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Mining Through H_2S Seam Gas Zones in Underground Coal Mines

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ABSTRACT

Hydrogen Sulphide (H_2S) has been encountered in several collieries in the Bowen Basin coal reserves located in Central Queensland, Australia. Significant occurrences have been found in the underground workings at Collinsville No 2 Mine, Oaky Creek No 1 Mine and Southern Colliery. Longwall panels at Oaky Creek and Southern Colliery have recently mined through H_2S zones, and mining will intersect more H_2S zones in the next few years. The release of up to 40 litres of H_2S per tonne of coal mined was predicted from the Southern Colliery panel and mining produced levels of up to 200ppm of H_2S in the return roadway from the longwall. This paper details the experiences associated with mining through these H_2S zones and the methods used to detect and predict its existence. It outlines safe working procedures and monitoring approaches undertaken. The paper provides an overview of research directions pertinent to the reduction and control of H_2S in coal.

RÉSUMÉ

On trouve du sulfure d'hydrogène (H_2S) dans de nombreuses mines de houille du bassin Bowen du Centre Queensland, Australie. En particulier, des quantités importantes ont été rencontrées dans des mines souterraines, plus précisément à la mine No 2 de Collinsville, la mine No 1 de Oaky Creek et la mine Southern. Les panneaux de long mur à Oaky Creek ainsi qu'à la mine Southern ont récemment progressé à travers des zones à H_2S, et de plus en plus de zones à H_2S seront exploitées dans les prochaines années. Il était prédit que la quantité de H_2S attendrait jusqu'à 40 litres de H_2S par tonne de charbon extraite en provenance du panneau de la mine Southern et que l'exploitation de la mine produirait jusqu'à 200ppm de H_2S sur la voie de retour du long mur. Cet article rend compte des expériences associées avec l'exploitation de ces zones à H_2S et des méthodes employées pour en détecter et prédire l'existence. Il est fait mention des procédures se rattachant à la sécurité du travail et des approches utilisées pour la detection. L'article fait le point sur les directions de la recherche liée à la réduction et au control du H_2S dans le charbon.

INTRODUCTION

The occurrence of significant quantities of hydrogen sulphide (H_2S) in coal seam gases is rare around the world. H_2S has been recorded as occurring in coal seams in North America, Russia, China, France and Australia. In Australia significant occurrences have been found in the underground workings at Collinsville No 2 Mine, Oaky Creek No 1 Mine and Southern Colliery (See figure 1). The Southern and Oaky Creek collieries are underground longwall operations, mining the German Creek seam, the lower major economic seam of the Bowen Basin's Permian German Creek formation.

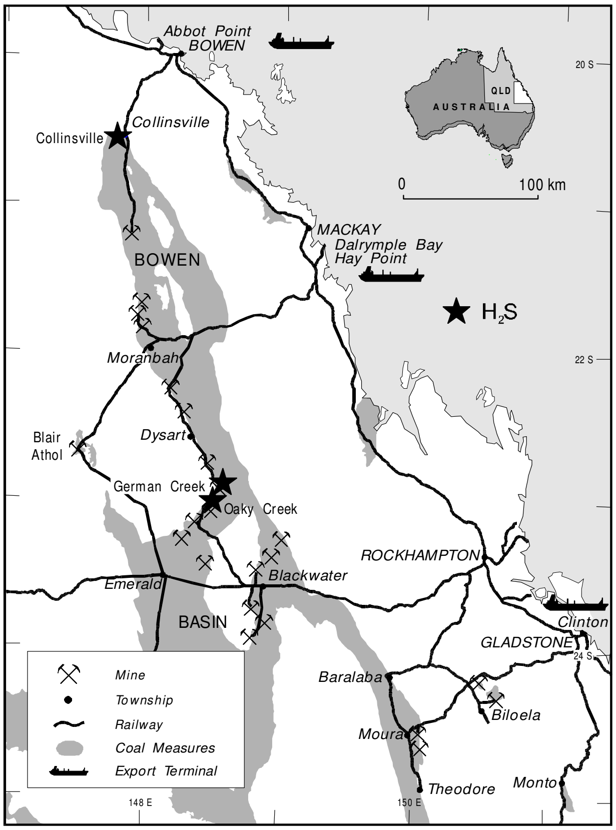

Figure 1. Locality Map

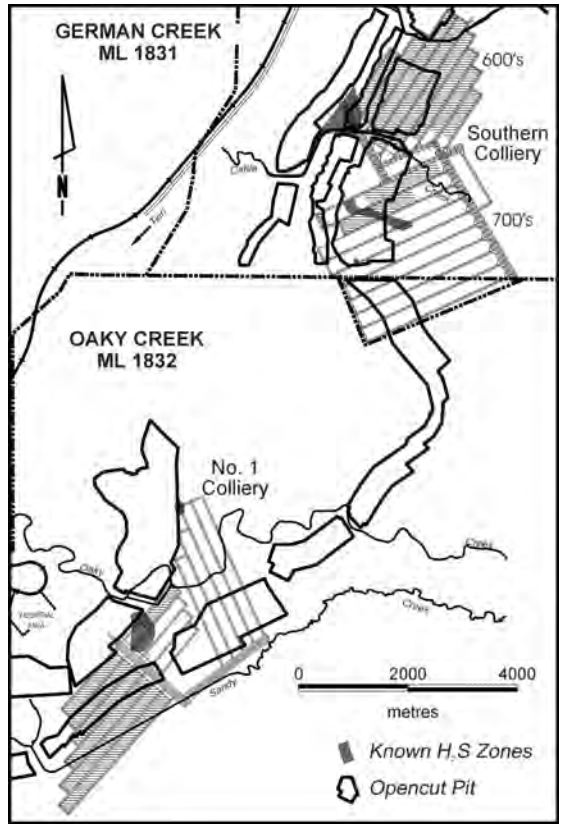

Figure 2. H_2S Zones in Oaky Creek and German Creek Collieries

At Southern Colliery H_2S gas was encountered for the first 800m of mains development (1988) and during the development and extraction of the first longwall block, 601 (Phillips et al 1990) (See Figure 2). Significant H_2S was not found again until the development of the gate roads for the 701 longwall block in January 1995 (Ko Ko and Ward 1996). The H_2S zone was not mined in 701 longwall panel as poor roof and weak floor conditions required the longwall face to be relocated outbye of the H_2S zone. In June 1996, H_2S was encountered again during development of the 702 panel maingate. Development, drilling and testing has delineated a continuous H_2S zone through at least four longwall panels (701 to 704). At Oaky Creek No 1 Colliery a zone of H_2S seam gas was intersected in longwall 8 block (See figure 2.). This zone was mined between October and December 1996. Other minor occurrences of H_2S have been found in the Bowen Basin at Newlands, Crinum, Gregory and Gordonstone mines.

GENERAL INFORMATION ON H_2S

Properties of H_2S

H_2S, which is also known as sulphuretted hydrogen or rotten egg gas has no colour but a powerful and unpleasant odour. It is liquid at high pressure and low temperature. It has a specific gravity of 1.19, and burns in air with a bright blue flame producing sulphur dioxide and water vapour. The human nose can detect concentrations as low as

0.02ppm, however increasing exposure desensitises the olfactory organ and concentration levels above 50ppm can no longer be smelt.

The residence time of H_2S in the atmosphere is fairly short as it breaks down readily. H_2S forms flammable mixtures in air in the range of 4.5 - 45%. It is highly reactive and corrosive to all organic and metallic compounds. For example, the corrosion rate of H_2S to carbon steel can be as high as 2.5 mm/yr (Grayson and Eckroth 1983). H_2S is soluble in alkanolamines, which are used as scrubbing solvents for removal of H_2S from gas streams. It is also soluble in water at the rate of 4 kg/m^3 at 20 °C - 2.9 vol. gas/vol. H_2O at 20 °C.

Occurrence of H_2S

H_2S has been found in deposits of rock salt, sulphur, gypsum, lead, petroleum and natural gas. It is also present in the gases from many volcanoes, sulphur springs, undersea vents, swamps and stagnant bodies of water. Bacterial reduction of sulphates and bacterial decomposition of proteins form H_2S (Grayson and Eckroth 1983). Large quantities of H_2S occur in natural gas deposits of France and Canada. The occurrence of fossil H_2S gas in coal measure strata has been noted in France, Canada, China, Russia and Australia (Ko Ko and Ward 1996).

In a study by Smith and Philips (1990) on the sulphur isotope ratio $^{34}S/^{32}S$, the source of the H_2S is biological reduction of sulphate supplied from a marine transgression which was generated in a low iron environment and was not converted to pyrite. This allowed large quantities of H_2S to react with organic matter and to be trapped within the coal seam during the maturation. Moelle (1987) (cited Phillips et al, 1990) suggests that the occurrence of H_2S in Europe was associated with sapropelic muds containing the remains of the Carboniferous plant families Neuropteris, Lonchopteris and Sphenopteris of Carboniferous age. Resent research into the sources of H_2S in coal at Oaky Creek and Southern Collieries has given more weight to an organic rather than an inorganic source (Golding et al, 1998).

Physiological Effects of H_2S

H_2S is an extremely toxic gas and can cause death at exposures above 500ppm. It irritates the lungs and respiratory tract and has a narcotic effect on the central nervous system (Strang and Mackenzie-Wood 1990). H_2S in sufficiently high concentrations will dull the sense of smell, preventing an unwary worker from detecting its presence. The reaction of H_2S with fluids in the nose and lungs forms sulphuric acid. The toxicity of H_2S is due to the H_2S molecule itself rather than to Hydrosulphide or sulphur ions (Elvers et al, 1989).

Much toxicological data has been published on animals exposed to massive dosages of H_2S. These data confirm observations made on humans though information on chronic or long-term effects remains limited. The acute toxicity of H_2S is comparable in animals and humans. Despite numerous detailed examinations of rabbits, rats and mice that inhaled daily doses of H_2S at concentrations in air up to 80 ppm over three to five months, no specific chronic effects have been reported (Toxigenics, Inc., 1983). The effect of H_2S on a person's health can be extreme, depending on the concentration to which they are exposed. The duration of exposure, while still important, is of secondary interest as indicated in Figure 3.

Threshold Limits of H_2S

The maximum allowable concentration of H_2S in the mine atmosphere permitted by the Queensland Coal Mining Act General Rules for Underground Coal Mines is 10 ppm (0.001%). This applies to any airway that workers may enter, including belt roads and returns. An exemption may be granted from the Chief Inspector upon receiving written application. The Australian Standard for exposure to H_2S are 10 ppm (TWA-8 hours) or 15 ppm (STEL-15 min.). The United States US Department of Labor, Occupational Safety and Health Administration's acceptable ceiling concentration is 20 ppm for 10 minutes once only if no other measurable exposure occurs. The acceptable maximum peak concentration above the acceptable ceiling concentration for an 8-hr shift is 50 ppm.

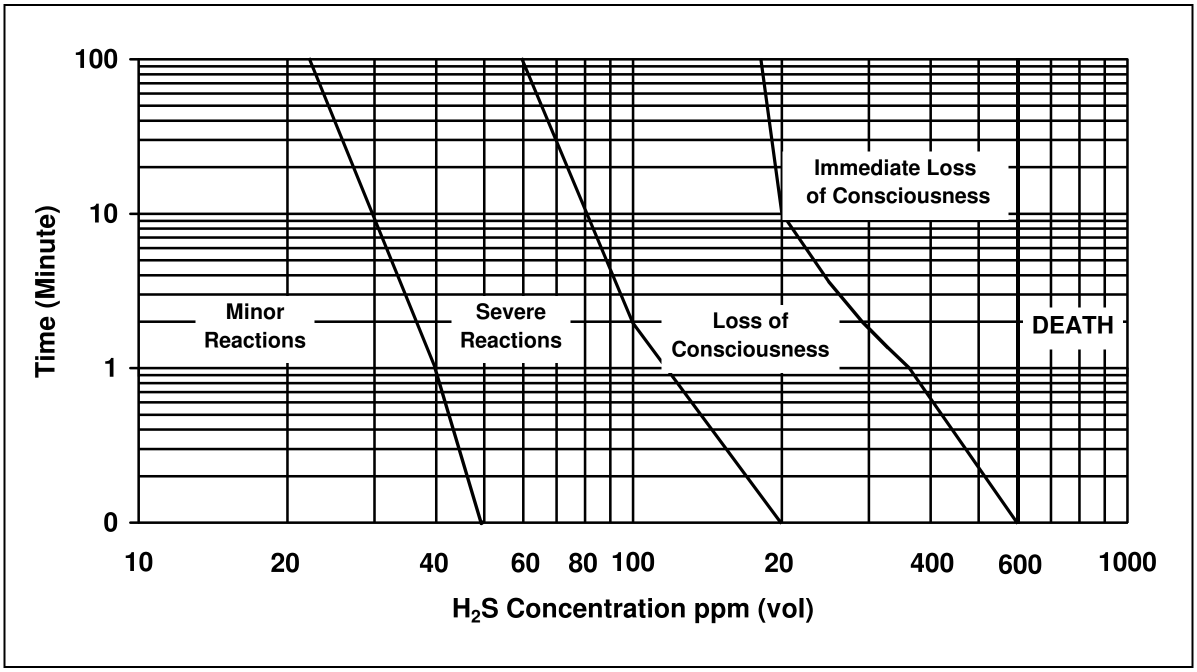

Figure 3. Effects of H_2S as a Function of Concentration and Exposure Time

AUSTRALIAN COAL ASSOCIATION RESEARCH PROGRAM (ACARP) PROJECT

A research project, *"Maximising Coal Production in the Presence of H_2S Seam Gas"* jointly funded by ACARP, Oaky Creek and Southern Collieries is being undertaken to investigate:

- Occurrence of H_2S
- Prediction of H_2S release
- Storage Mechanisms
- Mine ventilation system and control measurements
- Mining options
- Permeability
- In seam chemical neutralisation.

The project is being staffed by a research team from the University of Queensland, Departments of Mining, Minerals and Materials Engineering, Earth Sciences and Chemistry (Gillies et al 1997).

MEASUREMENT, MONITORING AND PREDICTION OF H_2S ZONES

The predicting of H_2S content ahead of mining has been improved by the development of testing and sampling procedures and the correlation of test results with the actual release of H_2S measured during mining.

Sampling

Obtaining representative samples from coal containing H_2S is complex. H_2S is a difficult gas to contain as it is highly reactive and is able to permeate through container walls. The desorption rates of H_2S varies with the mineralogy of coal, with gas desorbing more rapidly from inertinite than vitrinite (Golding et al, 1998). For longer-term storage of samples Teflon containers were used and for gas content tests samples were sealed in plastic bags and tested within hours of collection. Samples are either collected from ribs or face soon after mining or from core from in-seam horizontal drilling or vertical surface drilling, prior to mining. The results from sampling can then be contoured to estimate the extent of H_2S zone.

Testing

A drum tumbler system was developed to determine the H_2S content of coal at Southern Colliery (Phillips et al 1990). A modified design with the ability to constantly sample gas during coal breakage was developed by O&B Scientific (see Figure 4). The system rotates a 255 litre drum constructed from High Density Polyethylene (HDPE) end to end about a central stainless steel shaft. The drum tumbles a weighed sample at 20 rpm for 60 revs. The period of rotation is selected to produce coal breakage representative of the size of coal on the armoured face conveyor (AFC). The sample is sized after testing. The test is used to determine the volume of H_2S released into the atmosphere from a given sample under controlled conditions.

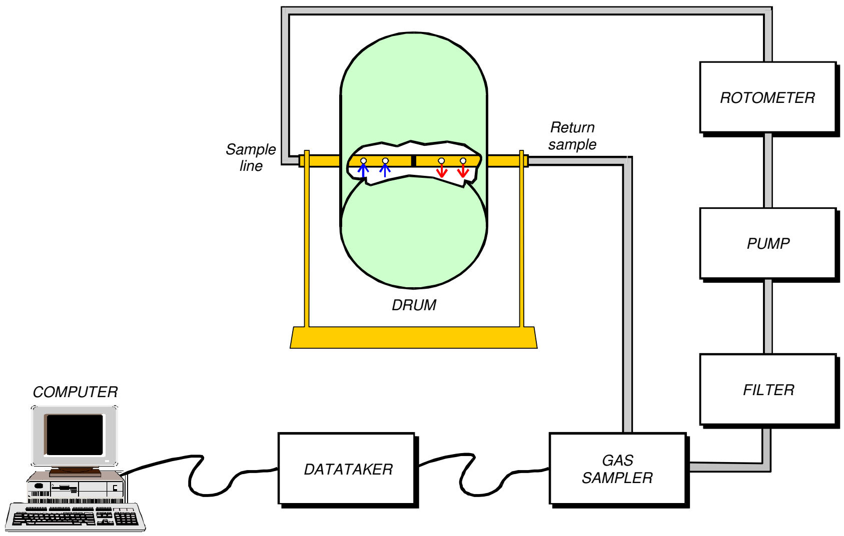

Figure 4. Drum Tumbler System

H_2S Detection And Monitoring

To protect against overexposure to H_2S continuous monitoring instruments are installed on face and in outbye areas. These instruments are based on the diffusion characteristics of toxic gases and usually incorporate an electrochemical detector, which generates an electric current, as the toxic gas passes over it. This current is converted into an audible and/or visual display signal. These sensors are used to continuously monitor H_2S gas concentration levels in face areas and outbye ventilation circuits. Portable sensors, set to alarm at 10ppm and to record TWA and STEL levels, are carried by mine officials and were provided to operators when mining in H_2S zones.

Prediction of H_2S zones

The prediction of in-situ coal H_2S gas liberation levels which will be released in the mining sequence during cutting, breakage and transport can be achieved by comparing the indicated and actual amount of H_2S released. The indicated H_2S released is determined from face and rib samples gathered during mining operations and tested using the drum tumbler. The actual release is determined by logging coal production, measuring ventilation quantities at regular intervals, and monitoring the H_2S levels in the return at 5-second intervals. The correlation between the results of indicated and actual H_2S released has varied. At Oaky Creek the correlation was reasonable while at Southern Colliery good correlation was achieved. This difference is thought to be mainly due to faster desorption of H_2S from Oaky Creek coal affecting the reliability of the test results.

Release of H_2S

A study was undertaken to determine where H_2S was released during mining. Data was collected from a series of H_2S monitors placed along the face and in the longwall conveyor roadway. This data together with shearer position information enabled a quantitative estimate to be made of H_2S release. Table 1 shows the proportion of H_2S released from each source.

TABLE 1. Sources of H_2S During Mining

Source	Range
Shearer	50% to 70%
Armoured Face Conveyor (depends on location of H_2S zone along face)	5% to 10%
Maingate corner	10% to 15%
Desorbed from face	5% to 10%
Crusher, Beam Stage Loader and longwall conveyor	10% to 20%

Attempts were made to determine the total H_2S content of coal using the silver nitrate test (Phillips et al 1990) and extended to drum tumbler tests. The results were far from conclusive due to desorption of H_2S from coal and the range of instruments used. However they did show that the total H_2S content of coal could be greater than 500 litres per tonne. This means that only between 2% and 10% of total H_2S is released during mining.

CONTROLLING H_2S EMISSION

Mine Ventilation Design

The existence of H_2S gas in a coal seam poses operational and health and safety problems. The mine ventilation system can be changed to maximise safe production through the affected zones. For a longwall face the best ventilation option would be to use a full homotropal system (ie ventilation in direction of coal flow on face and in longwall conveyor road) and keep all operators on the intake side of the shearer. However undercurrent Queensland legislation this is not allowed. An alternative system with antitropal ventilation on the face and homotropal ventilation in conveyor road was used with reasonable success. The H_2S emissions were controlled by increasing ventilation quantity and varying cutting rate (See Figure 5). For development sections an exhausting duct system was used for face ventilation with homotropal ventilation in conveyor roads. This in conjunction with personal monitors and remote operation of continuous miner enables operator exposure to H_2S to be controlled.

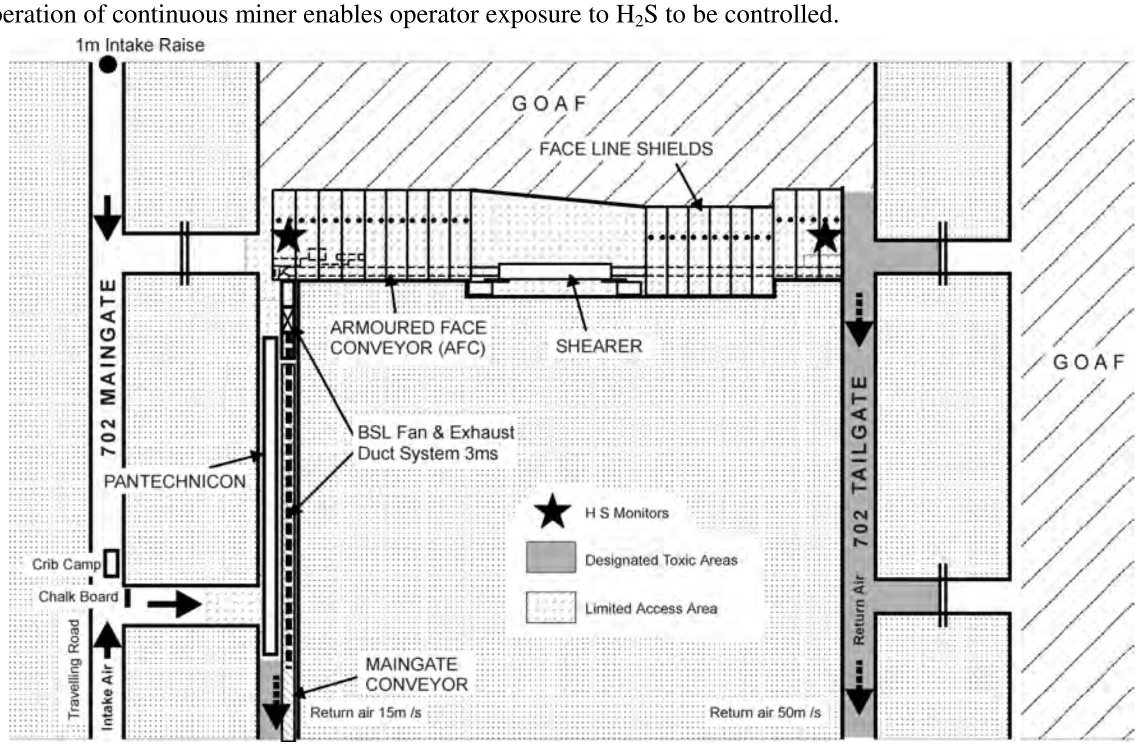

Figure 5. Face Monitor and Ventilation System

Mining Options to Reduce H_2S Emission

The reduction the H_2S emissions during mining can be achieved by cutting coal at a slower rate and by reducing the amount of fines produced. At Southern Colliery operators quickly learned that they could control the emission level on their personal H_2S monitors by varying the cutting rate. This combined with feed back on the H_2S released on previous shift contributed to the production rates achieved in the H_2S zone.

The size analysis of coal samples after drum tumbling and face samples together with H_2S release data have shown that the H_2S release is proportional to the surface area of broken coal. Although research into reducing the fines during cutting is being considered the incremental result is thought to be less than reducing H_2S content of coal by chemical infusion prior to mining.

Spray Chemical Neutralisation of the Gas

In order to determine the effects of sprays on reducing H_2S levels in atmosphere a test rig was set up by the CSIRO. The aim was to simulate a H_2S contaminated mine roadway and to test the effects of water, different chemicals, varying pH, varying flow rates and varying spray droplet size (see Figure 6). Three series of tests were undertaken and produced positive results. The best giving a 91 percent reduction in H_2S levels. The initial test used sodium hydroxide to control pH and sodium hypochlorite to oxidise H_2S. This test proved effective, however the pH of the solution at 12.4 was unacceptable for the mining environment. Varying spray droplet size between 50 and 150 micron produced little difference in the effective removal of H_2S. Later tests replaced sodium hydroxide with a buffer solution to keep the pH below 10 and these produced acceptable results. However tests without hypochlorite using buffer only reduced the effectiveness of H_2S removal to less than 50 percent.

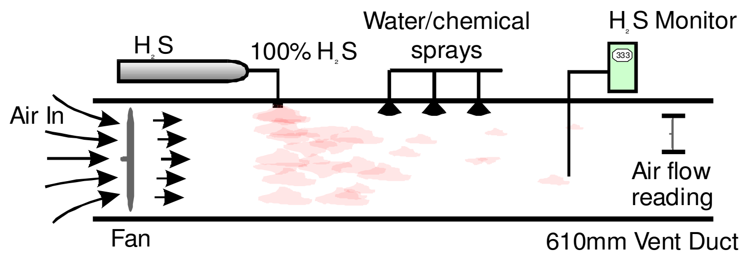

Figure 6. Set up for H_2S Spray Tests

In-Seam Chemical Neutralisation

Except for one study in China, there is no published research on suppressing H_2S gas in coal. In Wuda Coal Mining Area in China two years of underground testing and 3 years of laboratory experiments carried out in the late 1980's revealed that H_2S gas emissions can be reduced between 50 to 70 percent by forced injection of chemical absorbent into the coal seam and 77 percent reduction can be achieved by chemical spray at the workface (Peng et al, 1992).

An infusion experiment was carried out in the H_2S zone in 702 Longwall at Southern Colliery (see Figure 7). This tested the effectiveness of using water and buffer solution in removing H_2S from the coal seam and measured hydraulic properties of the seam. The results of the buffer solution test were encouraging and a larger scale infusion test is planned for the H_2S zone in 703 longwall panel.

Corrosion Protection

H_2S is highly reactive and corrosive to all organic and metallic compounds. This is particularly true of Copper. H_2S caused significant damage to the Copper-Tin alloy coating on chock legs at Southern and Oaky Creek collieries. Field and laboratory tests undertaken by consultants (ETRS, 1997) have shown that the coating is attacked by H_2S leaving an outer coating of copper sulphide underlain by layers of tin oxide and Tin. This coating, when mixed with coal dust, forms a rough crust on chock legs. Damage to chock leg seals can be attributed to this crust. To reduce the corrosion potential, the chock legs on 702 longwall were coated with soluble oil and wrapped in plastic. This method worked well provided the wrapping remained intact. During the mining of H_2S zone in 702-panel, test coupons of copper were placed in electrical boxes in face and outbye areas. No H_2S damage was recorded to coupons in flameproof enclosures on the face but minor damage was notice to one coupon in a non-flameproof outbye belt starter.

MANAGEMENT PLAN AND WORKING PROCEDURES

The development of management plans and safe working procedures for mining in H_2S zones have evolved from initial HAZOPS and the operating experience at both mines

Management Plan

The primary aims of the management plans are to preserve the health and safety of those working in areas affected by H_2S. In order to achieve this, the plans were designed to:

- Prevent any persons from being exposed to concentrations of H_2S above 10 ppm in the general body of air;
- prevent the maximum concentration of H_2S anywhere in the mine from exceeding 200 ppm,
- protect mining equipment from H_2S corrosion, and
- maintain adequate production.

Working Procedures

The rate of cutting coal was used to control the release of H_2S. When H_2S levels approached 10 ppm the shearer haulage was stopped to reduce H_2S emissions. Some of the procedures that were put in place to limit access to the face and reduce risk and exposure to H_2S were:

- All people on the face were to be located on the intake side of the shearer when the shearer was cutting,
- all people inbye of the last accessible cut-through on the intake roadway were required to carry a face mask at all times,
- face masks were worn by all persons on the face line when the armoured face conveyor was conveying coal and/or the shearer was cutting coal, and
- personal H_2S monitors were carried by the deputy, the chock operator and the shearer operator.

Several alarms, both visual and audible were situated in the face area to warn when H_2S was approaching pre-determined levels. These alarms were set at the following levels:

- The H_2S monitor on the maingate drive was set to give a visible alarm at 10 ppm,
- the power to shearer was cut off if the tailgate H_2S monitor recorded a level of 200 ppm, and
- coal cutting was stopped if the monitor in the homotropal conveyor road reached 100 ppm.

Protective Equipment

At both mines the personal protective equipment used consisted of full face masks fitted with a particle filter Class P3 and a Gas filter Class B2E2 which offers the highest level of protection for an apparatus of this type. A full-face mask fitted with this protection is approved for use in 100 times the TLV level or 5000ppm, which ever is the lowest.

OAKY NO. 1 MINE H_2S MINING EXPERIENCE

H_2S was encountered during the gateroad development for Longwall 8. The location of the zone was mapped from recorded values on Deputy's reports. Later nine boreholes were drilled from the surface to provide core to determine H_2S content. The results of this analysis proved unreliable. This is now known to be due to the high desorption rate of H_2S from coal and the time delay between sampling and testing.

The greatest difficulty during mining through the H_2S was experienced when the highest concentrations were experienced in the maingate. The immediate release of H_2S from the coal being cut by the shearer as well as that being released from the breakage of coal in the BSL and crusher meant it was very difficult to maintain the gas concentration below 10ppm. A short brattice wing was erected around the top of the crusher to attempt to segregate air passing over and through the crusher from air passing along the pillar rib.

It was clear to the operators and confirmed by sampling and testing that higher concentrations of H_2S were patchy. Zones along the face were high in H_2S for a number of metres and then reduced to low levels. The operators were able to run the shearer faster in areas where they knew no H_2S was present. Exposure to H_2S was extremely variable. For example, moving from the chocks towards the face could see an increase from 5ppm to 40ppm and two people standing 5 metres apart could see 3ppm and 20ppm.

Productivity in the highest concentration zone was reduced to about 30 percent of normal capacity with generally 2 to 3 shears achieved per eight-hour shift.

SOUTHERN COLLIERY EXPERIENCE

At Southern Colliery the workforce accepted the operating procedures, protective equipment and monitoring equipment. This was in no small part due to the previous experience of mining H_2S affected coal, the training given to the workforce and the daily feedback of exposure levels and face emissions. This feedback enabled longwall operators to gain confidence in their ability to control H_2S emissions. Overall productivity in the zone was reduced by about 20%.

Minor amounts of H_2S were recorded in outbye conveyor roadways but these were less than expected. A duct and hood arrangement was installed at the longwall conveyor transfer point as a precaution.

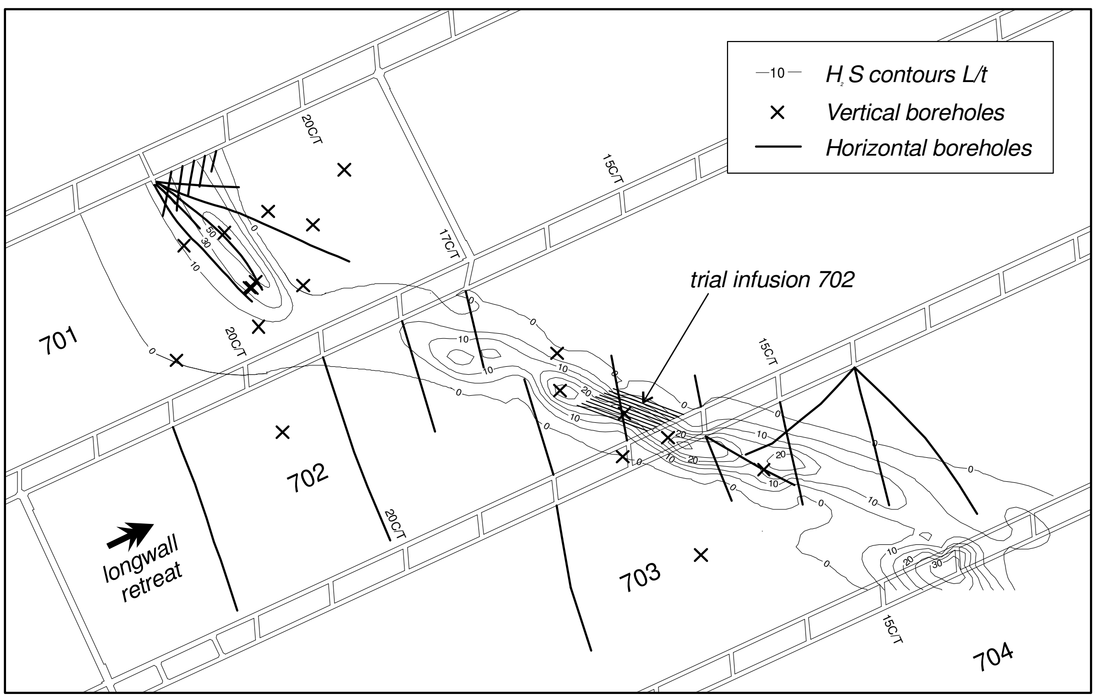

Figure 7. Predicted H_2S Zone and Drillhole Location Plan in 700 Panels

COMMENTS AND CONCLUSIONS

The detection of H_2S zones during exploration drilling has proven difficult due to the size and shape of zones. The ACARP research program includes a component to study indicators in coal that may improve detection. Drum tumbling of core or rib samples can give a good estimate of the H_2S released during mining. A reliable estimate requires the results to be correlated with actual release from mining in a H_2S zone in that seam and the samples must be tested on the same day that they are collected. The ACARP project is investigating the bonding between H_2S and coal and release mechanisms of H_2S from coal.

Infusion tests using parallel holes in seam and a buffer solution did reduce H_2S emissions. The extent of this reduction is still being evaluated and a more extensive infusion program is planned for next panel. Atmospheric control of H_2S levels by sprays has been shown to have the potential to greatly reduce H_2S levels, however the chemicals used are too corrosive for the face environment. A test using buffer solution to wet coal as it entered the longwall Beam Stage Loader (BSL) gave encouraging results and this concept is being evaluated for control of H_2S release for the next panel.

Extensive planning and appropriate training of operators in hazard management procedures contributed greatly to the success in mining through the H_2S zone. Previous experience and daily feedback enabled operators at Southern Colliery to build confidence in their ability to safely mine H_2S affected coal with a productive penalty of no more than 20%. The use of homotropal ventilation of longwall conveyor and an exhausting fan duct system on BSL proved successful. The use of an electric fan and smaller duct system to replace the venturi fans is being investigated for the next panel.

ACKNOWLEDGEMENTS

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