in Bulgaria and is also designed for tunnel construction. In this case, it mainly performs the functions of a heat-isolating layer, and so it has to be more porous. Synthetic fibers (in mis case polyester Fibers) are used for its production. The basic data of the geotextile are: thickness, 608 mm; width, 2000 mm; tensile strength, 50-90 MPa; and relative elongation, 80 %.

Preparation of the canvas is carried out beforehand on the surface according to the following method. A layer of PVC folio is laid on a horizontal surface, and a layer of geotextile is put on top of it; on top of this is put another layer of PVC folio. The ends of the folio are adhered by an apparatus for hot air to open fields with a width of 50 mm. Afterwards, diese are used for attaching and fastening to the massif. The width of the separate canvases is 1300 or 2000 mm, and their length is equal to the perimeter of the opening (without the floor) plus 500mm for putting down on the draining system. The coefficient of heat transmission of the "sandwich" element is $X = 0.058 \text{ W/mK}$.

The results of the experimental application of the materials described show that a good heat-isolating effect is achieved. On the one hand, this is due to the thermophysical properties of the geotextile, and on the other hand, it is due to layers of air between the separate canvases and between the canvases as a whole and the walls of the mine openings.

Different supporting structures were developed for respective methods of support. A very important condition is the reliable support of openings that will be subjected to isolation inasmuch as monitoring the roof condition after isolation is impossible.

4 CONCLUSIONS

Heat isolation of the walls of mine openings is of double importance for the heat regime. Convection flow, on the one hand, is reduced through it, and on the other hand, thermal radiation; the wall temperature is reduced, which is very important for the determination of normative values of temperature of the mine air. Underestimation of the radiation heat exchange, which is shown in the case

of high rock temperature (high wall temperatures), leads to significant errors in the dimensioning of the ventilation-conditioning system. Furthermore, for cases of wall temperatures higher than 60°C, there are no regulated standard temperatures for air, and working operations in the presence of people are not allowed. This is why investigating the opportunities for application of special additional measures for normalizing the mine microclimate, for example, heat isolation and hydro-isolation, is of huge importance.

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Managing the Impact of HIV/AIDS on African Mining

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ABSTRACT: Botswana has undergone rapid socio-economic development since independence, principally due to the sound management of mining sector revenues. All these advances are in the process of being reversed by HIV/AIDS, which will affect 19% of the population by end-2000. Sero-positivity amongst mineworkers exceeds 30%. A quantitative model is used to forecast the development of the pandemic over the next 30 years. Indications are that the workforce age profile will begin to alter radically within 5 years. In 5-15 years, recruitment systems will be placed under severe pressure and mines will experience a potentially critical loss of skills. A five-year window of opportunity is available during which to put into place management strategies that deal with the impact of HIV/AIDS, including: comprehensive testing, treatment of STDs, condom distribution and the immediate expansion of recruitment and training activities. Failure to do so may compromise the ability to exploit some of Africa's premier mineral deposits.

1 INTRODUCTION

Botswana is a sparsely populated (estimate 1.5M) Southern African Development Community member state. Since independence in 1966, Botswana has emerged as the World's largest diamond producer by value, with output likely to exceed 25Mct in 2000. Mining has driven one of the highest economic growth rates in the World (21.7% average annual growth from 1975 to 1995). In 1995, mining accounted for 32.1% of GDP and 76.3% of exports, 93% of which were attributable to diamonds. Mining is likely to contribute >60% of government revenues for the next decade (MFDP, 1996).

Sound economic management and uninterrupted political stability have resulted in steady socio-economic and infrastructure development. Botswana also had, prior to HIV/AIDS, one of Africa's highest life expectancies (62 in 1985-90) and population growth rates (3.5%). This has been accompanied by rapid urbanisation, ease of travel on a high quality road-network and a young population profile with 29% aged below 15 years and 45% aged between 15 and 49 years (CSO, 1991). Human capital development is prioritised by government, both to empower citizens and to support economic diversification through the availability of a skilled workforce. Consequently, education is the largest recipient of government's development and

recurrent expenditure (17.1% and 29.1 %, respectively).

Since 1992, annual HIV surveillance has been conducted amongst the 95% of women who attend antenatal care (CSO, 1998). Projections based on these surveys indicate that 19% of the population will be living with HIV by the end of 2000 (Ministry of Health, 1998). Sero-positivity amongst pregnant women exceeds 40% in the main urban centres. Mines who have conducted HIV surveillance record sero-positivity of 30-35%. Sub-Saharan Africa in general and Botswana in particular have the World's highest HIV/AIDS prevalence rates (UNAIDS, 1999). The combination of a mining dependent economy and high HIV/AIDS prevalence makes AIDS-impact management in the mining sector a matter of national importance.

This paper begins by forecasting the impact of HIV/AIDS on a typical mining workforce under different scenarios. It then goes on to analyse the implications of HIV/AIDS for the mining sector before reviewing both general impacts and specific issues emerging from model: in particular, for recruitment and the maintenance of operational skills. The conclusions present strategies for addressing these challenges, especially during the critical period during which the full impact of AIDS-mortalities is becoming established and before such time as public health initiatives are able to mitigate HIV/AIDS effectively.

2 HIV/AIDS IMPACT FORECASTING

This section uses a simple model to evaluate the broad implications of HIV/AIDS on mines by quantifying the impact of AIDS-mortalities on the workforce. A thorough analysis would require detailed health statistics, social and epidemiological characteristics to be subjected to sensitivity analysis, which was beyond the scope of this paper.

2.1 The Initial Population

The initial age distribution dataset used by the model was obtained in July 2000 from the production section of one of Botswana's mining operations (Figure 1). The distribution's relatively high mean age of 38 years 8 months ($\sigma = 8$ years 1 month), stems from a number of factors:

- Major mining operations in Botswana are less than 25 years old, so current retirement rates are low (<1% in this sample)
- Unemployment is high (21%; Seloilwe, 2000) and alternative jobs are scarce, reducing the incentive for employees to move
- Recent downsizing exercises have encouraged the redeployment of existing staff rather than the recruitment of new blood

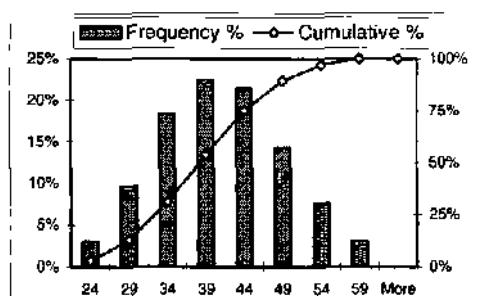


Figure 1 : Age distribution July 2000 (n = 197).

2.2 Model Assumptions

The initial workforce age distribution was projected in five-year increments over 30 years from today subject to:

- All staff retiring at age 60
- No resignations or non-AIDS related mortality
- Workforce size remaining constant
- All new employees being aged 20-24 years (mean 22.5) and HIV-negative
- HIV prevalence remaining constant throughout the population during the model period

- AIDS-related mortality occurring in fixed proportions after 5, 10, 15 and 20 years
- Life expectancy at the beginning of the model period being calculated conservatively by assuming no HIV-prevalence predating year 0

These conditions are assumed to provide a realistic basis for conservative estimation, even though several additional variables exist, such as: changes to risk-averse behaviour over time, age and gender related infection rates, the impact of secondary infections, sickness-related absenteeism, etc. For example, indications from mines in Botswana are that absenteeism has risen ten-fold in the past 5 years to an average of 3-4% of total available person-shifts, which would reinforce the effect of AIDS-mortalities.

2.3 Base Case Model Results

Figure 2 shows the cumulative results for 5-year periods from 2000-2030, based on the current sectoral HIV prevalence of 30%. Mortality is assumed to reach 10%, 50% and 100% after 5, 10 and 15 years respectively, which is equivalent to an average post infection life expectancy of 12 years.

The 5-year projection for 2000-2005 closely reflects today's age distribution incremented by 5 years. Cumulative staff turnover, as indicated by the 20-24 year category, is only 5.6% in 5 years or around 1% per annum. Consequently, this period is characterised by a negligible recruitment requirement. AIDS-mortality is likely to be a less significant factor than retirement or deaths due to other causes, e.g. car accidents. Operational units with less than 40 staff may not experience any AIDS-related deaths.

It is during the subsequent 5-year period, from 2005-2010, that AIDS begins to impact significantly. A strongly bi-modal age distribution of new recruits and older employees emerges and persists over the following decade.

Over the period 2000-2010, some 15.8% (one in 6) of the workforce is expected to die because of AIDS, with an additional 10.7% retiring. Replacing a quarter of the workforce over one decade should be within the capability of existing mine HR systems. However, the non-linear impact of AIDS is likely to mean that recruitment requirements towards 2010 may significantly exceed the 4.2%, or one in 24, annual average for the period. AIDS-deaths are likely to affect around 1 in 7-8 positions between 2005 and 2010.

By 2010-2015, the workforce age distribution will have radically altered. Projected staff turnover reaches 35.2%. This means that less than two thirds of the workforce will have more than 2.5 years of experience. AIDS-related deaths will affect one in four positions during this five-year period. The loss

of overall experience coupled with the significant potential for mortalities at supervisory and management levels, indicates the very real possibility of major skills shortages in key areas affecting productivity and operational viability.

The 20-25 year projections, covering the period 2015-2025, show AIDS-related deaths stabilising at around 3.9%, or 1 in 25, per annum. Retirements, which are purely a function of the present day age distribution, also peak during this period. This in turn leads to high annual recruitment levels of 5.2-6.2%, or one in 16-19, being required for a decade.

By 2025-2030, the long-term age distribution is established. This is characterised by a skewed, truncated pattern whose mean and variance depend primarily on AIDS mortality characteristics. Retirement is of negligible importance as few workers survive to 60. For comparison, current life expectancy in Botswana is 47 (UNAIDS, 2000). It takes the model a further 5-10 years, i.e. 35-40 years from now, before AIDS mortalities and recruitment levels begin to stabilise at around 28% every five years, or 5.6% (one in 18) per annum.

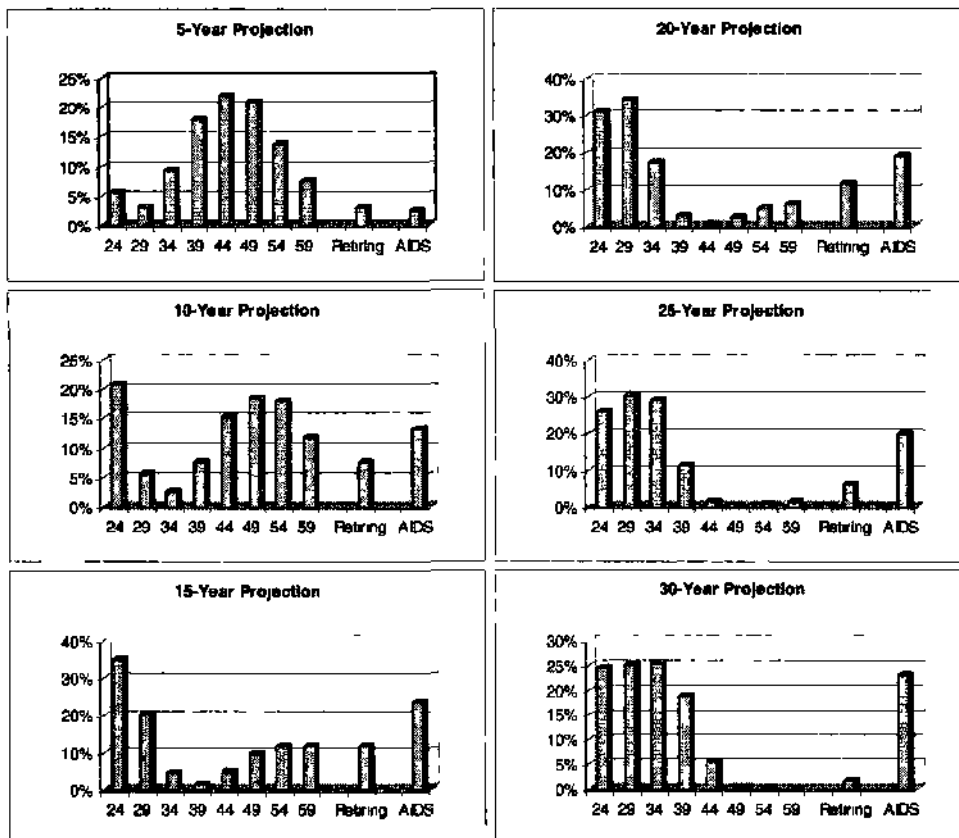


Figure 2. Evolution of base case age distribution, retirement and AIDS-related mortality over the period 2000-2030 (projections are cumulative over 5 year periods ending at the projection year from present, e.g. 25 year projection is equivalent to 2020-2025)

2.4 HIV/AIDS Impact on Recruitment and Experience

The model expresses AIDS-impact through the need to fill vacancies due to mortalities, which is a recruitment issue. Another consequence is the change in the workforce's age distribution. This can

be approximated by average ages, which indirectly correlate with the operational skills base of the organisation, its 'human capital' (Figure 3)

These two parameters behave in a complimentary manner: average age falling as recruitment rates rise. For the base case, recruitment rates increase 5-fold over the period 2005-2015, peaking at ten times

current levels before stabilising at a turnover of 25-30% every 5 years. After remaining artificially high, because of low retirement rates, average age plummets over the period 2010-2020 reaching a low of 26 years, or only 44 months of work experience, before stabilising in the range 28-30 years (average 7 years work experience).

The timing of these shifts reflects the assumed average AIDS life expectancy of 12 years. As the model does not make any assumptions about employees who are HIV-positive prior to year zero, i.e. 2000, these shifts are actually likely to occur earlier.

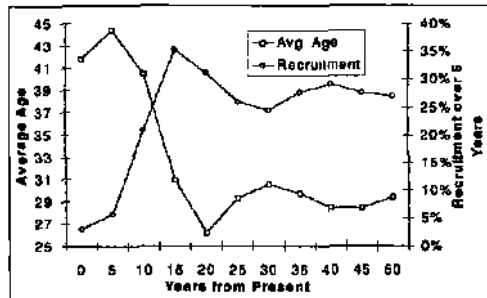


Figure 3^o Base case model long term trends in average ages and 5-year cumulative recruitment.

2.5 Alternative Scenarios

The simplicity of the model limits its use as a tool for analysing complex scenarios, but two basic ones are discussed:

- Scenario 1: The consequences of reduced HIV prevalence, e.g. through systematic behavioural changes
- Scenario 2: The consequences of increased life expectancies, e.g. through the use of medical treatment

Figure 4 shows average age and recruitment trends for Scenario 1, where HIV-prevalence is reduced from 30% to 20%. Although the patterns are broadly similar to the base case model, the peak and average age trough are less pronounced. Recruitment per 5-year period peaks around 28% from 2010-2020, compared to 35.2% in the base case, and stabilises around 20% compared to 27%. Average ages fall to 30.5 years in 2015-2020, equivalent to approximately 8 years of work experience, climbing by 1-2 months per annum thereafter.

Figure 5 illustrates Scenario 2, where life expectancy is increased from the base case's 12 to 17 years, whilst maintaining 30% HIV prevalence. This is achieved by altering the mortality

distribution to 5%, 15%, 40% and 100% after 5, 10, 15 and 20 years respectively.

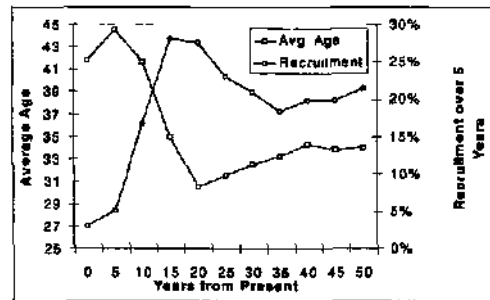


Figure 4¹ Scenario 1 long-term trends for HIV-prevalence reduction from 30% to 20%.

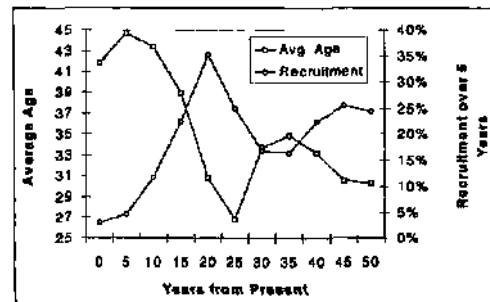


Figure 5^o Scenario 2 long-term trends for increase in life expectancy from 12 to 17 years.

Apart from offsetting the recruitment peak and average age trough by 5 years as anticipated, the patterns are notably more oscillatory. With the exception of the period from 2015-2020 when it peaks at 35.2%, recruitment averages at 4-5% per annum. Although average ages generally remain higher, in the range 30-35 years, there is still a significant minimum of 27 years (52 months average work experience) during the period 2020-2025.

2.6 Summary of Model Results

Starting from the present day, the following emerge as significant trends, patterns and events:

- The initial age distribution found in mines results in low retirement rates for the next 5 years
- Retirements will be more or less eliminated by AIDS-mortalities within 30 years
- Annual AIDS-mortalities will affect approximately one in 200 staff over the next 5

years, rising to one in 40 by 10 years and remaining between one in 20-25 thereafter

- Recruitment levels will increase sharply over the coming 10-15 years and may peak above 7% of the workforce per annum before stabilising around 5-6%.
- Over the next 30 years, the age distribution of the workforce will undergo a major transition: from today's normal distribution with 90% of ages between 25 and 55 years about a mean and mode of 40 years, to 90% of ages between 20 and 45 with a mean of 30 and a mode of 25.
- Between 10 and 30 years from now, the age distribution will be strongly bimodal, with increasing numbers of young and decreasing numbers of older employees. During this period, the effective average age is likely to be even lower due to the biasing effect of the progressively aging 'older' portion of the population. Loss of experience is consequently expected to be, if anything, worse than expected.
- The base case and scenarios show at least a 5 year period during which recruitment peaks and average ages slump, potentially to unsustainable levels, before these parameters stabilise.

3 IMPLICATIONS OF HIV/AIDS ON AFRICAN MINING

Much has been written about the broader implications of HIV/AIDS and readers are referred to the website of UNAIDS (www.unaids.org) as an excellent source of literature and statistics. General issues are only dealt with briefly and the main discussion will focus on specific consequences of the previously presented model.

3.1 General Impacts

Two of the principal concerns at national level are the reversal in economic gains and the reduction in life expectancy that result from HIV/AIDS. Having reached 62 years in 1985-1990, the highest in Africa at the time, life expectancy in Botswana had by 1998, fallen to 47 (UNAIDS, 2000).

Of direct concern to the mining sector is the increase in opportunistic infections that is symptomatic of high and growing HIV/AIDS morbidity. Hospital costs can represent a significant proportion of production costs, particularly where employers endeavour to provide high standards of health care or where they fulfil a community health-care role. Over the next 5 years, it is anticipated that bed-occupancy rates will approach and exceed 100% due to high readmission rates. Treatment costs will

also escalate, with obvious consequences for overall costs.

Providing care for people living with AIDS (PLWA) and orphans will inevitably prove to be beyond the resources available to Health Ministries in developing countries. Regardless of government initiatives, it is clear that the burden of care will increasingly fall onto those in employment. Household earnings are likely to be reduced, whilst expenditures increase, resulting in a trend to greater deficits and financial hardship. Although mining is usually not the largest employment sector, it generally provides a relatively reliable source of income for its workforce. Mine employees will inevitably become key players in providing support to extended family members affected by HIV/AIDS.

Projected single digit growth rates in developing countries national products are insufficient to provide the additional revenues that governments will require to meet the greater health and education expenditures resulting from HIV/AIDS in the coming decades. It can be anticipated that important foreign currency earners, such as mining operations, will see increases in direct and indirect taxation as a result.

3.2 Human Capital Impacts

The primary features of the model are the antithetic trends of recruitment and average age. Once prevalence reaches the levels of 20-30%, as is the case in sub-Saharan Africa, HIV/AIDS imposes such a dramatic cap on the life expectancy that it becomes extremely difficult to maintain skills within the workforce; particularly, if these take more than 5 years to acquire. Although the model does not consider the possibility of recruiting experienced people to fill vacancies, the pandemic is so widespread that it will affect the entire pool of potentially eligible employees.

Unless measures are taken to directly address life expectancy in infected populations through medical intervention, the base case and scenarios suggest that no more than 5 years from today, i.e. by 2005, recruitment requirements will begin to rise dramatically. Indications are that the proportion of AIDS-mortalities will rise to one in 20-25, or more, per annum. Operations or sections featuring high levels of specialist or supervisory skills, e.g. technology-rich, mechanised or large mines; maintenance, engineering and technical sections; or mineral processing plants, will increasingly struggle to maintain core competencies.

The sexual behaviour of individuals in senior management positions is a major issue. If prevalence within this group is comparable with the average, commensurate levels of mortality will impact directly on organisational planning and management

capabilities. These are areas in which skills take perhaps a decade or more to be developed and are difficult to replace.

3.3 Policy Impacts

Although critical to the well being of mining operations, HTV/AIDS containment policy is a specialist area that is outside of the scope of this discussion. Nevertheless, it is appropriate to highlight some of the more significant issues that stakeholders, i.e. government regulators, unions and employers, need to address.

Perhaps the most controversial of these is the issue of HIV testing and confidentiality. Although discrimination because of infection is not to be encouraged, it is important to recognise that the viability of some operations may be compromised, particularly at high prevalence rates. Similarly, employees requiring lengthy preparatory training need to be able to complete this and apply the acquired skills in order to add value in the workplace. Large-scale anonymous testing is therefore an essential prerequisite for robust planning, with implications for the design of health programmes, training and staff development, recruitment and the early detection and treatment of opportunistic infections.

HIV/AIDS considerations need to be incorporated into benefit policies, not only because of its effect on life expectancy and the chronic nature of infection, but because of the need to determine what sort of financial assistance should be made available to infected staff or those responsible for PLWA.

Finally, there is the vital importance of ensuring safety against work-place injuries.

4 MANAGING HTV/AIDS IMPACT AT THE MINE LEVEL

Despite considerable investments in awareness programmes, none have achieved the desired result of positively altering high-risk behavioural patterns. Surveys conducted at the University of Botswana indicate that the most effective tool in providing awareness is the radio, which has four times more impact than work-based education schemes. Unfortunately in Botswana, knowledge, regardless of its origin, does not appear to influence social behaviour significantly (Seloilwe, 2000). Although it is critical not to abandon these efforts, it is evident that most organisations have yet to design AIDS-education strategies that effectively communicate with their target groups.

The two most effective measures in controlling HTV/AIDS are the treatment of STDs and the

aggressive promotion of condom distribution. Other practical steps that all organisations should take include:

- * Incorporating HIV/AIDS record keeping and monitoring into systems of medium to long-term mine planning
- Co-ordinating HTV/AIDS activities, especially with planning and HR

At this stage, it is necessary to acknowledge that stakeholders must seek to actively manage the situation and not rely on being able to change social behaviour.

4.1 Managing Recruitment

The position in which mines currently find themselves is challenging. Intensive efforts to effect behavioural changes in employees are still to yield results, yet despite dire warnings AIDS-mortality rates are not significant, although absenteeism arguably is becoming so. Simultaneously, efforts to improve productivity combined with the erosion of competitiveness due to global market forces, have established conditions under which sometimes substantial downsizing of workforces is taking place. Recruitment is simply not a priority. The risk is that this situation will be assumed to remain constant, whereas the model shows that staff turnover will change quite suddenly and in an ever-accelerating fashion 5-15 years from now.

The recruitment and subsequent staff development process is the most direct way in which employers can control the makeup of their workforces, but this is a long-term process. In production environments, where work experience is a critical element, a significant proportion of the training is commonly conducted on the job under formal and informal mentoring arrangements. Consequently, there will be limits on the capability of any organisation to absorb and develop new staff.

Logically, most organisations are capable of turning over their workforce within the average period of employment. For example, mines should be able to replace 3-4% of the workforce annually, which is equivalent to saying that the average worker is in employment for 25-30 years. By comparison, the model indicates that annual recruitment requirements could exceed 7%. Whether this is sustainable depends on the point at which accommodating recruits becomes an unacceptable cost, e.g. through its impact on productivity. This will vary between mines and within sections, but is clearly a parameter that needs to be determined.

Future peak recruitment requirements can be offset by increasing present day recruitment; creating a staff surplus that can be offset against future needs. Maintaining a consistent level of

recruitment has the advantage of enabling appropriate recruitment systems to be established and maintained, with the expectation that these would be more cost effective than situations where recruitment targets are changing radically over short time-scales. The recruitment requirements of the model over the next 20 years are equivalent to a constant annual turnover of 4-5%. This rate would address, but still not meet, long-term requirements if AIDS continues on its present course, unless life expectancies can be increased and/or prevalence rates reduced. In the short-term, such a policy would increase the workforce by 15-20%, although this figure would be mitigated by the already high and still increasing rates of absenteeism.

To further evaluate this argument it would be necessary to analyse the potential impact of the peak in recruitment requirements that is expected in 10-15 years time and, more specifically, the potential implications on profitability of being unable to meet this need for new employees. A potential advantage of initiating a positive recruitment policy now, is that the pool of potential employees is still large. In future, it will become increasingly difficult for employers to be selective as more players are forced to address AIDS-impact.

One of the most significant features of the model is the dramatic, albeit short-lived, collapse in the average age of the workforce. This can be countered by selectively recruiting individuals with appropriate amounts of experience who are specifically earmarked to fill the anticipated gap in the 30-40 year group. This group, which currently provides the bulk of mines' experiential human resource reserves, is precisely the one that projections indicate will be decimated by AIDS in the medium term.

Before moving on, it is worth revisiting the issue of routine testing. If excess compliment is maintained on short-term contracts, this allows for legitimate testing as part of the contract renewal process. Politically, testing issues could be mitigated by the provision of additional employment.

4.2 *Managing Training and Development*

Many developing countries are prioritising investments in education, with the result that the available pool of talent is steadily increasing. Higher employee turnovers therefore offer companies a real opportunity to develop a more skilled and flexible workforce, which is better able to adapt to changing technologies and work practices.

AIDS' impact on skills will be two-fold. Firstly, there will be the need to rapidly incorporate new staff into the workforce. Secondly, and more critically, is the necessity to cover essential technical and supervisory skills that traditionally take time to

develop. Currently, most mine training is reactive, aiming primarily at providing essential skills or filling anticipated vacancies. However, once annual turnovers reach 5-7% different strategies will be needed. Experienced front-line supervisors and skilled artisans, who generally need to be available locally, are likely to be the most difficult group to replace; and acute shortages at this level could potentially threaten operations.

In Botswana, a collaborative technical training venture involving government and the mining sector was launched in 1994. Specifically aimed at preparing operators to move into supervisory positions, it allowed the identification of three factors that significantly impact on the potential success of training and development programmes: accessibility, motivational strategies and integration.

Many educational institutions are adopting modular life-long learning frameworks. These are intrinsically flexible, in terms of both their structure and their mode of delivery, which can be by full-time and part-time study, distance or web-based education. Access to learning opportunities and easy integration of training into the workplace is facilitated as a result. Furthermore, where training systems operate within a national qualifications framework, the ability to obtain recognisable and transferable qualifications becomes a powerful motivational factor encouraging individuals to actively participate.

In terms of learning content, mines need to adopt a less rigid attitude. It is important to acknowledge that environments in which muM-skilling is important require learners to have broad background skills, opportunities to quickly and effectively acquire new skills and an incentive to develop skills that are not necessarily required immediately, but may be in future.

Currently, training is often compromised in favour of production targets, particularly where it is not seen to be essential or where it cannot deliver measurable short-term benefits. However, the previous section's arguments for increasing workforces over the next decade would provide the necessary flexibility, because of overstaffing, to allow the proportions of training time to be increased. An advantage of this approach would be that skill levels could be substantially increased, providing a buffer against the anticipated loss of competencies 10-20 years from now.

5 CONCLUSIONS

- The features of the model have already been summarised, but it is worth reiterating the following critical points:

- The principal impact of HIV/AIDS will be on staff turnover and the amount of experience available within the workforce, both will reach levels where totally new approaches will be required
- The composition of mine workforces in the future will be significantly different from today, younger, less experienced and increasingly volatile
- Mines will come under ever-greater pressure to support nations suffering abnormally high AIDS-impacts. Both indirectly through providing the salaries of staff who are the focus of support networks, and as corporations that are vital sources of foreign exchange.
- Instead of focussing on AIDS initiatives aimed at encouraging behavioural changes, mines must concentrate on strategies for dealing with the consequences of AIDS. Unless massive investments are made in medical treatment, no more than 5 years are available to implement these strategies.
- Comprehensive, anonymous testing must be introduced as soon as possible to provide accurate data that will allow effective planning. This should be coupled with intensive efforts to treat STDs and distribute condoms, as the two currently most effective preventative measures.
- Recruitment should be stepped up immediately (a rule of thumb being to recruit 1.5% of workforce per 10% of present day HIV-prevalence), with the aim of creating a buffer against the rapid increases in AIDS-mortality and ATDS-related absenteeism that are anticipated 5-15 years from now.
- Training programmes should be incorporated into this recruitment policy. In order to target

those skills, currently residing primarily in the 30-40 year age group.

Perhaps the greatest potential threat to Africa's mining industry is the loss of competitiveness that may result from AIDS. A position is being faced where a strategic sector is being threatened by completely new forces, which are quite capable of making World-class deposits unexploitable and increasing the risk associated with mineral resource development on the African continent.

ACKNOWLEDGEMENTS

The author wishes to thank all members of the Botswana Mining Council for providing unrestricted access to HIV/AIDS information. The manuscript benefited from the input of Dr Esther Seloilwe of the University of Botswana AIDS Task Force. This work was supported by the University of Botswana Research and Publication Committee.

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Development of a Portable Coal Seam Gas Analyser

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ABSTRACT: Gas content and composition are important parameters in predictive models for coal seam gas emission calculations, ventilation requirements and design of mine gas drainage systems. Accurate measurement of gas content is not easy. A number of different methods and approaches have been developed in Europe, the US and Australia. This paper examines various testing methods particularly a recently developed instrument, the Portable Gas Analyser (PGA). The PGA is a lightweight and low cost instrument used for direct measurements of seam gases such as CH₄, CO₂ and H₂S. It significantly changes the way seam gas quantities and concentrations can be estimated quickly. It allows quick estimations of these values to be made and reduces the need for full laboratory testing of exploration cores and mine samples to only those with very significant levels.

1 INTRODUCTION

The most significant coal seam gases are CH₄, and CO₂. Smaller quantities of N₂, H₂S and heavy hydrocarbon may also be found. The majority of seam gases are found adsorbed onto the coal microstructures. It is important to be able to both predict the gas content of a coal sample and to be able to forecast and model the gas generating capacity of a coal deposit.

There are many reasons why insitu gas quantity determinations are important to mining. Safety is a primary consideration, particularly in underground coal mining operations where gases released into mine workings may pose a hazard associated with gas toxicity or explosibility. Data on seam gas content allows appropriate operational measures to be undertaken prior to mining to maximise production and safety. These may include increased ventilation quantities and use of seam drainage to maintain gas concentrations within the mine openings below safe limits.

Accurate measurement of gas content is not easy. A number of different methods and approaches have been developed in Europe, the US and Australia. These can be described as direct and indirect methods.

Direct approaches are based upon extracting a coal sample, enclosing it in a sealed chamber and measuring the gas evolved. Indirect methods approach the issue in a number of ways. These include:

- Use of empirical data obtained from ventilation records.
- Gas release from sampled coal fractions from a hole ahead of mining can be undertaken and can be related to high-pressure sorption isotherms determined in the laboratory.
- Detailed chemical analyses can be used to determine material properties including those of gas present.
- Approaches which rely on crushing or pulverising samples and determining release over a short time period.

This paper gives some attention to some aspects of sampling and gas content methods particularly the recently developed approach making use of the Portable Gas Analyser (PGA).

2 SAMPLING TECHNIQUES

The prediction of insitu coal gas liberation levels which will be released in the mining sequence during cutting, breakage and transport can be achieved by testing exploration cores or exposed rib coal. Exploration core samples results can be compared to those of face samples collected during mining through high gas zones to determine the correlation between the two for future prediction of gas levels from exploration core samples.

Intersection of a gas during gateroad development gives an indication of the seriousness of the problems that may be experienced while mining the

panel in the near future. In order to predict the levels of gas concentration, a number of different sampling and testing methods can be utilised. These include rib sampling and seam horizontal and vertical drill hole core sampling methods (Gillies et al. 1997 & 1998).

Obtaining representative samples from coal containing seam gases is complex. Some seam gases are highly reactive and difficult to contain.

Each sample collected for immediate testing must be as intact as possible and weigh approximately 1 kg. Samples must be put into plastic bags and sealed on site as soon as possible. The sample should be subdivided into two 0.5 kg pieces, one piece is used in the gas content test and the other is archived for future references. All samples should be named according to the location, sampling depth and time. For longer-term storage of samples Teflon containers or a plastic pipe capped at both ends (Figure 1) can be used. Samples must be tested as soon as possible and preferable within a few hours.



Figure 1. Core sample and plastic pipe container

2.1 Rib Sampling Technique

One of the methods of detecting seam gas content is to take channel samples from the rib sides of the gateroad headings when a gassy zone is intersected during development. A number of rib samples should be taken along the development maingate and tailgate headings as seen in Figure 2A. The rib samples can be taken from the middle of the rib sides (Figure 2B) using a handheld pneumatic chainsaw.

2.2 Seam Horizontal Drilling Technique

Rib sampling is a good method for predicting the location and the extent of gas zones along the panel if intersected during development. However, it does not provide any details of the size and shape of the zone and on the concentration levels of the gas

within the panel. One way of obtaining this information is through seam horizontal drilling.

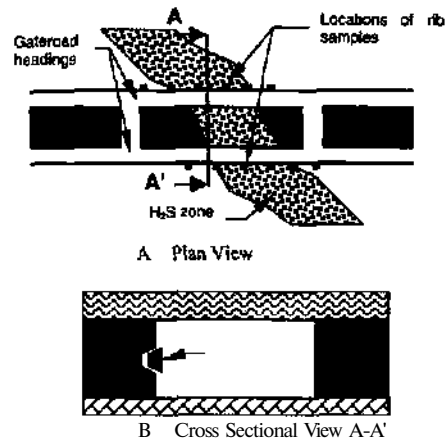


Figure 2. Rib sampling technique

After a gassy zone is located on one or both sides of a panel, a horizontal drilling program can be carried out to determine the extent of the zone within that panel. During this program, core samples should be taken and tested. The location of the horizontal holes and testing results can then be indicated on a plan map.

2.3 Vertical Drilling Technique

Another way of identifying the gas zones is the vertical drilling from the surface. Although it is easier to work on the surface and use heavier machinery it is more expensive to drill as a thick layer of rock must be penetrated before reaching the coal seam. In addition, more holes need to be drilled to precisely delineate the gas zone making the approach expensive and time-consuming option.

2.4 Face Sampling Techniques

The indicated gas released during mining can be determined from coal samples collected and tested from the panel face while mining through gassy zones. These results can then be compared to these predicted from horizontal and vertical drilling and rib sampling.

3 DIRECT GAS TESTING METHODS

The mechanisms in which coal seam gas is stored in coal assumes that the majority of the gas is

contained in the coal as absorbed layer "sandwiched" between adjacent coal layers or as free gas in pores and fissures existing within the coal structure.

In some circumstances the coal matrix pores are so enclosed that gas cannot diffuse out of the sample. These gases remain adsorbed to the internal surfaces even in instances where coal cores samples are exposed to atmospheric pressure for long periods. The gases are known as residual gas and an understanding of them is critical and necessary for evaluating gas reserves and for mine safety considerations.

The most frequent means of determining residual gas, after desorption is no longer evident, is to crush the coal finely enough in an attempt to release the remaining gas. Currently, the most popular techniques used to determine residual seam gas concentrations are through use of chemicals such as silver nitrate, pulveriser, Drum tumbler, and portable gas analyser approaches. Each method has its own advantages and disadvantages, which are discussed below.

3.1 Silver Nitrate Test

The silver nitrate test can be used to measure H₂S content. The test procedure requires the sample to be ground to a finer particle size to increase surface area. The test attempts to quantify the amount of H₂S present by allowing reaction with excess silver nitrate to form silver sulphide (Ko Ko & Ward 1996). The unreacted silver nitrate is back titrated against sodium thiocyanate. This value is then adjusted by subtracting the quantity of silver sulphide formed from a blank purged duplicate sample. The amount of H₂S can then be calculated using the formula below.

$$H_2S = \frac{(0.0282 * V_1 - 0.0250 * 22.4 * 1000 * V_2)}{2 * W} \quad (1)$$

where V₁ = Total volume of silver nitrate
 V₂ = Titration volume
 W = Weight of the sample

Final H₂S = H₂S in test sample - H₂S in blank sample.

If the blank sample has more H₂S content than the test sample, it is assumed that zero level of H₂S is present in that sample. The silver nitrate test has a number of disadvantages:

- It can give inconsistent results if H₂S reacts with the metal used for grounding the sample.
- The process of pulverising and treating the ground sample with silver nitrate solution is difficult.

3.2 Pulveriser Test

The pulveriser test has been developed at the University of Queensland to analyse the total quantity of gas within coal samples. A Siebtechnik standing type t-100 pulveriser has been modified for this purpose. A schematic diagram of the experiment set-up is illustrated below (Figure 3).

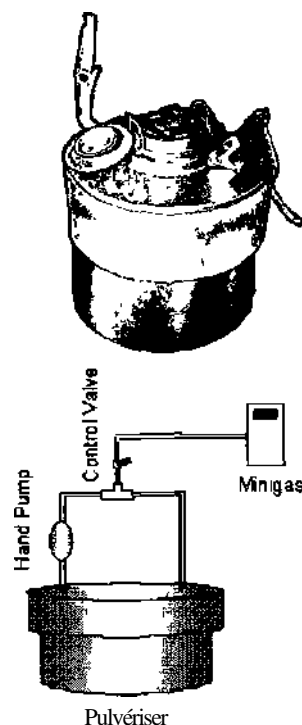


Figure 3 Siebtechnik standing type pulveriser.

The steel container of the pulveriser was fitted with a cover with two holes in it, for intake and outlet. A combination of plastic and Teflon tubes were connected such that a loop can be produced. A manual regulator was inserted between the T-connector and the electronic gas detector to regulate the incoming gas directly to the detector as trial readings were taken. The other section of the connector drives the gas back to the steel container as grinding is taking place. The regulator switch is always off during the grinding process. The manual hand pump is used to circulate the emitted gas from the closed loop before trial readings are taken.

In order to determine the H₂S gas emissions as a function of time, a number of 5g coal samples of approximately were pulverised. Samples were placed inside the pulveriser steel container (volume = 431 cm³) and trial runs undertaken for 5s, 10s and

20s. Gas readings were then taken with the Minigas gas detector and the ground samples were collected for size analysis. An example of gas release is given in Figure 4.

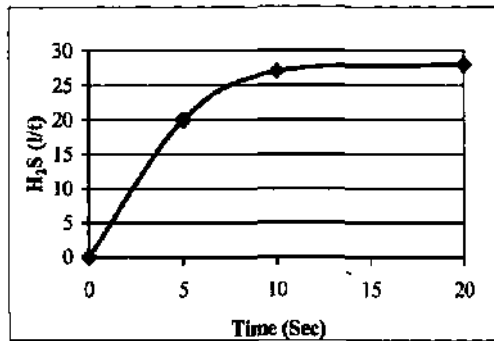


Figure 4. H₂S release rate vs pulverising time

The figure indicates that gas liberation increases as pulverising or grinding time increases. However, it can be noted that gas release decreases over time. This could mean that H₂S gas liberated at 5s time interval is not yet complete, since further grinding to

10s liberates more H₂S. The majority of gas is liberated within the first 10 s grinding time.

3.3 Drum Tumbler Test

The drum tumbler test is used to measure the level of gas liberated during comminution of a coal sample (Ryan et al. 1988). This test was developed in the late 1980s while mining through an H₂S zone near the Southern Colliery mine portal entries in Central Queensland. The initial drum tumbler had a steel drum of 200 litres coated with tiling cement. A sample of 150 to 180 g was crushed by autogenous milling and then tested for H₂S with a gas analyser. Crushing was effected by rotating the mill at 20 rpm about its long axis for 225s.

A modified version of this machine was designed and built by O&B Scientific incorporating new approaches proposed from operational experiments. The general structure of this drum tumbler is shown in Figure 5. The test predicts the volume of H₂S released into the atmosphere during mining by comparing gas levels measured during mining with drum tumbler results from samples taken from the mining face (Gillies & Kizil 1997).

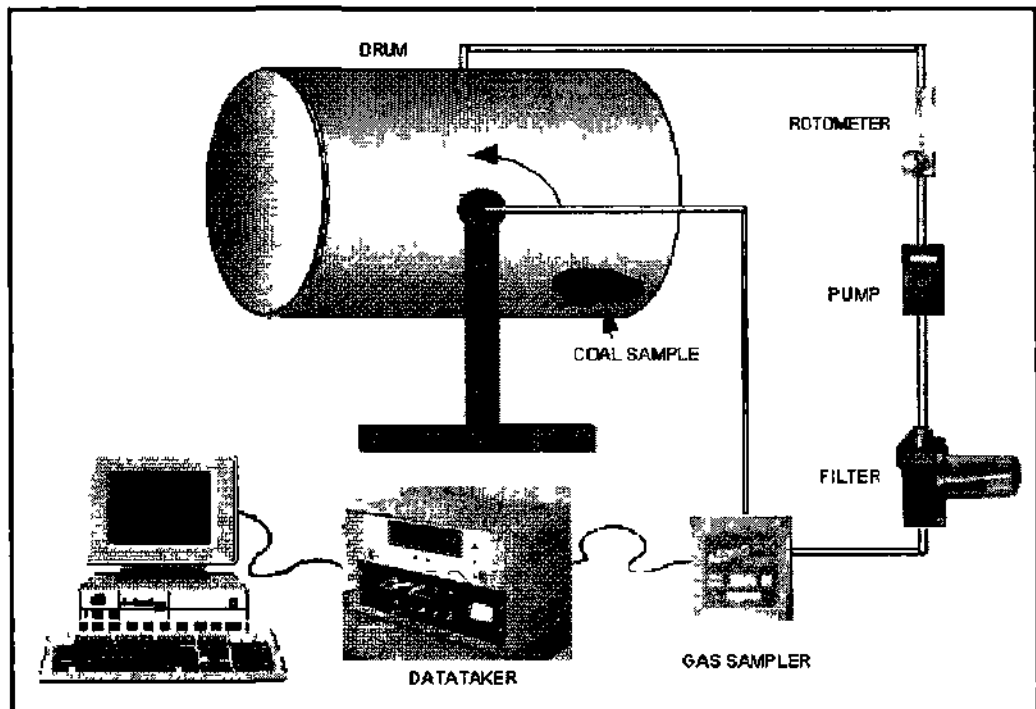


Figure 5 General structure of the drum tumbler (Gillies & Kizil 1997).

The Drum Tumbler is made up of a number of instruments and devices as described below:

Drum: a polyethylene 255 litres cylinder mounted on a steel axel providing 360° rotation.

Gas sampler: reads H₂S gas concentration levels upto 500 ppm within the drum atmosphere.

Datataker: a microprocessor based data logger which measures inputs from monotox device, thermocouple and Zener motor rotation drive and transfers to die computer for data handling and storage.

Computer: linked to the datataker for data read, handling and storage.

Rotometer: adjusts the airflow rate from the pump to gas sampler and keeps it constant.

Air pump: circulates the air in the drum between the drum and gas sampler.

Electrical motor: provides power to rotate the drum.

Electrical motor driver (Zener)- controls the frequency (speed) of the electrical motor.

4 DEVELOPMENT OF A PORTABLE SEAM GAS ANALYSER

Coal samples collection from the mine face and transporting to the surface for testing for seam gases is a labour intensive and time consuming process. To simplify the process and save time, an instrument called Portable Gas Analyser has been developed. This instrument is taken directly to the mining face for insitu gas testing.

PGA is a portable coal crusher that is intrinsically safe allowing it to be taken directly to the mining face for insitu seam gas testing. After evaluating several designs for the PGA, the design shown in Figure 6 was selected. Stainless steel construction was chosen to avoid corrosion. The grinding mechanism of the PGA is shown in Figure 7.

4.1 Testing Procedure

The coal is placed in the crushing chamber and the crushing plate placed on top. The sample is crushed by the pressing and rotating action of the movable metal plate against the firm metal plate bottom. Screw action crushing pressure is exerted on the coal to be ground. A bottom plate is fitted to stop the bottom portion from rotating while crushing. The crushed coal passes through the stainless steel screen to the containment chamber. The gas emitted by the crushed coal is then measured by fitting a rubber hose attached to a gas detector via the outlet valve.

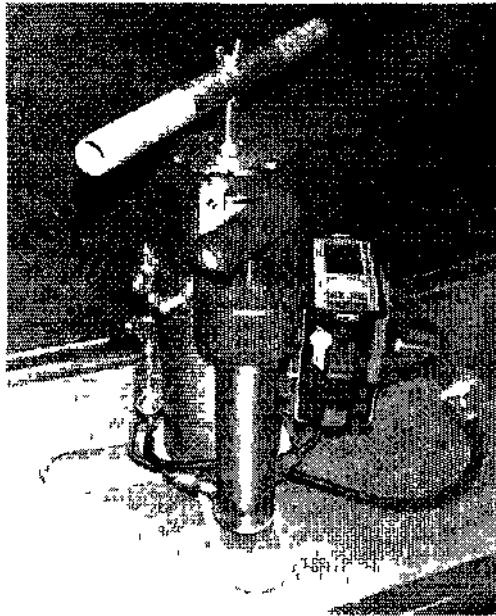


Figure 6. Photographic view of the PGA

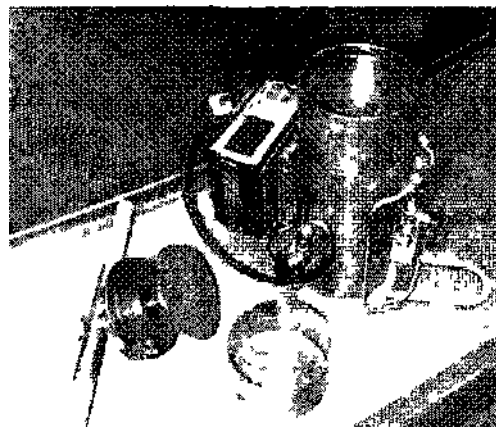


Figure 7. Photographic view of the PGA's accessories

4.2 Accessories

Container: The stainless steel cylindrical container, has a capacity of 2.5. Approximate weight of the stainless steel grinder excluding the gas detector is 5.6 kilograms.

Air Pump. The air pump is similar to a bicy pump. It is made in stainless steel and has length of 180 mm and diameter of 50 mm. Instead of the usual rubber bushings, the pump was installed with Teflon bushings to eliminate recirculation of gases. Holes of approximately 6

mm in diameter were drilled on top of the pump to serve as air inlets. A cover, made up of nylon material was placed on top of the holes to prevent foreign materials from entering the air inlet. To ensure *the* one way recirculation of the air/gas mixture, relief valves were installed along the inlet and outlet tubing.

Gas Detector: Modern mine electronic portable gas detectors such as the Minigas or Drager Multiwarn El (Figure 8) brand can be used as attachment to *the* PGA for gas level measurements. This approach to gas measurement was chosen because of portability, versatility and intrinsically safe design.

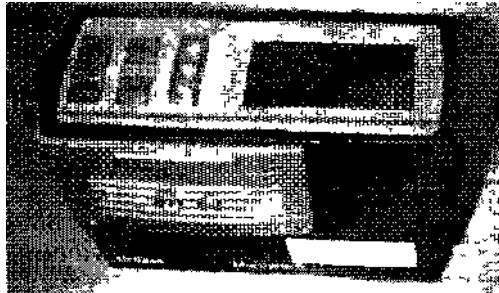


Figure 8 Drager gas instrument.

The Draeger Multiwarn H is a portable multiple gas monitor capable of monitoring and detecting a range of ambient gases such as O₂, CO, CO₂, H₂S and flammable gases. The instrument utilises an infrared sensor for measuring CH₄ and up to four individual electrochemical sensors to measure a range of other gases. It has a built in internal sampling pump for circulating gas to the sensors for measurements and is capable of logging data and providing TWA and STEL evaluation.

The Minigas (Figure 9) can detect H₂S, CR., O₂ and CO, simultaneously in one reading. It is a rugged, self-contained instrument with a diecast metal case. It has die option of either a dry cell or a rechargeable (NiCd) battery-pack, which can be changed in hazardous areas- Total weight of the gas detector is approximately 1.54 kilograms.

Dust Filter: A stainless steel dust filter is fitted in the gas stream to contain the fine coal dust produced in the crushing procedure and prevent it from damaging the gas detector. The removable filter element is made of stainless steel wire mesh of 40-micron size. The advantage of the inline fdter is that it's easy to replace and clean.

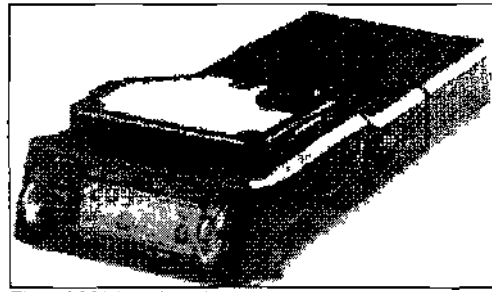


Figure 9 M ini gas 4 gas detector.

4.3 Testing

The PGA has simplified the testing of coal samples for seam gases. A small coal sample of known weight is required to be finely crushed by the instrument. The coal gases will desorb quickly from the coal sample into the vessel chamber of the PGA, where the gases are trapped. As die gases liberates, governed by the desorption mechanics, die gas concentration inside the vessel continues to rise towards an equilibrium state. When the equilibrium state is achieved and all free gases have been liberated the gas measurement unit will indicate concentration. The time requires for the readings to reach equilibrium is dependent on die coal matrix pore size, diffusivity, the type of gas and other aspects. This can be seen by plotting gas concentration versus time.

4.4 Case study

A number of H₂S measurement tests have been done to check the reliability of the PGA. The table below shows the resulting mass and percentage distribution from coal after passage through the coal grinder using a sample mass of about 5g.

Table 1. PGA test results

Sampled	Mass(g)	H ₂ S (ppm)	H ₂ S(l/t)
1	5.01	30	15
2	5.02	37	19
3	5.04	47	23
4	5.06	45	22
5	5.02	26	13
6	5.01	45	22
7	5.06	39	19
8	5.04	44	21
Average			19

As seen from the table, consistent results can be achieved by the PGA with some exemptions. The slight variations in the results might be due to the following factors:

- Distribution of H₂S gas within the coal sample is not uniform,
- Properties of coal is different even for a small portion of the sample,
- Time delay of testing the samples.

After the PGA tests, the crushed coal samples were sized using a Microtrac device. The results of this classification are shown in Figure 10. It can be observed that the size distribution obtained from the coal grinder is identical to the earlier results gathered from the drum tumbler test. However, the PGA results are finer compared to drum tumbler, with 80-90% less than 1 mm size.

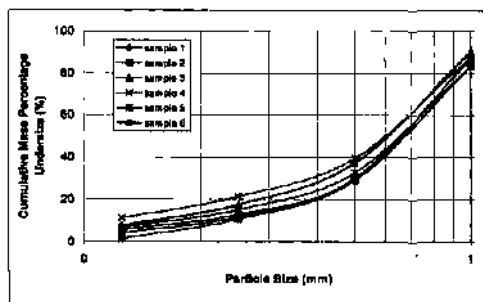


Figure 10. Trend of % weight undersize vs particle size.

4.5 Advantages

PGA has a number of advantages over the other direct seam coal gas measurement methods:

- It is light, weight just over 5 kg, can be carried underground,
- It's more accurate as it uses fresh samples underground,
- It is less labour intensive, as coal samples don't need to be taken to the surface,
- It is quick, gas levels of a coal sample can be determined in less than 5 minutes and results conveyed to operations personnel at the face,
- It is one tenth of the Drum Tumbler cost to fabricate,
- It is equipped with a gas detector that reads multi gases (for instance O₂, CO, CH₄, H₂S).

4.6 Areas of Usage

PGA can be used for:

- Testing surface exploration core samples for seam gases such as: H₂S, CH₄ and CO₂,
- Testing face coal samples,
- Testing rib samples, and
- Testing horizontal drilling core or chip samples obtained underground.

5 CONCLUSIONS

Despite the recent developments in instrumentations and testing techniques, accurate measurement of seam coal gas content is not easy. Time remains as a critical factor in obtaining accurate estimation of gas concentration. The PGA has been tested to be effective in measuring gas emissions from coal samples. It greatly reduces the sampling and testing time with more accurate results as it can be taken underground for measurements.

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