# The early detection of fires and spontaneous heatings in South African collieries*

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**SYNOPSIS**

The various methods of detecting fires and heatings in collieries are reviewed. The methods described range from those relying principally on human senses to sophisticated methods employing infrared technology to detect traces of the products of oxidation and combustion.

The advantages and disadvantages of various gases employed as indicator gases for the early detection of heatings and fires are discussed, and recommendations are made in this regard.

The operation of a modern infrared carbon monoxide detection system is described, and the differences in operation and application of telemetric systems, tube-bundle systems, and upcast-shaft monitors are discussed

In conclusion, some indication is given of the capital outlay required for typical early-detection systems.

**SAMEVATTING**

Verskeie metodes om vure en verhittings in steenkoolmyne op te spoor word bespreek. Die metodes wat beskryf word wissel van metodes wat hoofsaaklik op die menslike sintuie aangewese is, tot gevorderde metodes wat van infrarooi tegnologie gebruik maak om verbrandings- en oksidasieprodukte op te spoor.

Die voor- en nadele van die verskillende gasse wat as opsporingsgasse gebruik kan word vir die vroeë opsporing van vure en verhittings, word bespreek en aanbevelings word in die verband gemaak.

Die werking van 'n moderne infrarooi koolstofmonoksiedopsporingstelsel word beskryf en die verskille in werking en toepassing van telemetriese stelsels, buisbondelstelsels en optrekskagmonitors word bespreek.

Ten slotte word 'n aanduiding gegee van die kapitaaluitleg wat benodig word vir tipiese vroeë opsporingstelsels.

## INTRODUCTION

The purpose of this paper is not to introduce new concepts into the very important field of fire detection, but rather to review some of the techniques available for the detection of fires and heatings in collieries at an early stage of development.

Modern technology has brought about larger production units, higher production per unit, and higher rates of face advance, which, in turn, have led to the production of greater quantities of methane, dust, and heat, giving rise to the circulation of more ventilation air at higher pressures. The increased leakage resulting from these factors, coupled with the trend towards total extraction methods, are gradually increasing the liability of most mines towards spontaneous combustion.

Capital investment per working face has increased dramatically in recent years owing to the dual effect of increased mechanization and inflation. Consequently, the loss of a working face due to fire is now much more critical than in the old days, not only because of the greater financial risk involved in the loss of equipment, but also in the greater production losses, which stem from the fact that there are now fewer working units with a higher output per unit.

Spontaneous combustion, the greatest cause of fires in collieries, has largely been limited in South Africa to certain mining areas such as the Vaal Basin and some areas of Natal, but, with the changing scene in coal mining in South Africa, areas previously regarded as 'safe' can no longer be regarded as free from risk. It seems evident, therefore, that the techniques described in this paper will, in future, not only be applicable to mining areas known to be subject to spontaneous combustion, but may have to be extended to all the coal-mining areas in the country.

## METHODS OF DETECTION

The methods employed in the detection of fires and heatings can be classified as follows.

### Non-instrumental Detection

Non-instrumental detection relies on the human senses to recognize (detect) some of the concomitant physical and chemical phenomena associated with fires and heatings. These are listed below.

*Smoke*

This is obviously the sign of an active fire or very advanced heating, and to rely on smoke to indicate the presence of a heating or fire is not unlike closing the gate after the horse has bolted.

*Haze*

During the spontaneous heating of coal, surface moisture on the coal evaporates into the circulating air. This, together with water given off as a product of combustion, causes the air to become warm and saturated with water vapour. Where this air comes into contact with other, cooler ventilation currents, condensation takes place and a visible cloud of water vapour (haze) may form.

*Sweating or Condensation on Cool Surfaces*

For the same reason as for haze formation, water droplets may condense on cool surfaces. This is normally more prevalent on roofs than on other surfaces because convection currents carry the saturated moist air to the roof.

*Heat Radiated from Hot Surfaces*

Where heatings originate inside sealed areas (owing to leakage) or in a large heap of coal, it is conceivable that at some stage the heat radiated from the walls or the

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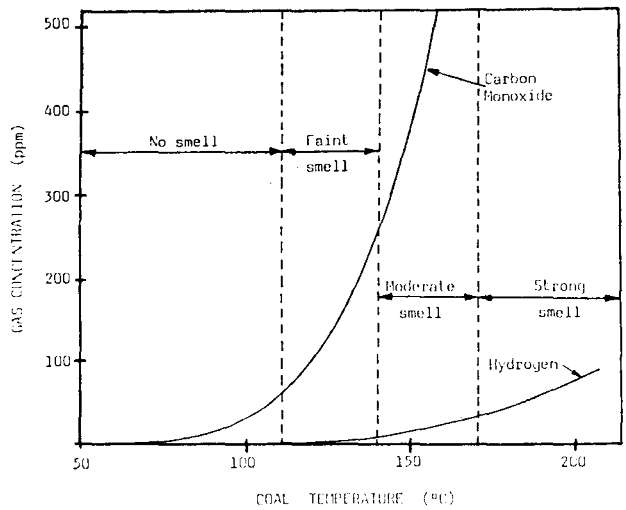


**Fig. 1— Development of smell with increase in coal temperature**

coal can be detected. However, it is unlikely that the first detection of a heating will occur in this way.

*Characteristic Smell*

Although a characteristic smell is given off by coal that is heating spontaneously, experience is needed to distinguish between this smell, which can be described as musty, oily, petrolic, aromatic, or tarry[1], and the characteristic smell normally found in some collieries (especially in return airways).

It may be well to point out here that, although some heatings have been detected on the strength of this characteristic smell, the human sense of smell cannot possibly be a substitute for instrumental detection. To disprove the long-held traditional theory that 'gob-stink' is the most reliable indicator of spontaneous combustion, Chamberlain and Hall[2] conducted some experiments in Britain with a large number of observers. Air was passed over coal while the temperature was raised gradually until the observer could detect a smell in the effluent air. It was found that no observer could detect any smell below 120°C, while carbon monoxide sufficient for detection by modern instruments was generated at least 50°C lower than that. Their results are summarized in Fig. 1.

## Instrumental Detection

Today, a wide variety of instruments of differing accuracy and application is available for the detection of spontaneous heatings and fires. Most of these instruments detect carbon monoxide as an indicator of heatings and fires.

Fire-detection instruments in collieries are usually of three general types.

*Chemical Detectors*

These detectors can be classified into detector tubes and meters.

Detector tubes can be of either the colorometric or length-of-stain type. Colorometric tubes usually contain an indicating gel that changes from yellow to progressively darker shades of green as the concentration of carbon monoxide increases. In South Africa, this type of detector tube is not used any more because of its inherent disadvantages such as the difficulty of matching colours in subdued light and the fact that substances such as ethylene and nitrogen dioxide are known to interfere with the reaction[3].

Length-of-stain tubes (e.g., the Draeger type) are well known, and are in general use in South Africa for spot sampling where micromatic accuracy is not of prime importance. These tubes show a progressively longer stain as the concentration of carbon monoxide increases, and are usually available in a variety of ranges for high and low concentrations of carbon monoxide.

Detector tubes in general suffer from the disadvantage that the accuracy cannot be assumed to be better than about 50 per cent of the reading because of certain factors that affect the accuracy of the tubes. These include the following.

(1) The results depend on the user: owing to differences in visual acuity, different users may obtain different results.

(2) The colour changes are gradual, thus compounding the problem in (1).

(3) The tubes usually have a shelf-life of approximately 2 years, which can be extended if they are stored in cooler-rooms or refrigerators. Conversely, the life is affected detrimentally at high temperatures.

(4) The accuracy is completely dependent on the accuracy of the volume of air that is aspirated through the tube. For example, if the aspirator (bellows, bulb, piston, etc.) is engaged only 75 per cent of the way (i.e., the volume aspirated is only 75 per cent of the required standard volume), an apparent reading of 200 p.p.m. on the tube represents a 'true' concentration of 267 p.p.m., i.e., there is an error of 33 per cent. In practice, it has been found that the squeeze-bulb type of pump is the least accurate of all the pumps.

(5) It has been found that gases other than the gas being tested (carbon monoxide) may interfere with the accuracy of the results. Not all makes of tube are affected equally, but substances known to interfere with the detection of carbon monoxide in some instruments include hydrogen, hydrogen sulphide, ethylene, acetylene, ammonia, and oxides of nitrogen.

(6) In addition to the point made in (1), user error can easily lead to incorrect results in practice. Different tubes have differing scales printed on the tubes, use different units of measurement (e.g., p.p.m., per cent), and require different numbers of pump strokes to give the desired result.

(7) Differences in humidity, air temperature, and barometric pressure may affect the accuracy of the results.

The meter-type of detector also makes use of chemicals that change colour when exposed to certain concentrations of carbon monoxide. The sensors used in these instruments may be paper, tape, or chemical filters treated specially for this purpose, and the colour changes in the sensors are measured photo-electrically. To the author's knowledge, none of these is currently being used in the South African coal-mining industry.

*Physicochemical Detectors*

Physicochemical detectors make use of the physical phenomena resulting from the chemical reactions that are triggered by the presence of carbon monoxide. More specifically, carbon monoxide is oxidized to carbon dioxide as a sample containing carbon monoxide is drawn through a bed of chemicals consisting of a mixture of cupric and manganese oxides. As a result of this oxidizing reaction, heat is produced in direct proportion to the amount of carbon monoxide present in the sample. This heat of reaction can be measured by a thermocouple or thermistor producing a voltage that varies proportionally to the amount of heat produced (and thus the amount of carbon monoxide present). This voltage can be read out directly on a sensitive voltmeter, or it can be amplified and telemetered to the surface, where it can be recorded. None of these instruments appears to be in operation in the mining industry in this country.

*Physical Detectors*

It is conceivable that temperature increases in coal due to spontaneous combustion could be used as indicators of incipient fires. However, it should be evident that surveillance of this nature would be unpractical and prohibitively expensive in the underground environment owing to the close spacing of sensors and analytical instruments that would be required.

The most common physical principle applied in sophisticated instrumental detection of carbon monoxide today is infrared absorption. Infrared rays in the wavelength range 2 to 8 $\mu$m are absorbed by air containing carbon monoxide. This absorption, being proportional to the concentration of carbon monoxide in the air being sampled, gives rise to a difference in radiation pressure when compared with a reference gas that is free of carbon monoxide (usually nitrogen). This difference in pressure can be measured and converted into an electrical signal, which, in turn, can be registered on a meter or recorder.

Fig. 2 shows a typical single-beam infrared gas analyser. The operation of this analyser is briefly as follows[4-6].

A gas pump (17) draws a sample of air continuously through a safety filter (19) into the analysis vessel (4) of the twin-vessel tube or cuvette (6) of the analyser. An automatic interference indicator (18) installed in the path of the gas flow controls the gas flow, and signals any fault in the gas supply that might be caused by a failure of the gas pump or choking of the lines. Infrared radiation from the radiation lamp (1) is divided by the modulation chopper (3), which is driven by the synchronous motor (2), into two equally intense proportions that pass alternately through the analyser vessel (4) and the reference vessel (5) of the cuvette (6). (The reference vessel (5) is filled with a gas that does not absorb infrared rays, such as nitrogen.) Both proportions of infrared radiation then enter the receiver block (8), which contains the detection chamber. This chamber consists of two absorption volumes (9 and 10), which are optically in series in the ray path but are separated pneumatically. These chambers are connected through channels (11 and 12) with a differential type of diaphragm capacitor (13).

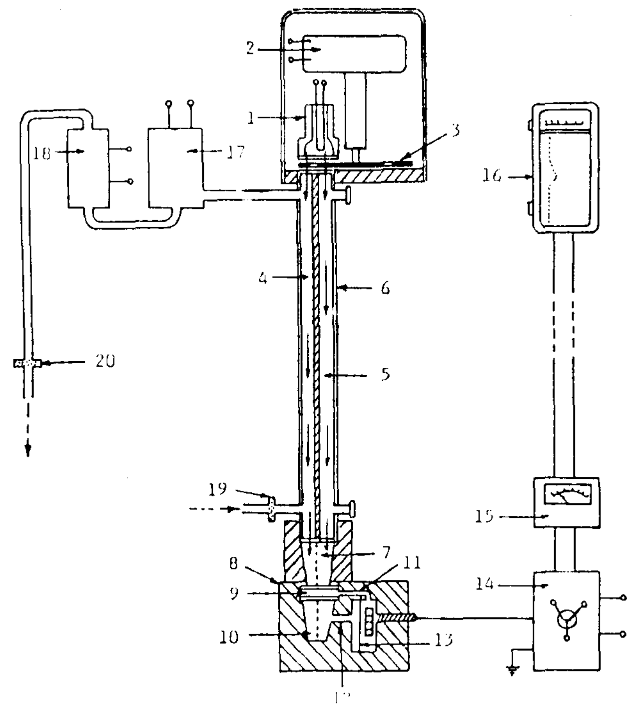

**Fig. 2—A typical single-beam infrared gas analyser**

1. **Radiation lamp**
2. **Synchronous motor**
3. **Modulation chopper**
4. **Analysis vessel**
5. **Reference vessel**
6. **Twin-vessel tube**
7. **Diffuser**
8. **Receiver**
9. **Front measuring chamber**
10. **Rear measuring chamber**
11. **Connecting channel**
12. **Connecting channel**
13. **Diaphragm of capacitor**
14. **Measuring amplifier**
15. **Check instrument**
16. **Recorder**
17. **Gas pump**
18. **Automatic interference indicator**
19. **Safety filter in gas inlet**
20. **Safety filter in gas outlet**

When the air being analysed contains carbon monoxide, some of the specific radiation energy is absorbed in the analysis vessel (4). The reduction affects primarily the front measuring chamber (9) of the receiver block, and the equilibrium of pressure between the front and the rear measuring chambers is disturbed. This gas-pressure differential in the two measuring chambers results in a deflection of the diaphragm (13) that is proportional to the pressure differential, and the capacitance of the measuring capacitor is changed accordingly. The change in capacitance is then converted by an electronic amplifier (14) into a proportional d.c. measuring signal, which is measured on a check instrument (15) and recorded on the chart of a continuous recorder (16).

These infrared instruments have proved to be very successful and reliable in practice, with a very high degree of accuracy. For example, commercial instruments for the detection of carbon monoxide are available today with a lowest measuring range of as little as 0 to 30 p.p.m., with a guaranteed error limit of $\pm 1$ per cent of full scale (i.e., an 'accuracy' of better than 1 p.p.m.).

The principle of infrared absorption is used in the detection not only of carbon monoxide but of a multitude of other gases such as carbon dioxide, nitrous oxides, sulphur dioxide, $Ch_4$, freon, acetylene, and ethylene.

## INDICATOR GASES FOR THE DETECTION OF HEATINGS

In a consideration of early-detection systems for fires and heatings in collieries, the question invariably arises as to whether carbon monoxide is the best indicator gas for such detection. Considerable difference of opinion has existed on this subject in the past, which can be attributed to a lack of knowledge regarding the sequence in which combustion products are generated during the development of a heating in coal, and also to the fact that the detector gases most suitable for use in gold-mine (timber) fires are not the most suitable for application in the detection of spontaneous heatings and fires in collieries, and *vice versa.*

Spectroscopic analyses of wood-prop fires supported by results from actual fires in gold mines have shown carbon dioxide to be the major product of combustion during the early oxygen-rich stages of a fire[7]. During that stage, the concentrations of carbon monoxide remain very low. Measurable concentrations of carbon monoxide were detected only in fires burning in oxygen-deficient conditions, and even then the concentration was only about half that of the carbon dioxide present. These results, together with the fact that the spectral absorption coefficient of carbon dioxide is larger than that of carbon monoxide, has led to the former being favoured above the latter for the detection of fires in gold and other metal mines.

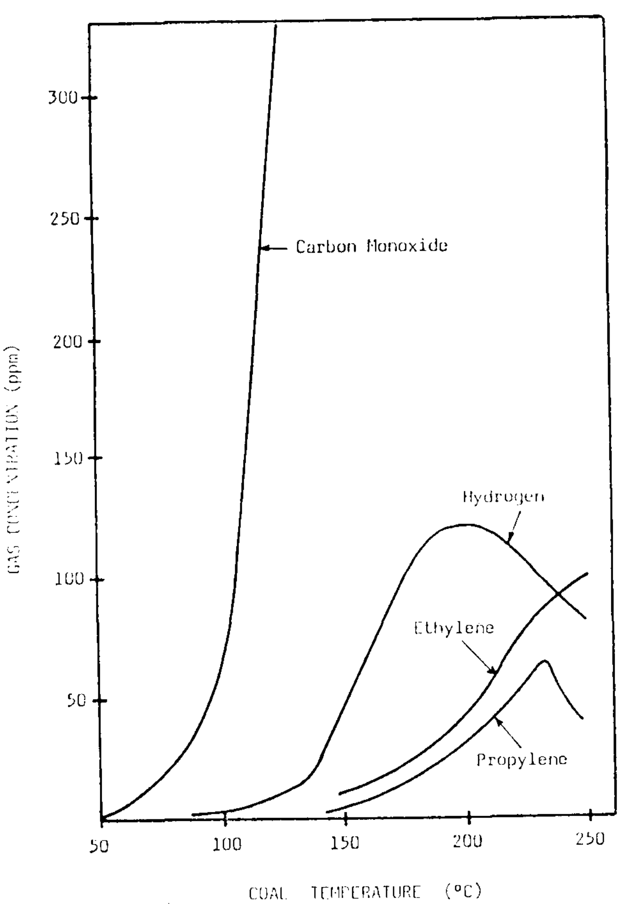


**Fig. 3—Gas concentration versus temperature during dynamic non-isothermal oxidation tests with paced heating**

In contrast to the situation on metal mines, where fires have to be detected as soon as possible after they start, the main emphasis in collieries is on the detection of heatings before they develop into fires. In order to do this, one has to take cognizance of the sequence in which gases are generated during the early stages of pre-combustion oxidation. Pioneering work in this regard was done by Chamberlain, Hall, and Thirlaway[2,8], who examined a whole range of British coals using the paced heating, dynamic non-isothermal method with air and nitrogen, and analysing the effluent gases in a train of equipment. They determined gas concentrations at various temperatures, using air and nitrogen alternately, and the difference in concentrations at any temperature was attributed to oxidation. The main indicator gases detected were carbon monoxide, hydrogen, ethylene, and propylene — in that order. In all cases, the concentration of carbon monoxide reached 100 p.p.m. before the next indicator gas (hydrogen) was detected, and, before the concentration of ethylene reached 10 p.p.m., the concentration of carbon monoxide was more than 1000 p.p.m. These results are illustrated graphically in Fig. 3.

As regards the use of carbon dioxide as an indicator gas for the early detection of spontaneous combustion, it was found that the concentration of this gas varied tremendously at temperatures below 200°C. Even where an attempt was made to use the ratio of carbon dioxide to total black damp (mixtures of carbon dioxide and nitrogen) as an indicator, the results varied to such an extent that the gas could not be used as an early detector of incipient heatings.

The conclusion that could, therefore, be drawn from these results is that carbon monoxide is the best indicator gas for the detection of spontaneous heatings in collieries. With the techniques of gas analysis now available to the mining industry, concentrations of carbon monoxide can be measured very accurately, and any increase in concentration above the norm for a particular mine would give a clear indication of an incipient heating at least 40 to 50°C earlier than any other gas.

The author can testify to the suitability of carbon monoxide as an indicator gas with some practical experience at Springfield Collieries, where a number of heatings was detected on the strength of an increase of 1 p.p.m. in the level of carbon monoxide above the norm of the mine[6,9]. In fact, in two instances the heatings were detected at such an early stage with the Unor infrared detection system that the exact location of the heatings could not be pinpointed, and a few days had to be allowed for the heatings to develop further and generate more carbon monoxide. Only then could personnel using hand-held instruments determine the exact locations of the heatings.

## EARLY-DETECTION SYSTEMS IN SOUTH AFRICA

Many mines use a combination of the methods described below as part of their procedure for the detection of fires and heatings.

### Fire Patrols

Despite the advanced state of the art of instrumental fire detection, fire patrols still remain the most widely used method of fire detection in South African collieries, especially in areas traditionally free of fires, e.g., the Witbank area. Where fire patrols are the sole means of fire detection, there is a large financial and safety risk since fires are mostly detected at a fairly advanced stage of development.

When fire patrols are used, the following basic factors are of importance.

*Fire-patrol Points*

Fire-patrol points must be located so that any fire that develops can be located with the minimum delay.

*Fire-patrol Systems*

It is absolutely essential that the system should ensure that all the fire-patrol points are visited every day. The system must be inexpensive, simple, and reliable. The fire-token exchange system and the watchman's clock are currently the most popular systems employed[10].

*Selection of Personnel*

Ideally, fire-patrol personnel should be non-smokers selected from reliable, sober men who hold valid first-aid certificates. They should be physically fit, and should have a good sense of smell, not be colour blind, and have a reasonable standard of literacy. It is also essential that they should have wide mining experience and an intimate knowledge of the mine itself.

*Training of Personnel*

It is essential that fire-patrol members should be adequately trained for their task and that they should be given frequent refresher courses.

*Control of Fire Patrols*

If fire patrols are to be successful, strict managerial control should be exercised over them.

*Use of Instruments*

The effectiveness of fire patrols can be enhanced by the use of hand-held instruments to test for carbon monoxide, rather than relying solely on the senses.

### Systematic Gas Sampling

An incipient fire can be detected by regular gas sampling at selected points underground. These samples can then be taken to the surface for analysis at laboratories with the required facilities, e.g., Chamber of Mines Dust and Ventilation Laboratories, Sasol.

Such a system would not normally be used on a routine basis owing to the cost, manpower, and time-lag involved, but would be used only in instances where other methods had given indications of trouble or when major changes had been made to ventilation systems that might cause heatings to develop (e.g., the changing of return airways to intake airways, and *vice versa*).

Of immense use to the coal-mining industry is the MOGAL, which was purchased in 1978 by the Chamber of Mines of South Africa from the Fuel Research Institute (F.R.I.). In 1976 the F.R.I. had built gas-analysis instruments into an industrial caravan to form the first Mobile Gas Analysis Laboratory[11] (MOGAL) specifically designed to suit the gas-analysis needs of the coal-mining industry. This MOGAL was first used on a colliery fire at Springfield Collieries in May 1977. During that fire, the MOGAL, which analysed 92 samples over a period of 9 days, proved to be an unqualified success[9]. Subsequent fires have confirmed this contention.

Two similar units were subsequently built for the Chamber, and the three units are now located at the Chamber of Mines Dust and Ventilation Laboratories at Witbank, Vereeniging, and Dundee. Any coal mine in South Africa can make use of these gas-analysis facilities free of charge[12].

These units are able to analyse any given sample in less than five minutes, and are capable of the following.

(*a*) The units are equipped to analyse the samples for oxygen, carbon monoxide, carbon dioxide, methane, and hydrogen. (Nitrogen is not measured directly, but is calculated as a residual value.)

(*b*) Each unit has a programmable electronic desk-top calculator programmed to calculate certain values automatically from the analytical data. These calculations include Graham's, Young's, and Willet's ratios.

(*c*) The programmable calculators also calculate all the figures required for the plotting of the position of the sample on the USBM Explosibility Diagram[13]. The values calculated are $R$ (limit line of explosibility triangle), $X$ (effective inerts), and $Y$ (effective combustibles).

It is clear that these units have already proved their worth, and they should play an inreasingly important role in the South African coal-mining industry, both for routine observations and during emergency situations.

### Continuous Instrumental Monitoring

Continuous instrumental monitoring of mine atmospheres in collieries for the detection of incipient heatings and fires has not had a very long history in South Africa, and is not yet very well entrenched in mining practice here despite the very notable successes achieved by mines that have been using such systems.

The first system of any significance for the South African coal-mining industry was installed at Springfield Collieries early in 1974. This system, an infrared carbon monoxide analyser employing the tube-bundle technique, was installed and tested on behalf of the Sub-Committee on the Problems Resulting from the Occurrence of Methane and Spontaneous Combustion of Coal, who recommended to the Explosion Hazards Advisory Committee of the Coal Mining Research Controlling Council in 1973 that such a system should be purchased and tested under South African conditions[14, 15]. The success achieved with this installation has been well documented[6, 9]. This experimental system was purchased by Springfield in 1977 and is still operating today.

Following the success of the first system, the Sub-

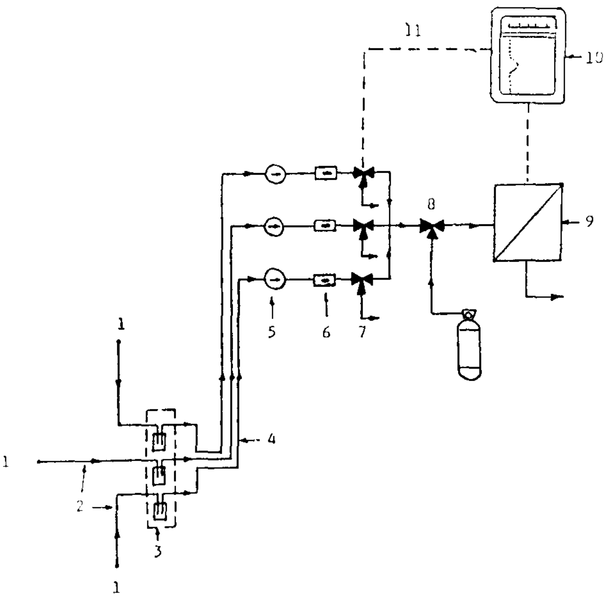

**Fig. 4—Layout of the tube-bundle system**

1. Sampling points underground
2. PVC tubing of 6 mm or 9 mm internal diameter
3. Bank of water traps at bottom of shaft
4. Tube-bundle in shaft
5. Diaphragm suction pumps
6. Flow meters
7. Three-way solenoid valves
8. Calibration valve
9. Infrared analyser
10. Continuous recorder (multipoint)
11. Signal line for synchronous control of solenoid valves

Committee decided in 1977 to purchase a telemetric system for similar investigations. A telemetric system was purchased and installed at Springfield in 1978, and it detected its first heating in August 1979. The testing of this system is continuing, but the Sub-Committee is also contemplating its sale to Springfield Collieries[15].

There are currently very encouraging indications that mine managers are beginning to appreciate the economic sense of continuous monitoring systems, and the author is aware of five collieries that have systems in operation or are in the process of installing monitoring systems. These are Springfield, Cornelia, Coalbrook, Arnot, and Kriel.

Continuous monitoring systems are of three types: tube-bundle systems, telemetric systems, and upcast-shaft monitors. The tube-bundle and telemetric systems are usually multi-point installations, while upcast-shaft monitors are generally single-point units.

*Tube-bundle Systems*

In this type of system, the infrared analyser is situated on surface, and the air to be analysed is drawn from the sampling points underground by means of diaphragm-type suction pumps via small-diameter PVC tubes (6 mm or 9 mm internal diameter). A number of these tubes are usually bundled together from shaft bottom to surface; hence the name *tube-bundle system.*

With reference to Fig. 4, this system operates as follows.

Samples of air are continually drawn from all the underground sampling points (1) through the individual tubes (2) and water traps (3) of the tube bundle (4) by the suction pumps (5), which are located on surface. Beyond the pumps the samples pass through contact flow meters (6) and then through three-way solenoid valves (7), each consisting of an incoming side, an outlet to the common line leading to the analyser (9), and an outlet to the atmosphere. This enables the analyser to analyse one sample at a time while all the other samples are passed through to the atmosphere. The synchronization of the sampling sequence for these valves is controlled by a signal from the recorder (10) via the signal line (11).

Once the sample has been analysed by the analyser, the output signal is amplified and transmitted to the recorder, where it is printed out. A three-way valve (8) for calibration purposes is incorporated in the line leading to the analyser.

The various pumps used to draw the air samples from underground vary considerably in pressure and flowrate, but generally the flowrates vary between 140 and 300 l/hr, while the maximum tube lengths that can be used usually vary from 2000 to 4000 m, depending on the pump specifications and tube diameter.

Owing to the low flowrates of the sample, there is a time lag in obtaining the results on surface. The time lag usually varies between 5 and 13 min/km for 6 mm tubing and between 12 and 28 min/km for 9 mm tubing in practice, and must be taken into account in the interpretation of the results.

*Telemetric Systems*

The telemetric system is identical to the tube-bundle system in principle, except that it has an analyser situated at every monitoring point underground and the output signal from each monitoring point is telemetered via a cable to a recorder on surface. Component parts of the system underground, such as the analyser, the filters, the pumps, are the same as for the tube-bundle system described above.

The whole system at each monitoring point is com-

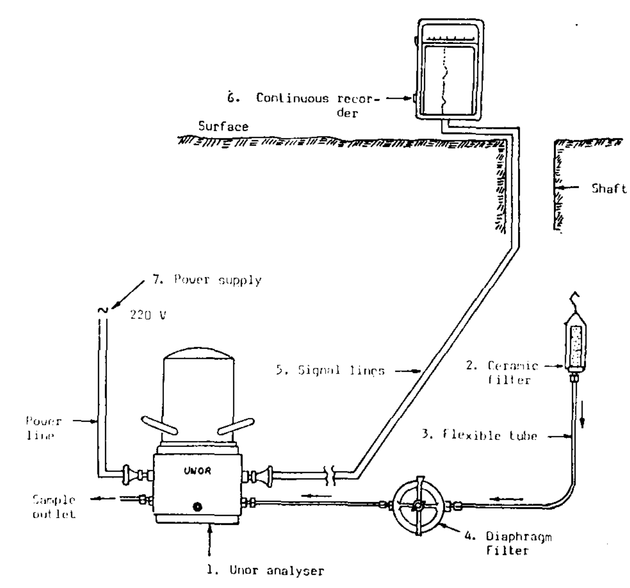


**Fig. 5—The telemetric system**

pactly designed and is housed in a flame-proof enclosure (if required). Fig. 5 shows the layout of this system. The operation of the system is briefly as follows.

The infrared gas analyser (1) can be situated anywhere near the point to be monitored. A ceramic filter (2) at the monitoring point is connected to the analyser pump with a sampling line (3) consisting of flexible PVC tubing of 6 or 9 mm diameter. A diaphragm filter (4) facilitates fine cleaning of the air samples.

After analysis, the output signal is transmitted via a signal cable (5) to a recorder (6) on surface. The power supply to the analyser can be tapped from any 220 V source (7) such as an underground lighting cable. The recording of the output signals from the various analysers can be done on one multipoint recorder or can be on a dedicated single-point recorder for each analyser.

*Upcast-shaft Monitors*

As the name indicates, this system usually consists of a single-point probe located in the fan drift to monitor the total upcast air in a shaft. This system, shown diagrammatically in Fig. 6, is relatively simple, and is similar in operation to the other two systems.

A sampling probe (1), fitted with a ceramic filter, condensate trap, and gas-sampling sleeve (for inspection of the ceramic filter), is installed through the side of the fan drift on surface. The air sample is drawn through this probe via the gas-sampling tube (2) and watertrap (3) by the suction pump (4). From the pump, the air enters the infrared gas analyser (6), where it is analysed and the output signal is printed on the record (7). The gas-sampling line is also fitted with a three-way valve (5) for calibration purposes.

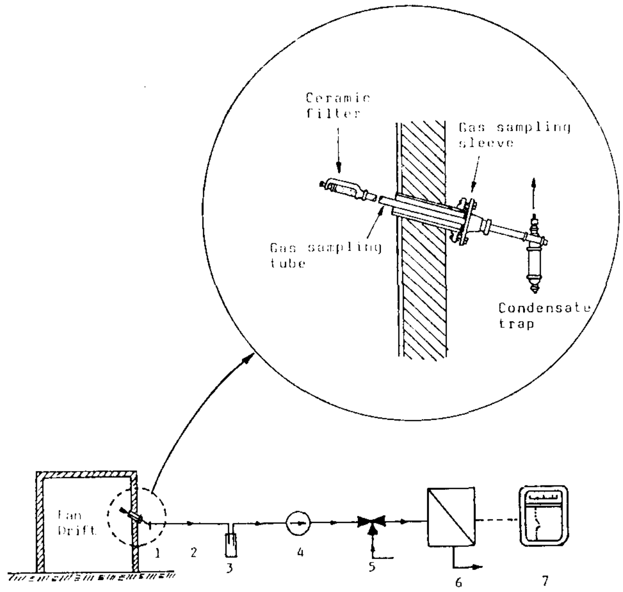


**Fig. 6—The upcast-shaft monitor**

1. **Gas sampling probe (see detail on inset)**
2. **Gas sampling tube**
3. **Water trap**
4. **Suction pump**
5. **Calibration valve**
6. **Infrared analyser**
7. **Recorder**

## Comparison Gas-sampling Systems

As a general proposition, the three systems should not be seen in competition with one another, but as systems each with its own field of application. For some installations, it may be difficult to choose between one or the other, and the choice would then become a matter of personal preference or marginal economics.

*Advantages of the Tube-bundle System*

(i) All the critical components (analyser, pump, solenoid valves, etc.) are located on surface and can be maintained very easily.
(ii) The capital outlay for multipoint installations is much smaller than that for the equivalent telemetric installation.
(iii) It can be used as a continuous sampling system for drawing samples during emergency situations at mine fires[16].
(iv) The number of monitoring points can easily be increased without significant additional costs (provided a large enough recorder was purchased originally).

*Disadvantages of the Tube-bundle System*

(1) Very long sampling lines can become maintenance-intensive, especially where such lines run along routes that are not normally used for travelling.
(2) The sample flow time, which can be as high as 28 min per kilometre of tube length, limits the acceptable tube length to a maximum of between 1 and 1,5 km.
(3) Condensation takes place in long tubes (especially at the bottom of the shaft), causing line blockages. This can be overcome to a large extent by the use of in-line water traps or coolers.
(4) The tubes are difficult to handle and install over long distances.

*Advantages of the Telemetric System*

(*a*) The response time is very short.
(*b*) The signal cables are easier to install than tubes.
(*c*) The signal lines are less prone to damage than tubes.
(*d*) The monitoring points can be located very far apart.

*Disadvantages of the Telemetric System*

(i) Maintenance of the units is very difficult because they are dispersed geographically and are located underground.
(ii) The capital outlay for the multipoint system is very high.
(iii) Power must be available close to the monitoring points.
(iv) The maintenance required by the system is increased with each monitoring point installed because each point has its own analyser, while the tube-bundle system employs only one analyser for up to 12 points.

*Advantages of the Upcast-shaft Monitor*

(1) The system is relatively cheap in terms of capital outlay.
(2) Maintenance to the system is easy and minimal.
(3) The response is instantaneous. (However, the time taken for the air to move from the fire area to the top of the upcast shaft should technically be regarded as the response-time lag.)

*Disadvantages of the Upcast-shaft Monitor*

(*a*) The dilution of combustion gases by fresh air may make incipient heatings difficult to detect during the early stages of spontaneous combustion. In practice, it is felt that shafts handling more air than about 70 to 90 $m^3/s$ should not be regarded as suitable for upcast-shaft monitoring.

(*b*) As there is only one monitor point, the location of any incipient heating cannot be narrowed down to a specific area or district without underground inspection.

### Choice of Gas-sampling System

From the advantages and disadvantages given, the following general conclusions can be drawn as guidelines.

(i) Where a large number of monitoring points are located close together (e.g., a number of R.A.W.'s leading to an up-cast shaft), the tube-bundle system would probably be most suitable and most economic.

(ii) Where monitoring points are located far apart, or where very long distances have to be traversed to reach the point where the output is required, the telemetric system would probably be most suitable.

(iii) Where there is no history of spontaneous heating (or small likelihood of spontaneous heating), or where there is a shaft system that serves relatively small mining areas with low ventilation requirements, the use of only upcast-shaft monitors at each upcast shaft could be considered.

### Location of Heatings

Once a heating has been detected by an early-detection system, the problem is not yet solved since the heating has still to be located in the underground workings.

With multipoint systems, the strategic placing of monitoring points could assist in the location of the area. However, no matter how sophisticated the system is, the heating can be located only by a reconnaissance team using hand-held instruments and starting from the monitoring point that detected the heating.

During such a reconnaissance, the team normally uses length-of-stain detector tubes (e.g., the Draeger) to follow the gas traces to their origin. However, with the accuracy of modern-day early-detection systems (better than 1 p.p.m.), heatings are sometimes detected before sufficient carbon monoxide has been generated to stain the detector tubes and, as a result, the heatings cannot be located immediately. Very often such heatings have to be left for a few days until more carbon monoxide has been generated.

In an attempt to overcome this problem, the Sub-Committee on the Problems Resulting from the Occurrence of Methane and Spontaneous Combustion of Coal is currently considering the purchase of an infrared viewer[17] for testing under operational conditions to locate the seat of heatings in underground workings. Infrared viewers are able to reveal temperature differences between adjacent objects and between objects and their background, and it is hoped that the scanning of coal heaps and walls in underground workings with the instrument will reveal 'hot spots' resulting from the spontaneous heating of coal.

## ECONOMIC CONSIDERATIONS

The costs involved in typical installations (June 1980 costs) are given below.

*Tube-bundle system* (*six-point*)

| | | |
|---|---|---|
| 1 | Infrared analyser | R 7 000 |
| 1 | Multipoint recorder | 3 000 |
| 6 | Solenoid valves | 360 |
| 6 | Flow meters | 300 |
| 6 | Pumps | 1 200 |
| 6 | Water traps | 840 |
| | Tubing (average length per point = 500 m) | 3 900 |
| | Miscellaneous | 400 |
| | TOTAL | R17 000 |

*Telemetric system* (*six-point*)

| | | |
|---|---|---|
| 6 | Infrared analysers (non-flameproof)* | R42 000 |
| 1 | Multipoint recorder (no. synchro.) | 2 000 |
| 6 | Water traps (optional, if required) | 840 |
| | Signal cable (average length per point = 1500 m) | 9 000 |
| | TOTAL | R53 840 |

*If flameproof analysers are used, the cost will increase by R4500 per analyser.

*Upcast-shaft monitor* (*single-point*)

| | | |
|---|---|---|
| 1 | Infrared Analyser | R 7 000 |
| 1 | Single-point recorder | 800 |
| | Sampling accessories | 1 000 |
| | TOTAL | R 8 000 |

Although the costs of these systems may seem excessively high at first glance, they must be weighed against the potential benefits. Examples can be quoted of major colliery fires in recent years in which the direct fire-fighting costs have amounted to between R250 000 and R500 000, and it is clear that the early detection of only one such potential fire would justify the expenditure incurred in the installation of such a system.

## CONCLUSION

Despite the rapid advances in modern mining technology in recent years, early-detection systems for the detection of fires and heatings in collieries have not yet attained their rightful place in the South African coal-mining industry.

The author is convinced that expenditure on this type of equipment could, in the longer term, result in major savings to the industry as a whole. Colliery fires are dangerous and costly in terms of wasted manpower, wasted materials, and lost production, and the industry should counter these wasteful incidents as effectively as possible with the aid of modern technology.

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# Hydrometallurgy

The Third International Symposium on Hydrometallurgy is to be held in Atlanta, U.S.A., from 6th to 10th March, 1983, as the 112th AIME Annual Meeting.

Since the last AIME symposium on hydrometallurgy in 1973, there have been numerous advances in both the fundamental and practical aspects. Among the major advances are the development of new solvent-extraction reagents and the increasing role of solvent extraction in solution purification and concentration on a commercial basis; the development of commercially continuous ion exchange; the growth of chloride hydrometallurgy, both in leaching and electrowinning; the appearance of novel electrodes, such as the fluidized-bed electrode; improvements in electrode materials; the discovery of new chemistries, such as the cuprous acetonitrile/sulphate system; the commercialization of *in situ* leaching; application of hydrometallurgical techniques to metal recovery from low-grade oxide ores, such as laterites and ocean nodules; uranium recovery from wet phosphoric acid; application of pressure leaching to zinc sulphide concentrates on a commercial scale; metal recovery from solid and aqueous effluents; and the growing interest in energy management.

In the case of basic studies, increasing attention has been paid to the thermodynamics of aqueous solutions; phase equilibria; rate mechanisms and reaction modelling; the role of electrochemical processes; applications of scanning electron microscopy; mineralogy and reactivity; modelling, design, and control of continuous unit operations. The Symposium seeks to present a critical review of these advances and to provide a forum for cross-fertilization and technology transfer across unit processes and operations.

Authors are invited to submit extended abstracts (minimum 600 words plus figures), which will be refereed for selection. Papers obtained by this avenue will be supplemented by invited papers and by keynote lectures by distinguished hydrometallurgists. The proceedings of the Symposium will be published for distribution at the meeting. The following deadlines must be noted:

December 1, 1981 — deadline for extended abstracts
February 1, 1982 — authors of accepted papers notified
June 1, 1982 — deadline for receipt of camera-ready manuscripts

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