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Is minewater a source of hazardous gas?

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Abstract: Most coal and coal-bearing strata contain significant quantities of gases. These gases are either potentially explosive in critical concentrations when mixed with air, while others are toxic to life forms. Gases found in coal mines are a mixture of atmospheric air, inert gases, water vapour and one or more of the following: oxygen, carbon dioxide, carbon monoxide, methane, hydrogen sulphide, hydrogen and nitrous oxides.

Gases such as "firedamp"(chiefly methane) and "blackdamp" (carbon dioxide and nitrogen) may accumulate in old workings that are not adequately ventilated. Any noxious or explosive gases present in abandoned mine workings pose no threat provided they remain sealed in the mine however gases can migrate through voids and fractured strata and be emitted at a target some point away from the source. All underground workings, new or old, are affected by atmospheric pressure variations and as such a mine can "breathe" over periods of rapid barometric pressure fall.

Although the targets of mine gas emissions are documented there is a lack of clarity as to the source of mine gas in abandoned workings. The gas in a semi-confined underground atmosphere can only come from three possible sources: desorption from exposed coal strata; exsolution from mine waters; and fossil gas trapped in pockets within the strata. As we are concerned with unventilated workings in areas where mining has ceased, fieldwork is being undertaken within north-east England, primarily at Beamish Colliery, and Caphouse Colliery in West Yorkshire. The desorption of gas from the rock will be estimated quantitatively from experimental work within Coal Measures strata. Exsolution of gas trapped in minewaters is being determined experimentally in the laboratory. This paper presents the findings of both field and experimental work and concludes that mine water is a source of hazardous gas in poorly ventilated mine atmospheres.

Résumé: La majorité des charbons et les couches de charbon contiennent des quantités significatives de gaz. Ces gaz sont soit potentiellement explosifs en concentrations critiques quand ils sont mélangés à l'air, ou bien ils sont toxiques aux formes de vie. Les gaz trouvés dans des mines sont certainement un mélange d'air atmosphérique, de gaz inertes, de la vapeur d'eau et d'un ou plusieurs des composants suivants: oxygène, monoxyde de carbone, méthane, sulphure d'hydrogène, hydrogène et oxydes nitreux. Les gaz tels que le "grisou" et "blackdamp" peuvent s'accumuler dans les vieux mines qui ne sont pas adéquatement ventilées. Tous les gaz nocifs ou explosifs présent dans les mines abandonnéss ne posent pas de menace pourvu qu'ils restent dans la mine, cependant les gaz peut migrés à travers les vides et le couches et peuvent être émis à un point cible loin de la source. Toutes mines souterrains, nouvelles ou vieilles, sont affectés par les variations de pression atmosphérique et ainsi une mine peut "respirer" sur des périodes de chute rapide de la pression barométrique. Bien que les émissions cibles de gaz sont documentées il y a un manque de clarté quant à la source de ce gaz dans les mines abandonnés. Le gaz dans une atmosphère souterraine semi confinée peut seulement venir de trois sources possibles: desorption des couches de charbon exposées; exsolution des eaux de mine; et du gaz de fossile piègé dans les poches des couches. Comme nous sommes concernés par mines non ventilées dans les l'extraction de charbon a cessé, le travail sur terrain est entrepris dans le Nord Est de l'Angleterre, d'abord aux Houillères de Beamish et Caphouse. La désorption de gaz de la roche sera quantitativement estimé a partir du travail expérimental dans les couches de gisement huilier. L'exsolution de gaz piègé dans les eaux de mines est expérimentalement déterminé dans le laboratoire. Cet article présente les résultats expérimentaux et les travaux sur terrain conclu que l'eau de mine est une source de gaz hasardeux dans les atmosphères des mines mal ventilées.

Keywords: Gases, mining geology, coal mines, geological hazards.

INTRODUCTION

Mine gases are as hazardous to the underground mining environment as they are to the surface environment.

Between 1851 and 1980 there were 186 major explosions in British Coal mines resulting in almost 10 000 fatalities, most of these prior to nationalisation in 1947, as a direct result of a build up of firedamp combined with an ignition source (Turton, 1980). This methane is believed to have desorbed predominately from coal seams within the mine and from the release of fossil gas pockets within the associated coal-bearing strata.

The problems of mine atmospheres depleted in oxygen (stythe) have been known for many years culminating in the Bill of 1842 stating that "an adequate amount of artificial ventilation shall be consistently produced in all coal mines, collieries and iron mines to render harmless, noxious gases, to an extent that all accessible places of the pits, levels and workings of every such colliery and mine shall, under ordinary circumstances, be in a fit state to work therein." This gas is particularly noticeable in times when there has been a rapid barometric pressure fall resulting in the expansion of the gas and emission of the fringe of the noxious gas concentration.

Although during mining, gas is controlled through the colliery ventilation system and exhausted appropriately, it is areas of poorly ventilated and/or abandoned mine workings which have given rise to a number of incidents that have been documented within the coalfield area of North East England.

BACKGROUND TO PROJECT

Apart from the conurbations of southern England and parts of Merseyside, the main centres of population in the UK are located over coalfields. This proximity of the population to the main coal and iron ore resources of the country is a direct legacy of the industrial revolution of the 18th century and the first part of the 19th century (Knill, 1975) when the coalfields drew large numbers to work in mining-related industries. Today, hazards resulting from this industrial heritage have the potential to affect large numbers of people.

Mine gas problems

Any noxious or explosive gases present in abandoned mine workings pose little or no threat whilst they remain underground. However mine gases may migrate through voids and fractured or gas conductive strata and be emitted at surface some distance from the original source.

Throughout the last 25 years there have been a number of cases where mine gas has accumulated in properties, in one case causing a fatality.

Firedamp (methane)

One of the most notable reported events occurred in the North Derbyshire village of Arkwright when, on the 9th November 1988, more than 40 families were evacuated by the council after methane was found to be seeping into homes affected by subsidence cracks. The council and villagers believed the gas to be migrating from underground workings, driven by rising minewater elevations. British Coal recognised that the village was at risk from methane emissions from the former Arkwright Colliery (closed early 1988) and in 1995, the whole village was demolished and relocated nearby as part of an opencast mining and reclamation scheme.

Blackdamp (stythe)

Blackdamp (or stythe in the north-east of England) is essentially de-oxygenated mine air, consisting mainly of nitrogen and carbon dioxide. There are a number of case histories over the last 25 years of stythe gas entering properties in Northumberland, one of which resulted in the fatality of a 61year-old man entering business premises in February 1995. It is still the only recorded death directly attributed to mine gas entering a domestic or industrial property.

As a result of these and other case histories, this project was set up to investigate the links between the origins and pathways of mine gas in poorly ventilated and/or abandoned workings.

Barometric pressure influences

All underground workings are affected by atmospheric pressure. Gases such as firedamp and blackdamp may accumulate in old workings that are not adequately ventilated. When the barometric pressure falls rapidly, these gases expand and may be emitted at surface. Conversely when the barometric pressure rises, fresh air is drawn into the workings and will assist in the oxidation process promoting further noxious gas formation.

Minewater/groundwater elevations

Following the cessation of deep underground mining in North East England, groundwater elevations are slowly recovering after some 200 years of industrial and dewatering activity in the region. As groundwater levels rise, current gas migration pathways may change, and underground void spaces decrease, thus increasing the pressure of the underground gases. This may lead to a series of ever-changing emission locations within the region, some with potentially life threatening outcomes unless measures are taken to reduce the risk.

ORIGIN OF MINE GASES

Mine gases may be of geological, biological or chemical origin. These gases will exhibit characteristics diagnostic of their age and origin (Creedy, 1989) following burial, compression and heating of organic material (thermogenic methane). In some instances these characteristics may be modified by biological or chemical agents introduced as a result of mining. Thermal degradation becomes the principal methane generating mechanism in mature sediments, such as coal seams. The volumes of methane found in the coal seams of Northumberland and Durham vary from trace to $20m^3/t$ (Creedy, 1988). Differences arise from variations in the composition of vegetation undergoing coalification, variation in the geological conditions under which coalification took place, and the proportion of methane lost subsequently over geological time.

Carbon dioxide will predominately originate as a result of either geological (ancient) processes or chemical (recent/modern) reactions in a mine. Under the influence of normal geothermal temperatures, the formation of coal from organic matter releases carbon dioxide and methane in varying volumes (Hooker and Bannon, 1993). Chemical reactions with carbonates, oxidation of carbonaceous material and high-temperature oxidation of mining materials will all liberate carbon dioxide into the atmosphere.

It is probable that much of the gas generated through coalification is dispersed through the surrounding strata and that some is removed in solution, as the moisture content of the enclosing rock is progressively reduced during compaction and diagenesis. Within the Coal Measures, methane is usually adsorbed on coal or held mechanically within the naturally occurring fractures of the rock. It may also be trapped in gas pockets, dissolved in groundwaters within adjacent strata, and may even exist in sufficient quantities to form commercial gas reservoirs.

GAS RELEASE INTO THE MINE ENVIRONMENT

There are a number of ways in which gases may be generated in a mine. However, there are only three main processes which will release significant quantities of gas into the mine environment. These are:

- Release of fossil pockets of gas stored in the strata
- Exsolution from groundwaters in the mine
- Desorption from the strata

Fossil gas

Through mining history, miners have always been wary of the hazard of underground explosions. These are often due to rapid expansion (due to the release of pressure) of a pocket of trapped gas, which is then ignited and explodes. During the coalification process, considerably more gas is produced than can be accommodated in the coal structure. The gas not retained by the coal is dispersed into the surrounding strata, where it may become trapped in rock pores and fracture spaces within the “reservoir structure”. There is evidence from surface exploration drilling and coalfield records for the occurrence of methane in porous or well-jointed rocks such as limestone and sandstone (Hooker and Bannon, 1993). In addition, higher than expected methane flows, which occur in some operational collieries, have been attributed to contributions of methane from sandstone reservoirs. Methane can also be adsorbed on carbonaceous surfaces as a solid hydrate (Creedy, 1991).

Gas adsorption and desorption

Methane

The process of adsorption is particularly important as it explains why methane is found highly concentrated on coals and other carbonaceous materials. Fine pores within the microstructure of coal provide a vast surface area onto which gas molecules may be tightly packed, so close in fact that the density of the gas can be similar to that of a liquid. The quantity of methane adsorbed depends on the composition, rank and moisture content of the coal and the temperature and partial pressure of the gas.

In addition, the production of methane gas in coal-bearing strata by desorption depends partly on particle size. For example, a 1mm particle will achieve 90% degassing in 1 month and a 1 cm particle in 15 years (Staff et al. 1991). Thus, coal remaining in abandoned workings will continue to emit methane by desorption over a considerable period of time.

Carbon Dioxide

Carbon dioxide forms in a variety of diverse environments. It may be adsorbed onto the surfaces of rocks, liberated from chemical reactions of acid waters on carbonates and sulphides in strata, be the product of anaerobic bacterial activity and be exhaled from animal and plant respiration into the atmosphere. High carbon dioxide concentrations have been recorded in unsaturated zones above coal and lignite deposits. Values of up to 8% carbon dioxide are reported over mine waste dumps undergoing pyritic oxidation (Harris & Richie, 1985). Even though the sorptive capacity of coal for carbon dioxide is three times that of methane, carbon dioxide tends not to be trapped at depth by coal-forming material since it occurs prior to methane generation and escapes during the thermogenic processes of coalification.

Exsolution of methane and carbon dioxide from groundwater

Groundwater can be an important transport and storage medium for gases in solution. Dissolved gases may be carried by the groundwater until the pressure is reduced and the solubility limit of the gas is exceeded when they will bubble out of solution and form a separate gaseous phase.

Methane has a very low solubility at atmospheric pressure but at elevated pressures significant volumes can be held in solution in groundwater. Solubility is also influenced by temperature and the concentration of other gases or minerals present within the water. In general, it is accepted that the concentration of methane increases with depth in groundwater systems, probably due to a combination of factors, including degradation of indigenous traces of organics in the rock mass, influx of methane from other sources and slower groundwater movements (Appleton et al. 1995).

Carbon dioxide dissolved in groundwaters may have mixed origins including dissolution from the atmosphere and soil at times of recharge, production in both shallow and deep crustal rocks from biological processes and rarely, migration from the mantle in areas of tectonic activity. Carbon dioxide is only one component of a complex set of gas-liquid equilibria which govern the carbonate system in groundwaters: the actual partial pressure of carbon dioxide is dependant on pH and its equilibria with the other carbonate minerals.

AIM OF PROJECT

The aim of the project is to determine if mine water is a source of hazardous gas in abandoned coal mine workings.

Study Site

An initial underground study site was secured at Caphouse Colliery near Wakefield, West Yorkshire. At this site, six water sampling locations incorporating the full range of worked seams have been identified. Driven piezometers and 'Waterra' (proprietary) tubing have been installed in two locations down the secondary access drift of Caphouse Colliery, one into the upper worked seam (Flockton Thick) and the second into the lowest worked seam (Wheatley Lime). In addition samples are being taken at four levels down the shaft at interceptions with the Flockton Thick, Flockton Thin, Old Hards and Green Lane seams.

A surface site has also been procured to investigate desorption of gas directly from Coal Measures strata and recently compacted backfill. At the time of writing, this fieldwork phase is awaiting commencement.

Preliminary results

Gas monitoring

Figure 1 shows that there is a relationship between atmospheric pressure and increased hazardous gas emissions of both methane and carbon dioxide within the underground environment. As the atmospheric pressure falls a distinct methane concentration peak can be noted in the area of unventilated workings. In addition, an associated increase in carbon dioxide into the underground environment is also recognised. The source of this gas is believed to be associated with mechanics of desorption from the surrounding strata with an influence from the waters and biological activity on the waste products left in the mine environment.

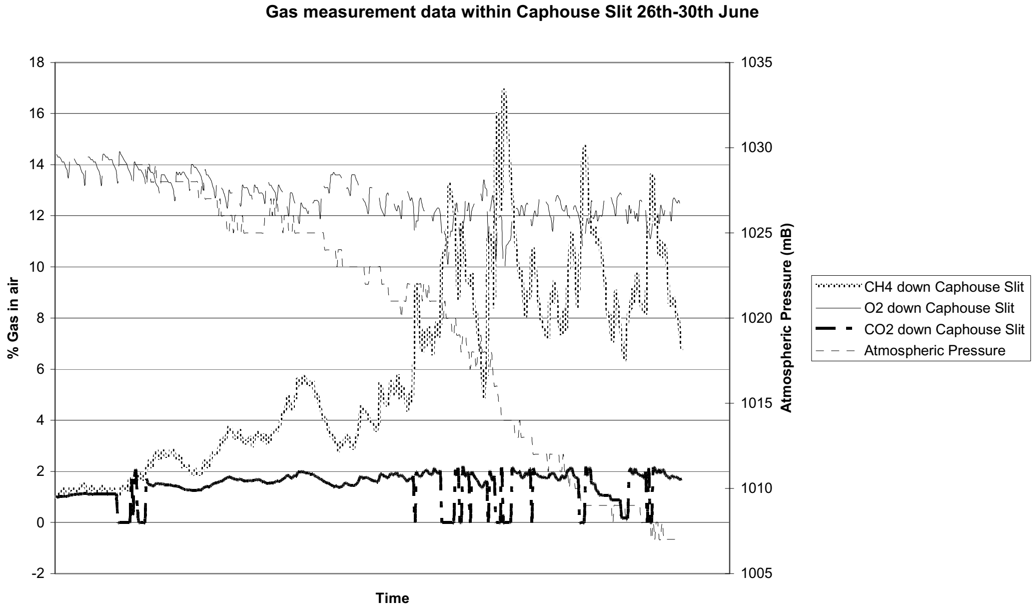

Figure 1. The relationship between atmospheric pressure and mine gases at Caphouse Colliery

Water monitoring

Table 1 shows the average water quality data taken from the main sample locations. As can be seen from these data, the measurements do not vary significantly between sample locations with the exception of pH. This confirms the expected results.

Table 1. A summary of average water quality field measurements for the main sample locations in Caphouse colliery

	Flockton thick	Wheatley Lime	Shaft Strata 'A'	Shaft Flockton 'B'	Shaft Old Hards 'C'	Shaft Sump 'D'
Alkalinity (mg/l)	440	350	325	360	494	364
pH	6.78	7.12	6.71	6.64	7.10	7.10
Total dissolved solids	1220	1550	2046	1565	1217	1297
Conductivity (µS)	1650	2090	2753	2179	1729	1833
Temperature (ºC)	11.5	15.5	12.7	12.1	12.4	11.9

The water samples collected were sub-sampled into a nitrogen-purged vessel, agitated for 15 minutes at room temperature after which the headspace gas was analysed using a gas chromatograph mass spectrometer.

Figure 2 shows increased levels of carbon dioxide equilibrated from the waters into the headspace of the sample vial for the Flockton waters. Although these waters are elevated in carbon dioxide there is an apparent relationship between the concentration of carbon dioxide present and atmospheric pressure. The exact nature of this relationship is still under investigation.

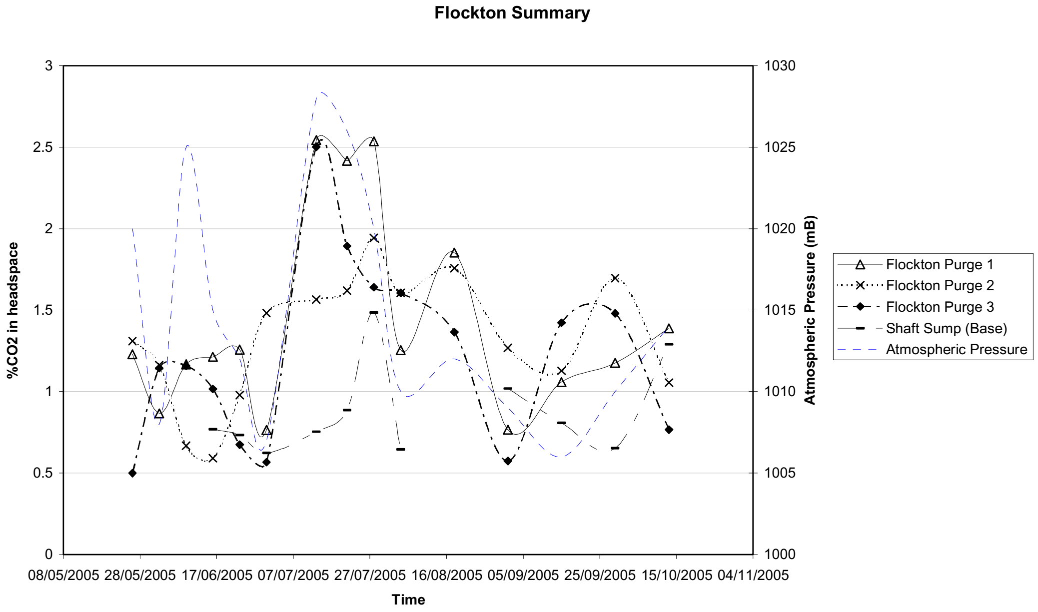

Figure 2. Flockton water sample points summary.

Although these results show elevated concentrations of carbon dioxide they are not considered sufficient at this stage to conclude that atmospheric pressure is a significant primary influence on the degassing of carbon dioxide from minewaters.

CONCLUSIONS AND FURTHER WORK

As can be seen from the preliminary results, the waters sampled show elevated carbon dioxide concentrations and they readily equilibrate in the headspace analysis sampling vessels.

The waters were also analysed for methane in the initial sample runs but the gas does not readily equilibrate with water and any concentrations present were below the detection limit of the GCMS machine.

In conclusion, the preliminary results indicate that minewaters containing elevated levels of dissolved carbon dioxide could be a source of hazardous gas within the mine environment.

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