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Gas Drainage Practices

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ABSTRACT: Coal seam gas problems, largely "gas-outs" and instantaneous outbursts of coal and gas, have created serious difficulties for the coal mining industry around the world. Typically, a single longwall face is now capable of producing an average 10 000 to 15 000 tonnes of coal per day. The total quantity of gas released in gassy mines could conceivably reach 5000 and 8000 litres of gas per second per single longwall block and for the total mine respectively.
The introduction of various gas drainage techniques in Australian gassy mines was necessary to complement ventilation systems and to satisfy the statutory gas limitation in underground workings. Methane drainage can simultaneously reduce the risk of dangerous methane concentrations accumulating as well as reducing methane emissions into the atmosphere; moreover, the methane recovered is a valuable energy source and can be used to considerable economic effect. The paper reviews Australian achievement in gas capture technologies, gas drainage

In many cases the quantity of gas emitting into coal mine workings is so high that the available quantity of air in the ventilation system is insufficient to dilute the gas to acceptable levels. In such a situation, other methods in addition to the ventilation system should be planned and introduced during different phases of coal mining activities.

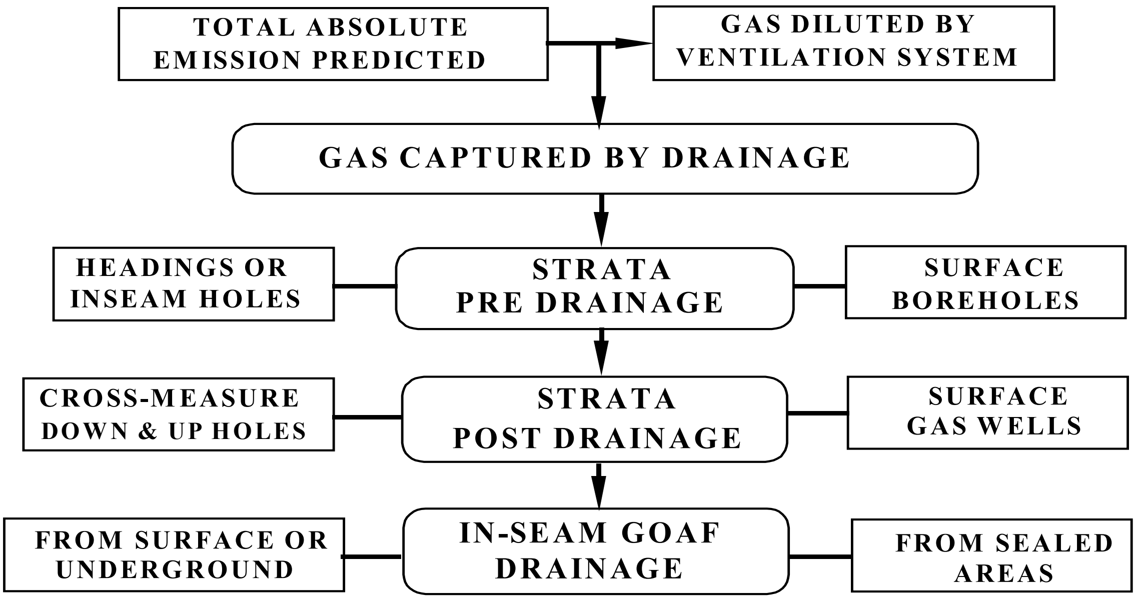

Fig. 1. Steps required for planning and designing gas drainage systems.

The most effective additional system is the introduction of gas drainage (recovery) techniques. Seam gas recovery from underground mines is the capture of seam gas from strata or underground workings for the purpose of reducing gas flow into the mine ventilation system, controlling gas hazards, and utilisation of the gas, if applicable. This is carried out for safety purposes to avoid fatalities or injury, and to reduce the loss and delay of coal production and development drivage rates.

The classification of gas drainage methods is based on the phase during which degasification is performed in relation to the coal extraction. The six basic methods used are:

- pre-drainage by vertical or directional holes drilled from the surface,
- pre-drainage by horizontal longholes drilled from development headings,
- pre-drainage by inseam headings,
- post-drainage of relaxed strata using cross-measure holes drilled into the overlying and underlying gas sources,
- post-drainage by holes drilled from the surface, and
- post-drainage of old or active goaf areas from underground.

Fig. 1 shows the logical and necessary steps required to design gas drainage systems for underground coal mine safety and gas utilisation purposes, taking into account the mine's or longwall predicted gassiness.

REVIEW OF COAL MINE GAS DRAINAGE PRACTICES IN AUSTRALIA

This section reviews the practices of gas recovery in selected Australian underground coal mines**.** In 2000, Australian black coal mines produced 240 Mt of saleable coal, of which 80 Mt came from underground mines, almost 88 percent of this from longwall units.

The maximum and average depths of underground mining are 550 and 280 m, respectively. The *insitu* gas content of coal seams in deeper operations between is 5 and 20m^3/t *insitu*, however, other gassy mines have experienced gas content levels between 2 and 5 m^3/t *insitu*. Specific gas emissions in the gassy mines range from 5 to 90 m^3/t of mined coal.

Full scale gas drainage is relatively new to Australia (Fig. 2), although some initial attempts were carried out much earlier; 1897 & 1945 - Balmain Colliery, 1925 & 1954 - Metropolitan Colliery, 1954 - Collinsville Colliery, 1965 - Hepburn Collieries, and 1970 - Appin Colliery (Hargraves & Lunarzewski, 1985).

Full-scale pre and post drainage of gas started in 1980 at West Cliff and Appin Collieries. Gas drainage is currently practised in fifteen (15) mines, most of which use the longwall mining method. Outbursts of gas and coal have been experienced in a number of mines. These occurrences have given impetus to the development of methods for draining gas ahead of mining to reduce *insitu* gas content and pressure. Both gas recovery methods - pre and post drainage are currently used in Australian gassy mines.

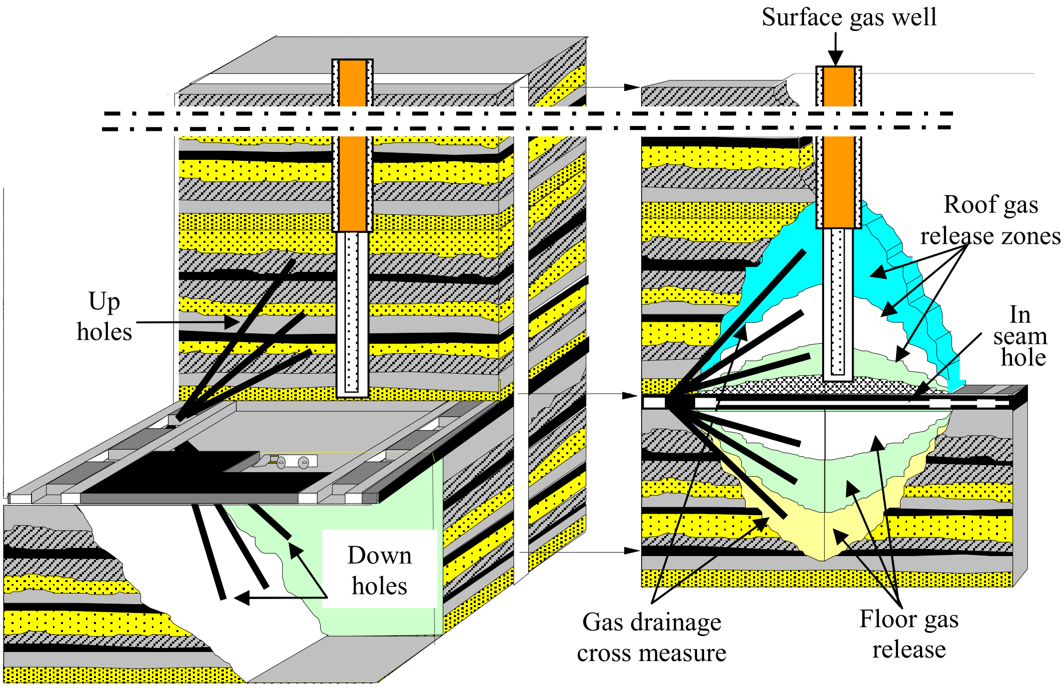

Fig. 2. Simplified output of strata relaxation and gas emission zones in relation to the local geology, coal rock properties, longwall face position and projected gas drainage holes

Pre-drainage

The term pre-drainage refers to a particular gas drainage technique. It deals with coal seam gas drainage from selected gas sources, prior to coal extraction, under conditions determined by their *insitu* parameters. The ability of the drainage system to capture gas in the pre-drainage phase depends substantially on the permeability of the coal seams and adjacent strata, their gas migration properties, connectivity, conductivity, and the provision of sufficient lead-time.

The method to supplement the ventilation system is to install horizontal holes, a technique that has been used in coal mining since the 1800s. This technique consists of drilling holes from the mine workings into the unmined areas of the working coal seam (Fig. 2). These holes are typically tens of metres to hundreds of metres in length, and within a single mine several hundred holes may be drilled. The horizontal holes are connected to an in-mine piping system, which transports all of the methane released into the hole out of the mine. By draining methane from the unmined coal, horizontal holes reduce methane emissions into the mine works and during mining. In some cases, 30 to 50 percent of the methane contained in the coal seam being mined may be removed with inseam pre-drainage holes.

Inseam pre-drainage holes are drilled as:

- fan-shaped single holes drilled from an adjacent double entry heading panel (Figs. 2 & 6)
- fan-shaped branched
- long holes parallel to a heading (Fig. 6)
- directional holes to the adjacent seams in the roof and/or floor drilled from underground or surface (Fig. 3)

The spacing and length of holes is dependent upon the permeability of the coal and the pre-drainage lead-time. Underground hole lengths of 300m are common, but long-directional holes up to 1800m in length have also been successfully drilled. Holes drilled from the adjacent panel are used to drain gas from longwall blocks as well as the next set of gate roads, in advance of mining using suction or very occasionally positive *insitu* pressure. The spacing between such holes, when drilled parallel to each other, varies from 8 to 100m. Combinations of fan-shaped parallel and lateral holes are used in high gassy areas when only a short lead-time is available. All inseam holes are fitted with standpipes of lengths varying from 3 to 9 m and hole diameter of 96 mm. In high gas emission areas, drilling is done through the standpipe. In areas where gas flows are low, holes are drilled first and the standpipes are installed before applying suction. Some holes are cased with steel or PVC – protected perforated pipes.

Directional Drilling Techniques

Considerable success has been achieved with inseam longholes drilling (Fig. 6) using down-hole drill motors and hole trajectory control techniques and equipment such as Directional Drill Monitor utilising Modular Electrically-Connected Cable Assembly (DDM-MECCA) & Drill Guidance System (DGS) survey instruments. The system provides rapid and easy underground hole survey measurements whilst drilling, including computer monitoring if required. It measures the earth's magnetic field and gravity in all three directions (x, y & z) with borehole placement accuracy of ± 0.1 inclination and ± 0.5 degrees azimuth. The instruments and connections are intrinsically safe, which allows for their application in underground gassy coal mines as well as fast and reliable data transmission irrespective of hole depth.

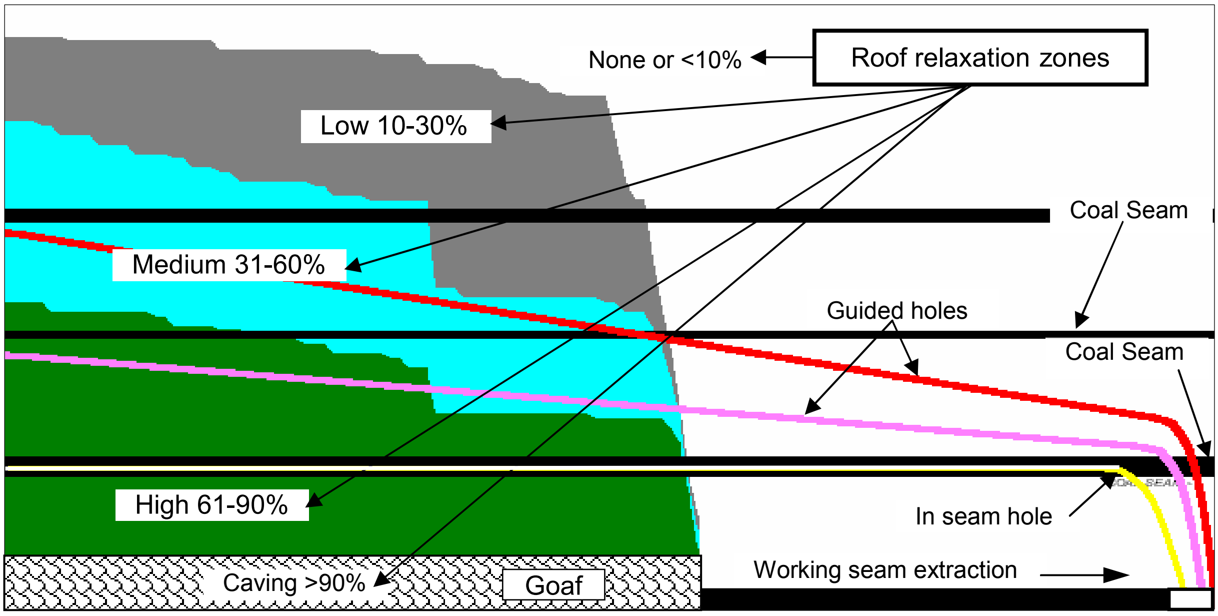

Fig. 3 Longwall block longitudinal cross section with relaxation zones and long-directional holes

The first directional (guided) in seam longhole was drilled in Australia at Appin Colliery in 1987 to drain gas from the adjacent coal seam located 18m below the working seam. Guided longholes are used for pre-drainage of longwall panels and post-drainage of goafs, with the main part of drilling being in the targeted seam. This method is a proposed replacement for those previously used in Europe 'Bleeder roadways - Hirschbach system; however, more research and practical applications are necessary to establish hole stability protection and lead time for various geological, mining and gas conditions.

Water-jet cutting technique

Recently a new drilling method for the accurate and efficient installation of long in seam boreholes has been tested in Australia. This involves the integration of pure water-jet drilling technology with conventional directional drilling technique. In effect, the system is similar to conventional directional drilling methods, but instead of relying on a down-hole motor rotating a mechanical drill bit for cutting, a pure high-pressure water-jet cutting technique is used.

Hydro-fracturing technique

Some surface vertical holes using the hydrofracturing technique were introduced in New South Wales and Queensland, however, majority of the experimental zones have not produced a gas flow rate of industrial significance. The results are not as promising as in the USA, this is mainly due to the different geology, coal seam characteristics (internal structure, connectivity and conductivity), *insitu* gas content, pressure and saturation as well as gas sources and surrounding strata's low *insitu* permeability.

Post-drainage

The term post-drainage refers to another gas drainage technique concerned with the relaxed strata during and after coal extraction (Figs. 2, 3, 4, 5 & 6). In post-drainage methods, advantage is taken of the phenomenon of increased strata permeability and connectivity-conductivity due to stress relaxation of the roof and floor coal seams and adjacent rocks, which occurs as a consequence of coal extraction and/or other mining activities in underground mines.

While horizontal holes can degasify the target coal seam, they cannot effectively degasify the overlying or underlying coal and rock strata. To accomplish this type of degasification, cross-measure holes are used. This technology consists of drilling holes from the mine workings into unmined areas of the coal seam and surrounding rock. Cross-measure holes, angled into the rock and coal strata above and below the mine workings, are used to recover methane from the relaxed strata sources and goaf areas. These holes are typically tens to hundreds of metres in length. The holes are connected to an in-mine vacuum piping system, and the recovered methane is transported out of the mine.

Post-drainage holes are drilled as:

- underground cross-measure up holes (Figs. 2 & 4),
- underground cross-measure down holes (Fig. 5), and
- gas wells - goaf & strata free gas drainage holes drilled from the surface (Fig. 2).

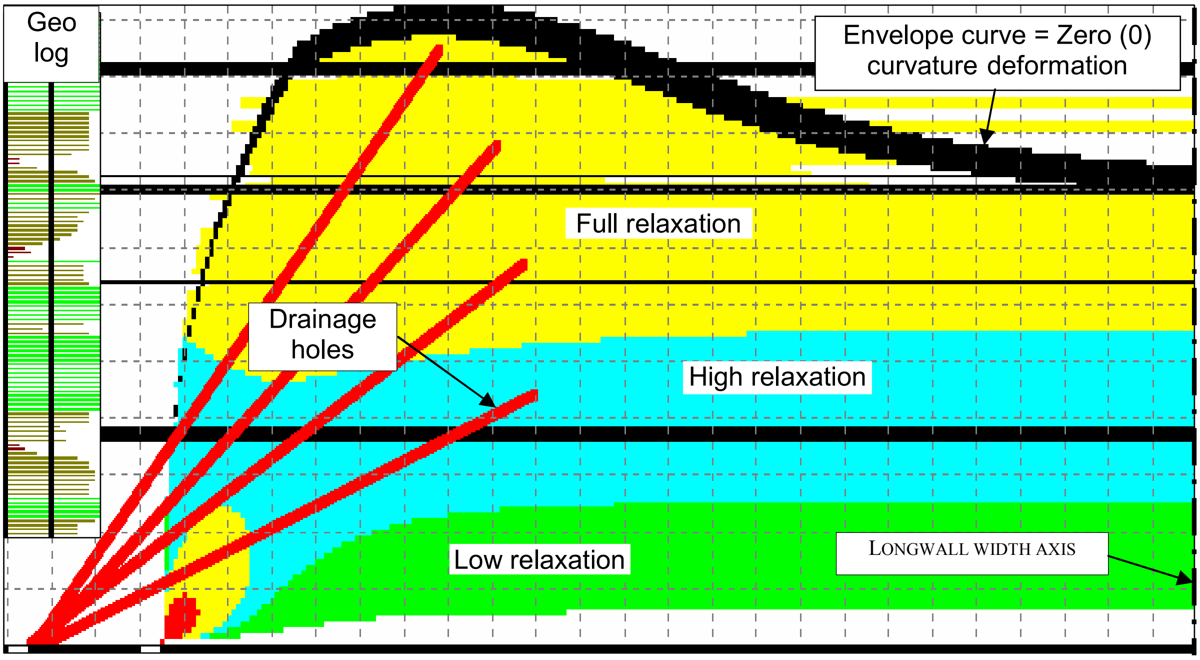

Fig. 4 Roofgas© version 3.0 output using rock strata curvature enforcement model - vertical cross section of half of the longwall with strata relaxation & gas release zones for 250 m distance behind the face

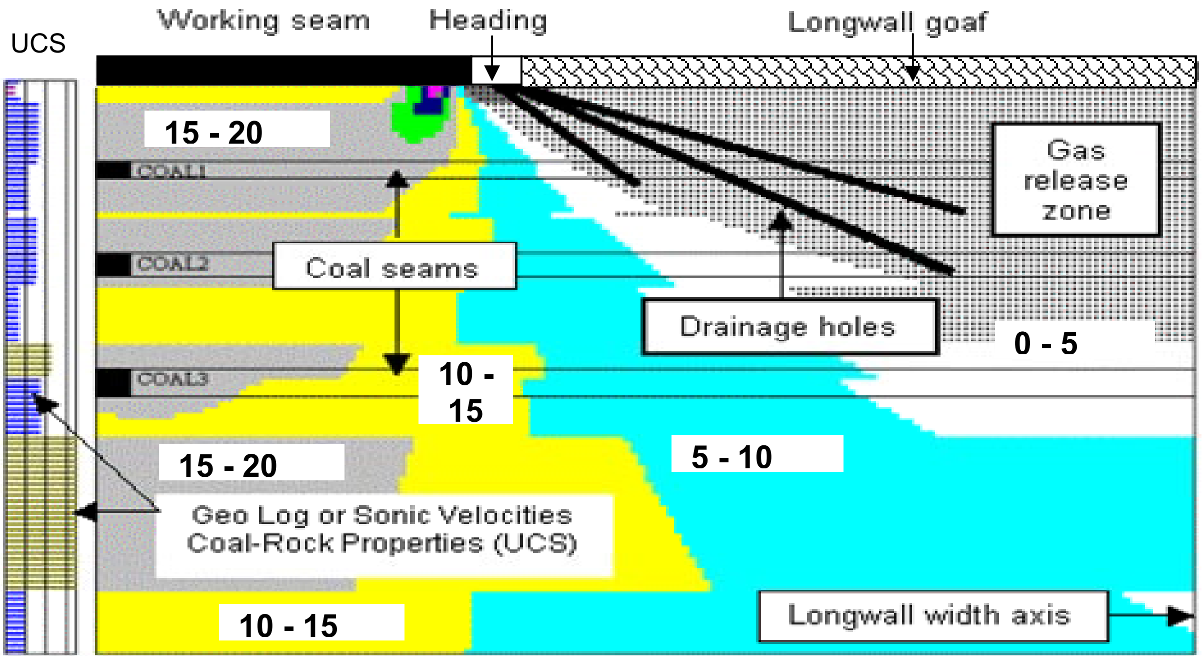

Fig. 5 'Floorgas'© output - vertical cross section of half of the longwall with single entry heading, strata relaxation and gas release shape and vertical stresses (MPa) as well as projected down holes

Post drainage hole diameters vary depending on the drilling technology used. Shorter length rotary holes have diameters of 65 mm to 75 mm. Longer holes drilled using downhole motors are 96 mm in diameter or larger.

Slotted steel casings are sometimes inserted along the length of a hole to maintain its stability. Gas drainage efficiencies typically vary from 30 to 80% for the districts and 25 to 60% for the total mine. The highest efficiency for an individual longwall was achieved for the 'protected' by pillar holes when drilling from double entry panel second heading, cut-through or stub as well as for perforated-cased holes. The diameter of surface holes is 150 to 300 mm, which depends on working seam depth, gas and mining conditions as well as source of gas transportation (suction or free flow - buoyancy effect). Hole position in relation to the strata relaxation zones shape and longwall goaf geometry is essential, and is designed using computer simulation for specific local geology and mining conditions.

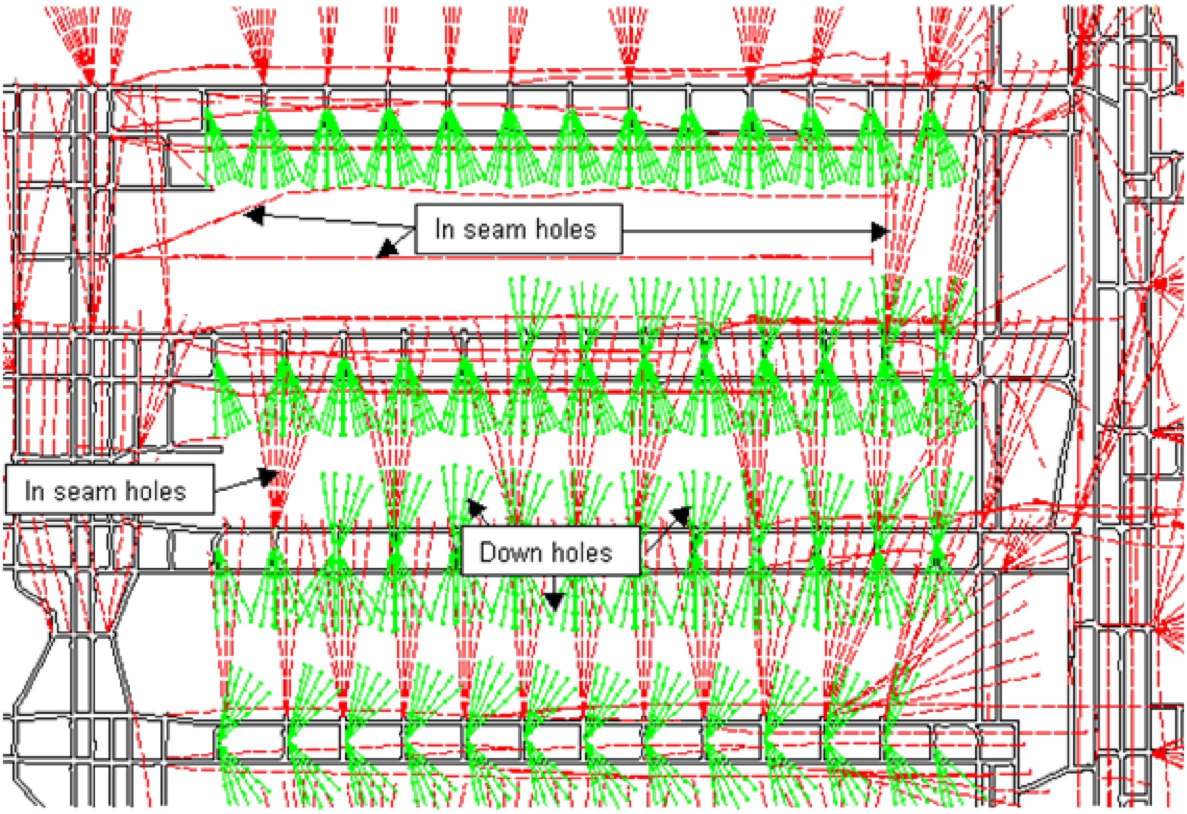

Fig. 6. An example of in seam and cross-measure gas drainage holes in longwall system

Water difficulty

Significant restriction for gas recovery from drainage holes could be caused by *insitu* and 'drilling' water, especially with cross measure down holes. A special technique has been introduced in Australia using PVC internal conduit for a self-dewatering system in each individual hole. Also, automatic gas-water separators, which do not require external power, are used for individual and grouped holes, as well as for horizontal and vertical gas drainage pipelines.

GOAF DRAINAGE

The term "goaf drainage system" refers to an independent gas drainage technique aimed at capturing a high percentage of gas from active or sealed goaf areas from both underground and/or surface.

The longwall extracted areas can be efficiently sealed off after completion of the extraction process. The exposed cavities and/or goaf areas form 'free gas' reservoirs that can be extracted by post-drainage techniques at a predetermined controlled rate. To avoid dilution of high percentage methane behind the seals, the quantity of captured gas should be in equilibrium with gas desorption rate from the strata gas sources. Part of the gas usually leaks directly to the ventilation system, however, the majority of high percentage methane could be recovered by goaf gas drainage systems.

The extracted gas can be diffused into the ventilated mine workings or transported by a methane drainage network to the surface for utilisation or controlled exhaustion to the open atmosphere.

The capture of gas from operating longwall goaf by an underground drainage system is rarely used in Australia, due to the common use of bleeder ventilation systems, however, some mines are capturing up to 75% of gas being released during longwall extraction, using surface gas wells. Following the collapse of the coal seam roof, the subsequent fracturing of the surrounding rock and coal strata allows the goaf wells to produce large quantities of methane in a short period of time. After the initial surge of methane, the quality of the gas may decline as it becomes mixed with air from the mine workings. However, in some cases, the methane concentrations have been kept very high for long periods of time. Over time, this production rate declines until a relatively stable rate is achieved. Most methane produced from the goaf wells is currently vented to the atmosphere.

When extraction is completed the systematic and appropriate sealing of individual longwall goaf and/or districts allows for capturing high concentration methane from sealed goaf areas. It allows for management of ventilation air pollution in the underground workings as well as protection of the environment by reducing greenhouse effects.

A prototype of automatic goaf gas drainage assembly, which utilises barometric pressure and methane concentration sensors for controlling both quantity and quality of captured gas was developed and installed in an underground gassy mine in Australia. This system substantially increases efficiency of every goaf drainage system.

COAL MINE METHANE UTILISATION PRACTICES

In some cases, extracted coal mine gas is vented to the atmosphere, however, many mines use extracted methane as a fuel for heating or power generation. A typical example is a power generation project (EDL-BHP) of a 94MW combined capacity in New South Wales. The coal mine methane is converted to electricity using state-of-the-art lean burn 1MW reciprocating gas engine technology. A key strength of this project is the adaptation of existing engine combustion technology with fuel system which enables gas engines to utilise fuel gas with very low heating value and of highly variable compositions typically varying from 30-80% methane, and utilisation of coal mine gas ventilation air containing typically 0.1-1.0% methane, as supplementary fuel for gas engines.

More recently a newer more advanced technology has been introduced for commercial use in Australia (Appin Colliery). It utilises ultra lean low pressure MVA as a primary fuel source. This approach represents leading edge technology in coal mine methane utilisation from ventilation air offering the opportunity to significantly reduce greenhouse gas emissions.

Coal mine gas could be diluted underground by the ventilation system, captured by gas drainage techniques, vented to the atmosphere and/or utilised. Coal mine safety, assurance of coal productivity and protection of the environment from greenhouse methane and carbon dioxide gasses emission, are the most important issues associated with gassy mines underground activities.

Since 1980 Australia has introduced various gas drainage technologies and developed some new techniques applicable to the local conditions. A comparison of coal mine gas parameters and achievements in Australia and other countries are presented in Table 1.

Table 1. Gas conditions for selected underground gassy coal mines (1997)

Country	Underground coal production	Methane emission	Gas capture	Gas drainage efficiency	Methane utilised
	*10^6 t/year	m^3CH_4/min	m^3CH_4/min	%	%
China	995	**20 700**	2700	13	2
Russia (CIS)	220	**12 000**	n/a	n/a	4
USA	350	**11 400**	2400	21	8
Germany	65	**3000**	n/a	n/a	23
South Africa	115	**2400**	n/a	n/a	0
Poland	128	**1800**	420	23	20
Australia	**60**	**1700**	**540**	**33**	**9**
UK	55	**1400**	n/a	n/a	22
Czech Rep.	25	**800**	240	31	32
India	75	**750**	n/a	n/a	0

GAS EMISSION PREDICTION, GAS RECOVERY LAYOUTS DESIGN & PARAMETERS OPTIMISATION

The quantity of gas to be released from gas-bearing sources and to be captured by various gas drainage techniques can be predicted with varying success using worldwide-recognised methods, including strata modelling and gas drainage hole design simulation software.

Gas drainage efficiency plays a very important role in the protection and prevention of gas and outburst hazards during various stages of mining activity. Both pre-drainage and post drainage techniques are essential in planning ventilation and in developing an efficient mine gas management system.

A strong direct relationship exists between the underground coal mining activities, strata relaxation, gas emission zones shape, and the quantity of gas captured by various gas drainage systems. Lunagas Pty Limited's new software - '*Floorgas*© and *Roofgas*©' allow for the design of optimum parameters for various gas recovery and methane utilisation systems, as well as accurate prediction of gas emission from roof and floor strata gas sources.

The advent of computer modelling methods, particularly finite element techniques, has improved predictions based on the nature and extent of the relaxation zone surrounding the longwall to be made when using nominated local geomechanical, geological, gas and mining input data. Such a model has been developed and evaluated under the name of *'Floorgas© and Roofgas© geomechanical & gas release model'*, and has been commercialised to operate on a PC Windows based platform.

Outputs from both programs (Figs. 3, 4 & 5) are used for routinely designing gas drainage technologies, including cross measure (Figs. 2, 4, 5 & 6) and/or directional holes drilled from underground (Fig. 4), and gas wells drilled from the surface. Both programs are the most advanced engineering numerical tools available, designed to calculate active and inactive gas source contributions, and improve the accuracy and quality of underground coal mine gas management, and coal mine methane utilisation

Floorgas© is the only known system to combine a precise rock mechanics analysis with gassy conditions to calculate stress and gas release zones in the floor strata of the working coal seam (Fig. 5).

Roofgas© is the only system known which can generate a roof strata break-line as a boundary between continuous and discontinuous rock masses (Fig. 3) and/or incorporates longwall face and side-heading edge effects, as well as the apparent geometry and shape of gas conductivity zones, due to bending curvatures and sag caused by dynamic edge migration specific phenomenon (Fig. 4).

GAS MANAGEMENT SYSTEMS

Current research emphasis is not on the search for new technology only, but on enhancing the organisational management to ensure the available, proven technology is used to best effect. A greater range of gas drainage technologies have been applied in Australian mines compared with those in the UK, as the higher production rates tend to induce problems with high gas emissions and the potential for outbursts at some mines. The support of an effective gas management framework is therefore even more critical. Following the explosion incident at Appin - 1979 & at Moura - 1994 as well as fatal outburst occurrences at South Bulli - 1991, Tahmoor - 1985 and Metropolitan - 1954, 1926 and 1896, (Harvey, 1994), new management concepts have been introduced in Australia including quality management system (Outburst and/or gas management plan), which specifies practices, resources, activities and responsibilities so that all procedures designed to manage gas hazards and the outburst risks are in place to guarantee the safety in underground gassy mines. Each outburst management plan is based upon a three tiered approach for managing the outburst risk by the prediction of outbursts, prevention of outbursts and protection from outbursts (Harvey, 1994).

An effective gas management system will include an operational framework to identify, provide, implement, monitor and develop the most suitable technology in an effective and sustainable manner. The procedures should ultimately address all relevant aspects in accordance with local legislation with regard to safety, gas use and the environment. Safety is always the highest priority. Effectively managing gas to ensure safe working practices essentially means achieving a correct balance between having sufficient ventilation quantities to dilute and disperse gas entering the general body of mine air at all levels of planned coal production and, where ventilation alone is unlikely to achieve this, gas drainage to ensure no more gas enters the mine airways than can be diluted to below statutory limits by the available ventilation air (Creedy and Lunarzewski, 2001).

UNDERGROUND CONTROL AND FUTURE DIRECTIONS OF COAL MINE GAS

Both safety and productivity in underground gassy coal mines can be substantially improved with the application of an appropriate gas management system, particularly if it includes gassiness calculations, implementation of appropriate ventilation, and gas recovery systems in various stages over the life of the colliery.

Underground coal mines with high coal production and gas emission levels require a combination of both ventilation and various gas drainage systems to be applied simultaneously in order to meet the needs and demands of each individual mine with regard to gas, geological, and mining conditions. Various systems of gas drainage should be applied in different phases over the life of the colliery, in order to minimise the gas hazard and to optimise the ventilation network and seam gas utilisation. Pre-drainage and post-drainage are gas recovery methods (Figs. 2 & 6), complementary to the ventilation system, which allow for the control of gas hazards in underground mines, as well as the utilisation of coal seam gas. Gas capture techniques are directly related to a colliery's life cycle; before, during and after coal extraction.

Improvements in gas control in underground coal mines involve the introduction of safety management systems and utilisation of modern gas drainage techniques. Multi-entry access configurations for retreat longwalls offer improved gas control benefits in terms of at least one heading being maintained behind the face to protect gas drainage holes, and to improve access for gas drainage in general. Developments in technologies for drilling, monitoring and guiding longholes hold promise for application to both pre-drainage and post-drainage methods of gas capture in such conditions. Further experimentation is needed with longholes drilled above and below retreating longwall panels, as this approach has the potential to optimise methane drainage performances. Where coal seams are of sufficiently high *insitu* permeability, a proportion of the gas from the seam to be worked, or from adjacent seams, can be removed prior to mining through holes drilled either inseam or from the surface. Pre-drainage from surface holes is generally a nonviable option for deep seams or in residential areas, and is a technique which is usually practised totally independently of mining to obtain coal mine gas for commercial exploitation. However, pre-drainage technology need not be confined to the conventional stimulated vertical well concept. A proposal to drill and complete long deviated holes from the surface and/or underground, into the target coal seam with enhancement using hydro-fracturing technology is currently being promoted as a viable alternative for reducing gas hazards ahead of mining. New techniques allowing the efficient sealing of single longwall or multi-longwall district goaf areas are of primary importance for the capture of huge quantities of gas currently being diluted and vented by the ventilation air (Creedy and Lunarzewski, 2001).

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