Methane Control Technology for Improved Gas Use in Coal Mines in China

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by

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EXECUTIVE SUMMARY

Objectives of the study

The overall aim of the project is to promote improved coal mine methane (CMM) capture and use in China. The specific objectives are to identify methods and technologies to improve gas control and capture, improve the flow, quantity and availability of mine gas for utilisation, improve safety in coal mine workings in China, reduce greenhouse gas emissions and identify opportunities for UK manufactures, suppliers and safety training and educational organisations.

Background

Previous UK-China DTI Cleaner Coal Technology Transfer projects have examined the potential for extracting gas from virgin seams (VCBM) and from abandoned coal mines (AMM) in China. This study features gas control technology (GCT) in working coal mines and examines the technology of CMM control, capture and use.

The project combines the important topics of mine safety, greenhouse gas emissions reduction and clean energy production. The importance of these issues in China's coal sector is illustrated by the 2436 gas-related fatalities, 128Mt CO_2 equivalent emissions and that only about 10% of the methane potentially available was captured and used in 2001.

Growing concerns about continuing mining accidents in China has led the State Council to allocate US$265 million (£145 million) for expenditure in 2004 to help improve coal mine safety, particularly with respect to mine gas control.

More than 95% of the coal mined in China originates from underground operations and some 300 of the Key State-owned coal mines are classified as gassy or prone to outbursts. Outbursts are near instantaneous emissions of gas or sudden movements of coal or rock which can occur unexpectedly when mining. By 2002 there were 193 coal mines with methane drainage systems draining about 1.15 billion m^3 of gas of which only 0.5 billion m^3 is used. Chinese mines liberated an estimated 14 billion m^3 of methane in 2002 from a coal production of 1.39Bt. If, on average, 30% of the gas could be captured in drainage systems, some 4.6 billion m^3 of gas is theoretically available each year and hence an additional methane utilisation and mitigation potential of 4.1 billion m^3. The growth potential for CMM utilisation schemes is therefore large. China is the world's largest CMM source awaiting commercial exploitation. Coal production is expected to rise steadily, 1.6Bt being mined in 2004 with a corresponding increase in gas emission.

Summary of work undertaken

The activities undertaken during the course of the project included literature reviews, exchange of published information and translations, in-house research and preparation of topic papers and reciprocal visits of experts between China and the UK. Academics, consultants and manufacturers were represented. A technology transfer workshop was held in Beijing during October 2003 and attendance exceeded expectations.

Experience of gas control practices in Chinese coal mines and technology needs were gained through field studies at mine sites in Hegang (Heilongjiang Province), Songzao (Chongqing), Jincheng (Shanxi Province) and Huainan (Anhui Province). Site visits were also made to Fuxin (Liaoning Province), Kailuan (Hebei Province) and Yangquan (Shanxi Province) to examine and discuss coal mine methane utilisation activities.

A survey of perceived gas drainage problems was undertaken by sending questionnaires to the large State-owned coal mining enterprises. The study revealed that gas drainage performance is often hampered by inadequate drilling equipment. Lack of monitoring and control facilities also hinders methane control in the mine environment and results in quality variations in drained gas. Too much gas is vented, even where utilisation schemes have been introduced, and mines often have difficulty raising finance to construct schemes. Analysis indicated that inadequate and ineffective management was at the root of many problems with difficulties compounded by poor equipment, insufficient measurement and monitoring facilities and a lack of technical knowledge of emission and gas control processes among some practitioners.

Gas drainage data for China were also updated in a survey undertaken by the China Coal Information Institute.

<u>Summary of the results</u>

Gas drainage in China involves a combination of both pre and post drainage methods. Underground goaf drainage is widely practised using pipes laid in the waste, cross measure boreholes and roadways driven above the working panels. Cross measure boreholes are drilled from rock galleries driven below the worked seam to intersect coal seams above and hence their effective lengths for gas drainage are short relative to the overall borehole lengths. A method for draining gas from long boreholes drilled above a longwall panel (super-adjacent borehole drainage) has been demonstrated by foreign contractors at Daxing mine, Tiefa as part of a UNDP project. Due to the complexity of the technology and geological difficulties the method has not been successfully replicated in China. Gas was successfully drained using roadways driven above the longwall panel for many years in the Saar coalfield in Europe and a similar method is in use at Huainan and Yangquan mines. However, this method is costly.

In-seam longhole drilling technology is being used successfully at Daning mine. Jincheng Coal Mining Group has also reported success with in-seam drilling at Sihe mine. Daning and Sihe mines are working a thick coal seam in unique geological conditions in the south Qinshui coalfield. Similar geological conditions and coal characteristics are not found elsewhere in China and considerable difficulties have been encountered with in-seam drilling in other coalfield areas in China. There is a clear need to examine the drilling systems and technology in use in China and to question whether pre-drainage is appropriate to the geological and mining conditions.

Most of the CMM used in China is distributed via pipelines to mining communities and neighbouring cities for domestic use, mainly cooking. Some CMM is used in colliery boilers and for small-scale power generation. Gas flows supplied to CMM utilisation schemes are typically in the range 5 to 100 million m^3/a. Financing of CMM utilisation schemes is sometimes difficult. After years of poor performance and large losses, many mines have poor credit ratings with banks and many schemes are too small to interest international financing institutions and private investors. There are, however, some notable exceptions, the largest being the Jincheng CMM project based at Sihe mine which will use an Asian Development Bank (ADB) loan to develop a $120MW_e$ power plant to generate electricity for local distribution. The Clean Development Mechanism (CDM) may become an important financing mechanism for assisting marginal utilisation schemes to be brought into operation.

A modified form of the British Coal gas emission prediction model has been used with some success to predict the performance of both pre and post gas drainage systems in Chinese coal mines.

Conclusions

Gas drainage in gassy working mines is an important safety measure as well as a source of clean fuel. These two aspects are intimately linked and both have a high profile in China due to an unacceptably high number of gas explosions, a shortage of clean energy and an urgent need to reduce greenhouse gas emission from coal mines.

Current GCT technology requirements are being primarily driven by new regulations on gas drainage and gas control to reduce explosion risks, a need to replace obsolete methane drainage borehole drilling machines and CMM utilisation for greenhouse gas mitigation and clean energy production.

The effectiveness of gas drainage and utilisation systems in China is currently limited due to:

- lack of gas distribution pipeline infrastructure and poor design of existing infrastructure
- aging gas drainage drilling and extraction equipment
- poor performance of current drilling, drainage and monitoring equipment
- lack of preventative maintenance
- sometimes inappropriate technology unsuited to geological and mining conditions
- inadequate monitoring and control systems
- a need for more advanced gas cleaning, treatment and metering on a heat supplied basis.

The quantity and quality of CMM captured could be increased by improving borehole sealing, better monitoring and control of drainage systems and development of management practices to maximise gas capture for safety and utilisation. Quicker drilling rates and improved borehole performance may be achievable using intermediate drilling technology (IDT) to increase gas drainage capture, improved gas quality and enhanced safety.

The predominant use of CMM at UK coal mine is for power generation. In China, distribution of gas for domestic consumption is the main use but mines are showing increasing interest in using CMM for on-site power generation. Selling electricity power generated by small-scale power schemes to the grid in China is problematic at present due to the inflexibility of the large power companies. Electricity prices are currently fixed by government.

Technology alone cannot solve the gas control problems which afflict China's coal mines. There is also a need for safety management systems, improved training and education. Liaison between UK and Chinese training specialists and educational establishments should be encouraged to fill this knowledge gap.

Financial support from the government of China to assist the introduction of modern safety-related technology into China's coal mines provides an opportunity for UK equipment manufacturers and suppliers.

Recommendations

Reliable gas emission prediction techniques are essential for planning safe and productive coal extraction on longwall faces. Development and wider implementation of practical gas emission prediction methods would have benefits for both gas utilisation and also mine safety. More research should be undertaken in this area.

There is considerable scope for increasing the availability and quality of gas drained from coal mines in China for utilisation, however, investment is needed in modern underground drilling equipment, computerised real time monitoring and control systems and management practices. More research is needed into the design and operation of safe, cost effective gas drainage technologies suited to the geological and mining conditions in modern Chinese mines.

CDM financing could make more CMM schemes viable and thus increase the size of the technology market. Due to the potential importance of this mechanism, it is recommended that a UK-China collaborative project is initiated aimed at developing a methodology to promote CMM applications.

The use of information technology and computer based management information systems is likely to expand rapidly in China's coal mines as an important tool for improving safety standards. The possible role of UK expertise in gathering and processing real-time monitoring data to predict and forestall mine gas control and other operational problems should be examined with some urgency.

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Appendices

ABBREVIATIONS AND ACRONYMS

ADB	Asian Development Bank
AMM	Abandoned mine methane
ATEX	*Atmospheres Explosibles* (French) EU Directive on Equipment and Protective Systems for use in Potentially Explosive Atmospheres
Bt	Billion tonne
CCII	China Coal Information Institute
CCRI	China Coal Research Institute
CDM	Clean development mechanism
CICETE	China International Centre for Economic and Technical Exchanges
CMA	Coal Mining Administration
CMM	Coal mine methane
DTi	Department of Trade and Industry
ESHR	Essential Safety and Health Requirements
FES	Future Energy Solutions
GCT	Gas control technology
GT	Gas turbine
HSE	UK Health and Safety Executive
ILO	International Labour Organisation
ITD	Intermediate drilling technology
KSOCM	Key State-owned Coal Mine
MA	Mei Anquan (coal safety mark of approval)
MOST	Ministry of Science and Technology
M^3/a	Meters cubed per annum
Mt	Million tonne
MW_e	Mega watts ,electrical
NDRC	National Development and Reform Commission
NSTC	National Safety Training Centre
RMB	People's Money (Chinese currency: 1 Yuan=US$8.3 stable, UK rate varies)
SACMS	State Administration of Coal Mine Safety
SAWS	State Administration of Work Safety
SETC	State Economic and Trade Commission (now abolished at State level)
SOCM	State-owned Coal Mine
SOE	State-owned Enterprise
t	Tonne
TVCM	Town and Village Coal Mine
UNDP	United Nations Development Programme
UoN	University of Nottingham
VAM	Ventilation air methane
VCBM	Virgin coalbed methane

FOREWORD

The overall aim of the project is to promote development of new, and improvement of existing, gas drainage systems and coal mine methane (CMM) power generation projects in China.

The specific objectives were to:

- identify methods and technologies to improve gas control and capture
- improve the flow, quantity and availability of mine gas for utilisation
- improve safety in coal mine workings in China
- reduce greenhouse gas emissions
- identify opportunities for UK manufactures, suppliers and safety training organisations.

The project comprised the following activities:

- start-up meeting with the principal collaborators in Beijing
- literature review by exchange of published information and translations
- in-house research and preparation of topic papers
- reciprocal visits of experts between China and the UK (academics, consultants and manufacturers represented). Details of these visits are provided in Appendices 1 and 2
- a technology transfer workshop in Beijing with additional site visits, October 2003. Further details are attached as Appendix 3
- reports and dissemination material.

The participants in the project were Wardell Armstrong, University of Nottingham (UoN), State Administration of Coal Mine Safety (SACMS), China Coal Information Institute (CCII), China Coal Research Institute (CCRI) Chongqing Branch. The key contacts are listed in Appendix 4.

Many other organisations and companies, both in the UK and China, contributed to the project. These included; Alkane Energy, Edeco, Future Energy Solutions (FES), Health and Safety Executive (HSE), Nash-elmo, South Birmingham College, Trolex, UK Coal, Heilongjiang Development and Planning Commission, Songzao, Hegang, Jincheng, Huainan, Kailuan, Yangquan and Fushun Coal Mining Groups, North China Institute of Science and Technology, CCRI Coal Safety Division (MA).

The overall total cost of the project was £447,460. The project was jointly funded by the UK Department of Trade and Industry's (DTI) Cleaner Coal Technology Transfer Programme (42%), the UK participants and UK industry (35%), and the government of China, participating institutes and companies (23%). The work of the China research teams was co-ordinated by the China International Centre for Economic and Technical Exchanges (CICETE), Wardell Armstrong was responsible for the overall project management and FES supervised the project on behalf of the DTI. The project started in November 2001 and was initially planned for a duration of 18 months. The initial contract was subsequently extended to 31 December 2003 to include for the organisation of a technology transfer Workshop in Beijing. The Workshop, held on 30-31 October 2003, was organised by the China Coal Information Institute and attracted over one hundred delegates.

1. INTRODUCTION

1.1 Background

The UK Department of Trade and Industry's (DTI) Cleaner Coal Technology Transfer Programme has supported three UK-China projects on the production and use of coalbed methane (CBM). Previous projects have examined the potential for extracting gas from virgin seams (VCBM) and from abandoned coal mines (AMM) in China. This, the final study of the trio, features gas control technology (GCT) and examines the technology of coal mine methane (CMM) capture and control in working coal mines.

The GCT project was initiated in November 2001 at the International CMM/CBM Investment Symposium in Shanghai, China and completed in December 2003. The project aims to improve gas drainage in coal mines and promote greater use of the captured gas. It thus combines the important topics of mine safety, greenhouse gas emissions reduction and clean energy production. The importance of GCT to the coal mining sector in China is clear given 2436 reported gas-related fatalities, 128Mt CO_2 equivalent emissions and that only approximately 10% of the methane potentially available was captured and used (2001). The ability to achieve higher gas captures could bring additional advantages to working mines in terms of increased coal production without exceeding statutory gas emission concentrations in airways, reduced ventilation costs and increased coal reserves by enabling more gassy coals to be worked economically. Improved gas utilisation means lower greenhouse gas emissions, reduced energy costs and the potential to displace some coal burning.

The government of China has implemented measures to strengthen inspection and enforcement of safety regulations in Chinese coal mines. Gassy mines are required to drain gas, although not necessarily to the surface. The State Administration of Coal Mine Safety (SACMS) believe that to ensure safe conditions, gassy mines should drain gas both before and after mining (pre-drainage and post-drainage). Although this guiding rule is well meant, the prescriptive requirement does not encourage account to be taken of the gas emission characteristics of the workings or the geological and mining conditions when determining the most appropriate methane drainage strategy. Another important regulation is that mines should only produce coal within the limits of the available ventilation. Coal mines in China, therefore, need to predict the maximum coal production safely attainable with their existing ventilation and gas drainage systems which have been designed to national, but out-dated, design standards. In contrast, commercial coal mining companies from other countries design ventilation and gas drainage to ensure that planned coal production can be achieved safely.

Growing concerns about continuing mining accidents in China has led the State Council to allocate US$265 million (£145 million) for expenditure in 2004 to help improve coal mine safety, particularly with respect to mine gas control. This will complement the US$481 million (£263 million) of State bonds spent in improving coal mine technology in the past two years.

A fine of US$2.6 million (£1.4 million) imposed on owners of a Shanxi mine, where 72 out of the 87 workers were killed by a gas explosion, should help to strengthen pressure on mine management to change from a "production first" to a "safety first" mindset. New regulations introduced in Shanxi in August 2003 state that senior officials at all levels will be held responsible for coal mine safety and failures will be punished. Dereliction of duty by local government leaders could result in dismissal. This is an important regulation as city and county governments in coal mining areas are often dependent on local mines for fiscal income and their allegiances are divided.

1.2 Methane emissions from coal mines in China

More than 95% of the coal mined in China originates from underground operations. Some 300 of the Key State-owned coal mines are classified as gassy or outburst prone. By 2002 there were 193 coal mines with methane drainage systems draining about 1.15 billion m^3 of gas (a 17% increase on the previous year) of which only 0.5 billion m^3 was used. Assuming an average specific emission of $10m^3$ of methane per tonne of coal mined, Chinese mines liberated almost 14 billion m^3 of methane in 2002 from a coal production of 1.39Bt. If, on average, 30% of the gas could be captured in drainage systems, some 4.6 billion m^3 of gas is theoretically available each year and hence an additional methane utilisation and mitigation potential of 4.1 billion m^3. The growth potential for CMM utilisation schemes is therefore large. The total potential revenue, assuming half of the gas can be commercially exploited and a price of 1.0 yuan RMB/m^3 of pure methane obtained, is US$247 million (£135 million) per year. China is the world's largest CMM source awaiting commercial exploitation. Coal production is expected to rise steadily, 1.6Bt being mined in 2004 with a corresponding increase in gas emission.

The coal sector in China has undergone substantial reform to improve efficiency, safety and price stability. Large numbers of small illegal and irrational mines have been closed and returns-to-scale are being achieved by larger mining enterprises formed by merger and acquisition. Initial estimations indicate that CMM emissions could have increased by more than 1 billion m^3 as a result of replacing small mine capacity with large longwall operations. This is due to the greater extent of strata disturbance and hence gas release around a longwall compared with the room-and-pillar method employed in most small mines.

CMM drainage technologies only capture a proportion of the gas released into mine workings. Captures achieved in individual mining panels can typically range from 30 to 80% depending on the drainage technology used, the geology and the mining conditions. Technologies also exist for removing the diluted methane from mine ventilation air (Ventilation Air Methane or VAM) but these are not yet commercially viable. The potentially drainable CMM resource in China achievable using tried and tested technology is currently so large that treatment of mine ventilation air is not yet warranted. Gas capture and use could be enhanced significantly through improvements in the management of existing technologies and control practices. There is a danger that diversion of attention to attempt commercial use of methane in ventilation air will reduce the drive on improving the capture and control of gas in the mine to ensure safer working conditions.

1.3 Gas control technology status

Experience of gas control practises in Chinese coal mines and technology needs were gained through field studies at mine sites in Hegang (Heilongjiang Province), Songzao (Chongqing), Jincheng (Shanxi Province) and Huainan (Anhui Province). Visits were also made to Fuxin (Liaoning Province), Kailuan (Hebei Province) and Yangquan (Shanxi Province) to examine and discuss coal mine methane utilisation activities.

A survey of perceived gas drainage problems was undertaken by sending questionnaires to Coal Mining Groups. Detailed replies were obtained from 16 Groups, largely representing areas with the most gassy mines. The results are summarised in Table 1. The study revealed that gas drainage performance is often hampered by inadequate drilling equipment. Lack of monitoring and control facilities also hinders methane control in the mine environment and results in quality variations in drained gas. Too much gas is vented, even where utilisation schemes have been introduced, and mines often have difficulty raising finance to construct schemes. Analysis indicated that inadequate and ineffective management was at the root of many problems with difficulties compounded by poor equipment, insufficient measurement and monitoring facilities and a lack of technical knowledge of emission and gas control processes among some practitioners.

Table 1. Survey of gas drainage problems

Perceived problem	Survey result %
Drilling difficulties	14
Inadequate monitoring	19
Poor performance	33
Low use of gas	12
Lack of funds	21

Gas drainage in China involves a combination of both pre and post drainage methods. Various post-drainage methods are currently used. Most are underground methods as the application of surface goaf drainage is limited due to seam depths, surface access costs, terrain, inrush hazards and lack of experience. Underground goaf drainage is widely practised using pipes laid in the waste, cross measure boreholes and roadways driven above the working panels. Cross measure boreholes are drilled from rock galleries driven below the worked seam to intersect coal seams above and hence their effective lengths for gas drainage are short relative to the overall borehole lengths. A project undertaken by contractors from the USA demonstrated effective drainage from a guided longhole drilled above a longwall panel at Daxing mine, Tiefa, Liaoning Province. Three 1000m long boreholes were drilled about 20m above the longwall panel, parallel to the access roadways. Flows as high as $11m^3min^{-1}$ were obtained on individual boreholes. This application has not been successfully replicated either at Daxing, or elsewhere in

China due to difficult geological conditions, the high cost of the imported drilling equipment and spare parts, complexity of the drilling and lack of skills. A method of draining gas using roadways driven above the longwall panel was used successfully for many years in the Saar coalfield in Europe and a similar method is in use at Huainan and Yangquan mines. However, this method is costly and may be difficult to justify when the mines are subject to more open competition.

Pre-drainage technologies are of particular interest at coal mines in China due to:

- a need to drain outburst prone strata and seams in advance of working
- regulations requiring drainage before and after mining
- thick seams often being mined, some with relatively high gas contents, where a high proportion of the gas emission originates from the worked seam
- significant advances in pre-drainage technology achieved elsewhere in the world.

Of particular interest is longhole drilling technology. The Asian American Company Inc. (AACI) has successfully drilled long in-seam degassing boreholes at Daning mine near Jincheng. To ensure consistency of drilling and drainage to support their high driveage and coal production rates, AACI employed an experienced Australian drilling contractor. Jincheng Coal Mining Group has also reported success with in-seam drilling at Sihe mine. Daning and Sihe mines are working a thick coal seam in the South Qinshui coalfield that has a well-developed fracture system that lends itself to pre-drainage. However, similar geological conditions and coal characteristics are not found elsewhere in China and therefore the advanced drilling technology may not be transferable to other coalfields.

Many other coalfield areas in China exhibit much lower permeability than the South Qinshui coalfield. Effective pre-drainage is difficult to achieve in low permeability coal, and in the absence of an outburst risk it is of little benefit as a safety measure. Both USA and Australian contractors experienced difficulties in trying to drill a long in-seam borehole at Songzao. Longhole in-seam drilling, using imported drilling equipment, also failed at Fushun, Pingdingshan and Huainan due to problems with soft coal and high stresses. There is a clear need to examine the drilling systems and technology in use in China and to question whether pre-drainage GCT solutions currently being considered are appropriate to the geological and mining conditions.

1.4 Use of coal mine methane

Most of the CMM used in China is distributed via pipelines to mining communities and neighbouring cities for domestic use, mainly cooking. Some CMM is used in colliery boilers and for small-scale power generation. Additional uses being considered include vehicle fuel and chemical feedstock. Gas flows supplied to CMM utilisation schemes are typically in the range 5 to 100 million m^3/a. The demand from domestic consumers varies widely both daily and seasonally, gas often being vented in summer. In comparison, a power generation scheme can consume gas at a steady base load rate throughout the year, offering higher returns on investment and greater reductions in greenhouse gas emissions as more gas will be used.

There are few CMM power generation schemes in China because local authorities and mining enterprises, for social reasons, often consider domestic consumers as a priority. Achieving an electrical grid connection is problematic at present. However, there is potential to develop more CMM schemes to supply power to the mines themselves (cf. Tower colliery in the UK) as they have a predictable base electrical load and offer a number of advantages as a customer for generated power.

Financing of CMM utilisation schemes is a problem. After years of poor performance and large losses, many mines have poor credit ratings with banks. Many schemes are too small to interest international financing institutions and private investors. There are, however, some notable exceptions, the largest being the Jincheng CMM project based at Sihe mine which will use an ADB loan to develop a $120MW_e$ power plant to generate electricity for local distribution. The commercial feasibility of CMM projects can be improved by combining schemes to increase scale and selecting the gas use which brings the highest returns and for which there is a market. Increased transparency, streamlining of approvals procedures and gas price stability will help to create an environment to attract both domestic and foreign investors. The Clean Development Mechanism (CDM) may become an important financing mechanism for assisting marginal utilisation schemes to be brought into operation.

Measurement, monitoring and control procedures and technologies, an integral part of an effective utilisation scheme, tend to be basic mainly due to financial constraints. Domestic users appear to be highly tolerant of gas pressure and quality fluctuations. A feature of most schemes is that the mine forms a CMM company which accepts the gas as delivered by the mine's gas extraction stations and delivers it to the customer. The management of the CMM scheme and the management of the methane drainage system are therefore virtually independent. Considerable improvements could be made underground in some instances to improve gas flow and quality, which in turn would benefit safety conditions. One way of creating an impetus to drive improvement would be for the mine to receive payment for gas supplied to the CMM scheme, which met the minimum gas flow and quality requirements. Bonus payments could be offered by the CMM company to the mine based on revenue gained from sales of gas supplied in excess of the contracted amounts. Such incentives would improve the standards of schemes and the quality of product available to customers. Proper metering of customer supply and usage should also be installed and customer charges determined by heat value delivered.

1.5 Barriers facing the introduction of new technology

China could benefit from a wide range of imported gas control technology for its mines and CMM utilisation schemes. However, some companies are reluctant to enter the China market for various reasons including:

- concerns about copying equipment designs. Patent law is being more strongly enforced but manufacturers still need to exercise caution

- equipment being blamed for client failings thus damaging the credibility of the manufacturer in the international market place. For example, inappropriate equipment selection, inadequate maintenance and lack of investment in training of operators. Suppliers should recognise the importance of providing “whole life cycle” support to customers to ensure equipment is properly selected, commissioned, used, serviced and refurbished to ensure maximum availability and performance. Training programmes should be included as part of equipment packages
- the higher cost of imported equipment can deter some Chinese buyers but many understand the benefits of using robust, imported equipment manufactured to high standards with high grade materials and with performance abilities in excess of domestic equipment
- imported coal mining electrical equipment must be submitted to an assessment, inspection and approvals process before it can be used in a mine in China. This process is cumbersome, costly and time consuming. Unless exempted, explosion proof and intrinsically safe equipment cannot be used in a Chinese coal mine unless it carries the MA (Mei Anquan) mark. The Chinese standards are based on an outdated international standard EN5004 (1968) which not only hinders import of modern, safe, efficient mining equipment into China, but also deters Chinese manufacturers from modernising their designs and participating fully in international markets. This barrier should be removed to enable coal mines to source the most effective equipment for their needs. MA represents an unnecessary impediment to the introduction of the best international technologies
- tendering procedures are not always transparent and are rarely performance based leaving little opportunity and encouragement for innovation.

Current GCT technology requirements are being primarily driven by:

- new regulations on gas drainage and gas control to reduce explosion risks
- a need to replace obsolete methane drainage borehole drilling machines
- growing interest in CMM utilisation and power generation for clean energy and greenhouse gas mitigation.

2. SAFETY

2.1 Mine gas accidents in China

A combination of a lack of adequate enforcement, and the following mine conditions contribute to high annual accident rates in the Chinese coal industry:

- 95% of coal production comes from underground mines
- the average mining depth exceeds 400m
- almost half of the Key State-owned coal mines are classified as gassy or outburst prone
- coal in 58% of mines is prone to spontaneous combustion
- 88% of mines are considered at risk from dust explosions.

China has been improving it safety standards and enforcement capabilities, particularly in Key State-owned mines. However, accident rates in China's coal sector are far below acceptable International safety standards. During 1980 to 2001, fatalities in coal mine accidents in China reduced from 8.2 to 4.9 persons/Mt of which fatalities in the large Key State-owned coal mines (KSOCM) reduced from 4.5 to 1.2 persons/Mt. However, the fatalities in the small township mines in 2001 remained very high at 11.8 persons/Mt. Gas explosions and roof falls have caused the most deaths (2436 and 1879 respectively). Other causes include flooding, transportation, fire, mechanical and power. The predominance of gas accidents as a cause of fatalities in recent years is shown in Table 2. Despite continuing improvements, fatality rates in China's coal mines are still among the highest in the world. The Government of China recognises the problem and is determined to respond positively through the auspices of the State Administration of Work Safety (SAWS).

Table 2. Deaths caused by mine gas accidents (1994 to 2001)

Year	Total coal mine fatalities	Fatalities caused by mine gas accidents	% of accidents caused by gas	Annual coal production (Mt)
1994	5855	2257	39	1223
1996	5602	2973	53	1374
1997	6141	3502	57	1325
1998	6304	3218	51	1233
1999	6478	3209	50	1045
2000	5798	3132	54	999
2001	5670	2436	43	1106

Source: "China Coal Industry Yearbook" of corresponding years.

In assessing data on the causes of fatal accidents in China's coal mines consideration must be given to the different scales of mining operations. The accident statistics (Table 3) record a significant difference in the occurrence of gas related fatalities in the different types of mines:

- Key State-Owned Coal Mines (KSOCM) which are large fully or partially mechanised mines owned by Provincial governments

- State-Owned Coal Mines (SOCM) which are medium to small scale operations owned by local city and county governments
- Township and Village Coal Mines (TVCM) which are mainly privately owned.

The fatalities expressed per million tonnes of coal mined are shown in Table 4. The high incidence in the TVCM arises from a combination of poor safety standards and a low level of mechanisation so the number of miners at risk is highest.
The seriousness of a coal mine accident is classified according to the number of deaths. More than three deaths is considered serious and more than ten deaths very serious.

Table 3. Fatalities caused by gas accidents in different types of mines (1999 to 2001)

Year	Fatalities caused by mine gas accidents	% of all coal mine fatalities	KSOCM		SOCM		TVCM	
			Fatalities caused by mine gas accidents	% of all fatalities caused by mine gas accidents	Fatalities caused by mine gas accidents	% of all fatalities caused by mine gas accidents	Fatalities caused by mine gas accidents	% of all fatalities caused by mine gas accidents
1999	3209	50	203	6.3	354	11.0	2487	77.5
2000	3132	54	389	12.4	292	9.3	2279	72.7
2001	2436	43	171	6.7	384	15.4	1801	73.9

Source: "China Coal Industry Yearbook" of corresponding years.

Table 4. Summary of coal mine fatalities in China per Mt coal mined (1990 to 2002)

Year	Total	KSOCM	SOCM	TVCM
1990	6.16	1.43	5.00	12.79
1991	5.21	1.06	6.20	10.10
1992	4.65	1.01	4.50	9.20
1993	4.78	1.12	4.90	8.50
1994	5.15	1.19	4.82	8.32
1995	5.03	1.16	4.90	8.13
1996	4.67	1.17	4.02	7.70
1997	5.10	1.45	4.13	8.44
1998	5.02	1.02	3.76	8.60
1999	5.30	0.92	3.73	12.95
2000	6.10	1.90	4.19	14.61
2001	5.07	1.26	4.64	14.81
2002	4.64	1.25	3.83	12.10

Records show that for all mine incidents with more than three fatalities gas accidents account for between 71 to 83% of total deaths (Table 5).

Table 5. Deaths caused by mine gas accidents involving more than three fatalities (1991 to 2001)

Year	1991	1995	1996	1997	1998	1999	2000	2001
Total fatalities	1862	3020	3352	3692	3160	3121	3188	2602
Fatalities caused by mine gas	1364	2162	2585	3080	2470	2489	2662	1903

accidents								
% of total coal mine fatalities	73	71	77	83	78	79	83	73

Similarly, records show that for all mine incidents with more than 10 fatalities gas accidents account for 76 to 92% of total deaths (Table 6).

Table 6. Deaths caused by mine gas accidents involving more than 10 fatalities (1991 to 2001)

Year	1991	1995	1996	1997	1998	1999	2000	2001
Total fatalities	733	1014	1378	1917	1463	1246	1405	1015
Fatalities caused by mine gas accidents	653	816	1158	1759	1175	1060	1326	772
% of total coal mine fatalities	89	80	84	92	80	85	94	76

2.2 International comparison of coal mine accident statistics

Table 7 shows that the coal mines of China are significantly more hazardous than those in other major coal mining countries. Improvements of two orders of magnitude are needed to bring safety into line with international standards.

Table 7. World wide comparison of coal mine fatalities

Country	Year				
	1996	1997	1998	1999	2000
China					
No. fatalities	6404	6753	6134	5518	5798
Fatalities per Mt mined	4.67	5.10	5.02	5.30	5.90
USA					
No. fatalities	39	30	29	34	38
Fatalities per Mt mined	0.04	0.03	0.03	0.03	0.04
India					
No. fatalities	146	165	146	-	-
Fatalities per Mt mined	0.48	0.52	0.46	-	-
South Africa					
No. fatalities	45	40	42	28	30
Fatalities per Mt mined	0.22	0.19	0.19	0.13	0.13
Poland					
No. fatalities	45	-	33	20	28
Fatalities per Mt mined	0.25	-	0.28	0.18	0.26
Russia					
No. fatalities	179	241	139	104	115
Fatalities per Mt mined	0.74	1.06	-	0.44	0.46
UK					
No. fatalities	-	4	4	0	0
Fatalities per Mt mined		0.13	0.15	0	0

2.3 Classification of gassy mines

The description of a gassy coal mines in China is identified in the "Coal Mine Safety Regulation". A gassy mine is one with a specific emission of greater than 10 m^3/t. Similarly, coal mines with a history of coal and gas outbursts (at least one) are classified as outburst prone. A study undertaken in 1998 of all KSOCMs shows some 29% to be gassy, 21% outburst prone and the remaining 50% non gassy. Figures for 2001 shows a similar split with gassy mines 29%, outburst prone mines 19% and non gassy mines 52%.

Currently there are approximately 600 KSOCM, 2400 SOCM and 25,000 TVCM (Wang Hao 2003). A recent survey of the KSOCMs carried out as part of this project indicates that in 2002, after a review of classifications about 32% are considered gassy, 31% outburst prone and the remaining 42% non gassy mines.

2.4 Policy and regulations on gas control in China's coal mines

The third session of the State Council Work Safety Commission (2002) confirmed that safety in coal mines should focus on gas control stating that coal mines should adhere to the principle of pre drainage of gas, gas monitoring and testing in the course of production and deciding on coal production rate according to secured ventilation.

The State Administration of Coal Mine Safety (SACMS) recently stated a number of key objectives relating to gas control policy, these being:

1. all coal mines listed as gassy or outburst prone mines must construct their gas drainage systems in accordance with the relevant laws and regulations
2. small-sized coal mines shall undergo ventilation capacity check-ups to ensure their production capacity matches the ventilation capacity and measures taken to prevent over-capacity coal production (due to a coal supply shortage in winter 2004 this regulation does not appear to have been enforced)
3. coal mine safety supervision authorities and coal industry management authorities shall organise special inspections of gassy and outburst prone mines. Those (gassy) mines without mine gas drainage systems, or those where mine gas drainage systems are not complete, shall be fined or receive administrative penalties and ordered to rectify their situation within a required time limit or to stop production activities until rectification is complete.

China's mining laws and regulations are highly prescriptive. Conditions are specified for classifying a mine as gassy, for the introduction of gas drainage and for safe operations with in the mine. The current philosophy seems to be that if a mine is classified as gassy or outburst prone than it should install and operate a methane drainage system irrespective of whether the conditions that necessitate its introduction are met.

2.5 Comparisons with UK legislation

The most common methane concentration warning criteria used in UK coal mining legislation are 1.25% and 2%. The lower concentration value is considered to represent the lowest methane concentration that can be detected on a flame safety lamp. More importantly, these criteria incorporate a factor of safety relative to the lower explosive limit of methane in air of 5%.

In China there is a requirement for the cessation of work and withdrawal of men:

- if methane concentration in the return airway of a coalface exceeds 1% (compared with 1.25% in the UK unless the return is electricity free, and hence the risk of accidental ignition lower, then the limit is 2%)
- if there is more than 1.5% methane on the working face or within 20m of an electric motor (1.25% applies in the UK).
- drained gas must have a methane concentration of 30% or more to be used (35% in the UK at a working mine but can be reduced to a lower concentration with an exemption from the mine safety inspectors subject to the installation of additional specified safety protection).

The differences in methane concentration action and alarm levels between the UK and China are not significant and certainly cannot explain the contrasting gas control safety record.

3. GAS EMISSION PREDICTION

3.1 Background and theory

Estimations of the expected gas flows from the working area of a mine are needed to facilitate ventilation planning and an assessment of methane drainage requirements. Gas emission prediction usually involves one or a combination of empirical, numerical, analytical or statistical techniques. Predictions may be applicable over a time basis of a few minutes or a few weeks. They may assume steady coal production or allow for variable rates of advance. Some models are designed specifically to predict emissions in longwall sections, others to predict emissions in headings. There are also a substantial number of coalbed methane simulators, which have been developed to assess the gas production potential of virgin coal seams. Emissions of gas which occur as a function of the rate of strata disturbance, assuming a fixed geology and mining method, can generally be represented by simple models.

Specific emission method

The most common method of gas prediction utilises specific emission values (termed *relative emission* in China) obtained from previous experience of a mine, a particular area of a mine or of neighbouring mines where similar mining methods are being used in similar geological conditions. District ventilation and gas drainage planning is often adequately served by this approach. Occasionally, estimates are scaled to take account of known differences in seam methane contents.

For many practical mining purposes this simple method is considered satisfactory provided that factors which may lead to unusual emissions can be identified in advance. Implementation of the method is assisted by systematic measurement, recording and processing of mine environmental data.

Specific emission is used as a ventilation planning parameter in many collieries throughout the world, but not always correctly. Emission on a particular day depends not only on the rate of advance achieved on that day but also on previous days - gas continues to flow when coal production stops. The parameter must therefore be determined from measurements made over a period of at least a few months of steady production, and preferably longer. The time-scale over which measurements are made in China's coal mines for this purpose are uncertain.

The observed relationship between specific emission and face advance or coal production rate derived using spot measurements exhibit scatter. Flows measured near the beginning of a production shift would be lower if the previous shift had not produced coal than if they had been taken towards the end of the current shift because of the general decrease in background due to periods of non production. When a high coal production week follows a low production week, the emission in that week will be lower than for continuous high production.

Empirical methane prediction methods

Empirical gas emission prediction methods for longwall workings have been developed in most major coal producing countries. The mathematical methods are generally simple, requiring few input parameters and some are specific to a particular country or coalfield. The longwall gas emission prediction methods consider some or all of the following gas emission sources:

- coal seams in a gas emission zone above and below the worked seam
- rock strata in the gas emission zone
- the worked seam itself including the coalface and any unworked coal left in the roof and floor
- coal on conveyors.

The gas emission zone is the volume of ground above and below the worked seam that is ‘destressed’ by the action of mining.

3.2 Gas prediction in UK coal mines

Gas emission in coal mines

Underground coal production in the UK is facilitated by a retreat longwall mining method typically involving two parallel access roads, up to 300m apart and linked by a mechanically supported coal face.

Gas is emitted from the coal exposed on the coal face, coal broken by the cutting machine and coal on the conveyors which transfer the product to the surface. As each strip of coal is removed, the face supports are moved forwards allowing the now unsupported area (‘waste', `goaf' or `gob') to collapse. A consequence of the caving is that seams above and below the worked horizon are also disturbed and release gas. The faster the coal is extracted, the higher the gas flow into the district.

In addition to the gas released from coal seams, gases can also be released from conventional sandstone reservoirs when they are disturbed by mining activity. Gas can also be introduced onto a longwall district from old workings which emit gas into the intake ventilation air. Emissions from old workings are usually exacerbated by rapid falls in barometric pressure.

Coal seams in the UK are generally of low permeability and gas does not generally flow readily from coal seams unless they are disturbed and fractured by mining activity.

Gas release processes

Longwall caving can theoretically de-stress strata from 160 to 200 m above and down to 40 to 70m below the worked seam. Gas sources within the disturbed zone will release a proportion of their gas which will flow towards the workings. The extent of the disturbance may be reduced where strong beds are present in the strata. Seams lying 40m or more below longwall workings do not always release significant gas flows. The extent of the zone disturbed by longwall mining, at a particular location, depends on the length of the coalface, the height of the coalface, the strata strength, the depth of working and effects of previous workings. The rate of gas flow into a particular mining district depends on the gas contents, number and thickness of seams in the disturbed zone, the proximity of the seams to the worked seam, the age of the district and, most importantly, the rate of advance or retreat.

The gas flow on the coalface correlates closely with the coal cutting activities but the emissions from seams above and below the workings depend not only on the current day's retreat rate but also on that of previous days. This occurs due to the cumulative effect of progressive disturbance on gas emission.

Prediction of gas emission rates

The likely gas emission into a longwall district can be predicted using a method developed by the former British Coal Corporation (Dunmore & Kershaw, 1984) which takes account of the above factors. The British Coal gas prediction method is unique among empirical prediction methods in that it takes account of the age of a working longwall i.e. a gradual increase in specific emission over the life of a district due to the cumulative increase in the volume of coal contributing to the gas flow. Account is also taken of gas removed by previous under or overworking of a longwall. Predicted gas flows from coal seam sources made using this method in the UK have been generally within 20% of measured flows.

More detailed numerical models of stress regimes, permeability enhancement and gas flow around longwalls have been developed at the University of Nottingham (Ren & Edwards, 2000). These models have been used for research into specific mine gas problems and to further the understanding of gas emission phenomena in coal mines

3.3 Gas prediction in China's coal mines

Application of the UK method

A simplified gas emission model based on the British Coal method (Creedy & Kershaw, 1988) was modified and applied to a longwall in China at Songzao's Datong No.2 mine. The results were compared with measured data and Chinese predictions. This simplified gas prediction model has been widely used in various countries, including UK, Canada and South Africa since its inception in 1987 and has proved to be remarkably accurate in most instances. The model considers that all seams within a zone up to 150m in the roof and 40m in the floor release gas, the quantity depending on the thickness of coal, proximity to the workings and initial seam gas contents. Coal seams in the zone disturbed by mining are considered to be the only sources of gas. The method facilitates estimation of specific emission, district methane flows and air requirements to ensure safe dilution of gas in the return airways of a well-established longwall district. The approach also allows maximum coal production to be calculated to comply with the regulation that production should be maintained within the limits controllable with the existing ventilation system (having taken due account of gas drainage).

The model assumes:

- simple geology obtains, i.e. the strata are horizontal or gently dipping
- coal seams are the sole source of gas
- the strata are of low permeability, therefore gas is only released from beds disturbed by mining
- the proposed method of extraction is fully caved longwall mining
- pre drainage uniformly reduces the gas content of the worked seam and any uncut roof and floor coal.

Data from a study site on N1709 face at Songzao's Datong No.2 mine was used to evaluate the method. The geological data are shown in Table 8. The measured total gas flow was 546 ls^{-1} and the predicted flow 506 ls^{-1}. Considering the lack of control over the measurement process this is a close result.

Table 8. Typical geological section

Seam Ref	Thickness of coal seam (m)	Distance to the worked seam (m)
2	0.26	9.4
3	0.25	7.7
4	0.74	6.0
5	0.22	1.9
6	0.19	1.2
7 worked seam	**1.23**	**0**
8	2.30	10.0

To demonstrate the importance of pre-draining thick coal seams worked by high production longwalls, gas flow predictions were made for Sihe mine, Jincheng under various conditions to examine the possible constraints on coal production. At Sihe a 220m log, 4m high face is cut in a 5.7m thick seam. The seam has a gas content of $15m^3t^{-1}$. At a production rate of 4 Mtpa, the prediction model indicates 804 ls^{-1} of gas could be captured from adjacent seams and 1571 ls^{-1} emitted into the airways requiring 157 m^3s^{-1} of air to dilute methane peaks to 1.5%. Such an air quantity is too high and impractical. However, if 60% of the gas is removed from the worked seam prior to mining (pre drainage) the gas emission into the airway can be reduced to 749 ls^{-1} and the air requirement to 75 m^3s^{-1}. The air demand on the longwall district could be reduced further by the use of non travelling bleeder roads. The estimated average flow of gas from pre drainage boreholes under these conditions is 822 ls^{-1}. The magnitudes of the above results should be regarded as preliminary pending the availability of more accurate gas content, seam quality and production information. Some tuning of the seam emission function may also be necessary, however, the principle is very clear.

<u>Application of the Chinese method</u>

Empirical gas prediction methods are routinely used in coal mines in China to assist ventilation and methane drainage design. These calculations are often included in new mine feasibility studies to assess whether a mine is likely to be gassy. In some instances the gas content used in the emission prediction is estimated which can lead to significant error. Seam gas content measurements and estimation are undertaken by specialist institutes, the most notable being Fushun and Xi'an branches of China Coal Research Institute (CCRI). Chongqing branch of CCRI specialises in designing gas control and methane drainage systems.

CCRI Chongqing branch undertook a gas emission prediction for the No.7 seam study site in Songzao's Datong No2 mine to compare with the UK prediction. Their approach is demonstrated in the worked example below.

Key coal and production characteristics of the working face in No.7 seam are:

- gas content 18.6 m^3t^{-1} (raw coal)
- ash content 22.6%
- moisture content 1.7%
- volatile matter 9.1%
- density 1.5 $t.m^{-3}$
- average development rate 93 m/month
- coal face fully caved
- working face 990m long x 140m wide
- face retreat rate 2.4 $m.d^{-1}$
- coal recovery coefficient 97%

<u>Prediction of gas emission from a working coal face</u>

Calculation of gas emission in worked seam (including surrounding rock)

$$q_1 = K_1 \times K_2 \times K_3 \times m \div m_0 (X - X_c)$$

Where

q_1 — gas emission from the working seam (m^3t^{-1})

K_1 — gas emission factor of surrounding rock, taking K_1 as 1.20 during roof control by full caving

K_2 — gas emission factor of uncovered coal in the face K_2=1/ is the recovery rate of the face.

K_3 — influence factor of gas pre-discharge in preparatory workings of mining district on the gas emission from coal body of the extracting seam. When coal is extracted by longwall retreat mining, K_3 is determined by following formula K_3= L-2h/L

L — length of the working face (m)

H — width of gas pre-drainage zone in a roadway, it relates to the coal type and the exposing time of the roadway side and here h = 9m

m — thickness of coal seam (m)

m_0 — mining thickness of coal seam, m.

Thus:

$$q_1 = 1.20 \times 1 \div 0.97 \times (140 - 2 \times 9) \div 140 \times 1.23 \div 1.23 \times (18.63 - \frac{100 - 22.64 - 1.68}{100} \times 5)$$

= 16.0 m^3t^{-1}

Calculation of gas emission from adjacent seam

$$q_2 = \sum_{i=1}^{n} \frac{m_i}{m_0} \bullet K_i \bullet (X_i - X_{ic})$$

Where

q_2 — gas outflow in working face from adjacent seam (m^3t^{-1})
m_I — coal thickness of No. i adjacent seam (m)
m_0 — mining thickness of extracting seam (m)
Xi — gas content of No. i adjacent seam (m^3t^{-1})
X_{ic} — residual gas content of adjacent seam (m^3t^{-1})
K_I — gas discharging rate of No. i adjacent seam which is affected by mining, it is calculated by formula: K_i=1-h_i/h_p
h_I — vertical distance from No.i adjacent seam to extracting seam, m;
h_p — failure range of surrounding rock which can discharge gas from adjacent seam to working face while adjacent seam is affected by mining of extracting seam, m; h_p is calculated by following formula:

- for upper adjacent seam: h_p=$K_y m_0$ 1.2+cos
- for lower adjacent seam: h_p=35 to 60m when inclined seam or gentle inclined seam is extracted, and when the dip angle of the seam being mined is 8°, takes h_p=40m
- — dip angle of coal seam °
- K_y — it depends on the factor of roof control form, when mining thickness is 2.5m and roof is controlled by full caving, Ky=60

So the predicted gas emission in the adjacent seam is:

$$\begin{aligned} q_2 &= \frac{18.63-(100-22.64-1.68)\times 5 \div 100}{1.23}\{0.19\times[1-\frac{1.24}{60\times 1.23\times(1.2+\cos 8)}] \\ &+0.22\times[1-\frac{1.87}{60\times 1.23\times(1.2+\cos 8)}]+0.74\times[1-\frac{5.99}{60\times 1.23\times(1.2+\cos 8)}] \\ &+0.25\times[1-\frac{7.71}{60\times 1.23\times(1.2+\cos 8)}]+0.26\times[1-\frac{9.41}{60\times 1.23\times(1.2+\cos 8)}]\} \\ &+2.3\times 0.75\times\frac{20-(100-22.64-1.68)\times 5 \div 100}{1.23} \\ &= 42.07 m^3/t \end{aligned}$$

The total gas emission volume (relative gas outflow) is:

$$Q = q_1+q_2=16.01+42.07=58.08 \text{ m}^3\text{t}^{-1}$$

When daily advance of a working face reaches 2.4m, the absolute gas emission is:

$$Q = \frac{58.08\times140\times1.23\times2.4\times1.55}{24\times60} = 25.84 \text{ m}^3\text{min}^{-1}.$$

<u>Verification of gas prediction</u>

Assessment of measured data from actual coal production shows a maximum gas emission for the working panel of 20.0 m^3min^{-1}. The predicted gas emission was 25.8 m^3min^{-1}. The difference may be due to gas drainage from adjacent seams reducing the gas emission into the working face.

4. GAS DRAINAGE TECHNOLOGY

4.1 UK technology and methods

Control of gas in UK coal mine workings

Effective gas control is essential for safe working and involves providing either:

- sufficient air to dilute and disperse gas at all levels of planned coal production; and, if necessary
- sufficient gas drainage to ensure no more gas enters the mine airways than can be diluted to below statutory limits by the available ventilation air.

In the UK gas drainage involves drilling boreholes from the return roadway at an angle of typically 60^0 back over the face intersecting the de-stressed strata behind the coal face. Where advancing methods are used gas drainage boreholes are drilled over the goaf from the return roadway just behind the face line. As the face advances more boreholes are added. On a retreating coal face, boreholes are usually drilled behind the face line where special support and ventilation arrangements are needed to enable the gas drainage boreholes to be drilled safely. Poor roof conditions, or floor lift behind the face can create access difficulties and seriously delay borehole installation. To reduce the access problem and ensure a safe drilling environment, boreholes are sometimes drilled from the return roadway before the face passes. Limited success has been achieved with pre-drilling but consistency of capture and high capture efficiencies are rarely achieved due to the effects on the boreholes of high stresses around the face area.

Gas capture efficiencies on longwall faces typically lie between 50 to 70% of the total gas on advancing faces and from 30 to 50% of the total gas on retreat faces. Higher capture efficiencies (70% plus) can be obtained with good practice in favourable geological and mining conditions (i.e. where all seam gas sources are in the roof and more than, say, 20m above the workings; stable roadway and roof conditions obtain). Lower captures tend to be achieved on retreat faces compared with advancing faces because the producing boreholes cannot always be monitored, adjusted or maintained once they are more than 15 to 20m behind the face. In contrast, all the boreholes on an advancing face remain accessible and available for the full life of the district.

Gas contents of coal seams currently being worked in the UK range from less than 1 m^3t^{-1} up to around 15 m^3t^{-1}.

Design of gas drainage systems

Gas drainage requirements are determined on the basis of expected gas emission rates. The likely variability in gas flow and quality can be obtained from a study of the mine development plan, the geological conditions, seam gas content data and historical gas emission data. Account must be taken of changes in seam gas content across the reserves and geology together with the degassing effects of previous workings in a colliery where more than one seam has been worked.

The methods used for capturing coal seam gas in coal mine workings are conventionally classified as either pre-drainage methods or post-drainage methods depending on whether gas is drained from unmined coal before mining or from the coal disturbed by longwall extraction.

Pre-drainage

Where gas pressures are relatively high and the seams exhibit reasonably permeability, horizontal boreholes drilled in-seam from underground roadways or shafts can be effective in reducing the gas contents of coal seams in advance of mining. This approach is not appropriate for controlling longwall gas hazards in currently operating UK mines and, with a few exceptions, attempts to apply it in the UK have not been successful.

Pre-drainage of roadway driveages, and adjoining coal panels, was practised in the former Point of Ayr colliery where unusually high gas emissions were experienced in virgin coal areas. Elsewhere, short, vertical boreholes have been drilled in the roofs of headings to control emissions of gas from discrete fractures in gas bearing sandstones. Where there is a frictional ignition risk in mechanised driveages, due to the simultaneous presence of flammable gas and incendive rock (quartz), low angle boreholes have sometimes been drilled in the roof to terminate ahead of the face to release the gas in advance of mining.

The depth of most underground workings, low seam permeability, high drilling costs and surface environmental and access constraints precludes the application of surface VCBM gas capture technology to deep mines in the UK.

Post drainage

All methods for intercepting gas released by mining disturbance before it can enter a mine airway involve obtaining access, by some means or other, to the de-stressed zone above, and also sometimes below, the worked seam.

Access is gained by drilling from the underground roadways, drilling from the surface, driving roadways into the de-stressed zone or exploiting old workings which lie within the disturbed zone. Irrespective of the method of access, the aim is to consistently capture sufficient gas to ensure that the mine ventilation can satisfactorily dilute any remaining emissions at the planned rate of coal production. The choice of method is determined by practicality, safety and cost.

Goaf drainage from underlying or overlying roadways

In the late 1940s a method of gas drainage sometimes termed the *"superjacent heading"* or *"Hirschbach"* method was developed in the Saar coalfield which involved driving a heading above the worked seam prior to its extraction by a longwall method. Where practicable the roadway was driven in coal to reduce the cost. Sometimes boreholes were drilled from the roadway to extend its zone of influence. The roadway was then stopped-off, a methane drainage pipe being installed in the stopping to draw the gas away. Typically, a drainage roadway would be situated 20 to 25m above the worked seam or less than 20m below. The method is only practicable in the UK where advantage can be taken of existing roadways above or below the worked seam.

Goaf drainage using long, horizontal boreholes above or below the worked seam
Modern guided longhole drilling techniques have the potential to achieve a similar result to the above method without incurring the additional cost of driving an access drift and a gas drainage roadway. A borehole started from the worked seam can be guided through an arc to run parallel to the workings at a selected horizon above or below. To achieve a reasonable gas capture, and also to make due allowance for borehole damage as the longwall face retreats, three or more boreholes are required. An attempt to demonstrate the method in the UK failed due to drilling difficulties resulting from swelling of mudstones and borehole instability. Successful applications have been demonstrated in Australia and the USA. However, the method does not seem to have been widely adopted by coal mining companies.

Goaf drainage from the worked horizon
Direct drainage of gas from the goaf can be achieved from pipes laid in the return roadway of a retreat face and left open at the face start line, from pipes inserted through stoppings erected at the return end of the face or in crosscuts driven from a parallel roadway. These methods are not usually efficient, high drainage capacities are required and the captured gas can be of too low a purity for utilisation. The method may be adequate where gas emissions are relatively low. However, where thick seams are mined in China, high flows and purities are obtained using this method.

Cross measures gas drainage
All UK mines with gas drainage use a cross-measures drilling method. Boreholes are drilled at an angle above, and also in some instances below, the goaf. The method involves undertaking drilling operations near to the coal face where working room is limited and high temperatures and gas concentrations can arise. Gas drainage activities therefore need to be carefully managed to ensure that personnel are not exposed to unacceptable environmental conditions and health and safety risks.

On retreat coalfaces, special face-end ventilation arrangements are essential to ensure that these potentially explosive mixtures are kept well back in the goaf and away from coal face operations. Air from the face is diverted along the waste edge a distance of some 10 to 20m before it is allowed to pass onto the rib side and flow into the return. The pressure gradient thus formed prevents high gas concentrations in the goaf from migrating towards the face-end. This arrangement is formed by either constructing a curtain in the return roadway or leaving a narrow coal pillar at the face-end. Most retreat longwall faces in the UK use prefabricated curtains.

Gas drainage capacity
Gas drainage systems are designed to accommodate the maximum captured gas mixture (methane and air) flows from all sources in the mine including working faces, salvage districts and abandoned areas. The capability of the gas drainage system to transmit the gas depends on:

- the volume of gas produced
- flow capacity of the pipeline system
- effectiveness of de-watering systems
- the suction generated by the exhauster pump or pumps.

The volume of pure gas produced is estimated using a gas prediction method. Assumptions as to dilution with leakage air are then made to obtain total expected mixture flows. Manual or computer based methods are used for pipeflow calculations. The effectiveness of de-watering depends on the design allowing for the incorporation of water traps at appropriate locations, installation of the devices, their maintenance and operation. The highest mixture flows likely to be encountered are whilst working faces in virgin conditions. Where coal production can be limited by gas emission, the aim of gas drainage is to maximise pure methane flow from the district at all times. The drainage system should therefore be designed to accommodate a gas mixture of the worst case purity likely to be consistently encountered. The estimated worst case mixture flow should be within the planned capacity of the gas drainage system when all the extraction pumps are operating.

Methane extraction pumps are generally installed on the surface although underground installations, which vent the collected gas into return airways, have been used in some mines where drained quantities of gas are relatively low. Water seal extractors (Nash pumps) are used in UK mines. These are of relatively simple, robust construction, suitable for continuous operation, of proven reliability and usually arranged in parallel.

The demand for methane pumping capacity varies with the resistance of the drainage network which depends on the capacity of the underground pipework (which is fixed) and the variable number and quality of boreholes connected to the system (a variable).

Gas drainage boreholes draw gas from the strata together with ventilation air through vertical breaks in the goaf and the roof of the roadway behind the face. Each borehole, therefore, provides a parallel flow path, the system resistance reducing with increasing numbers of boreholes connected. As the system resistance reduces, mixture flow increases in accordance with the pump curves. Whether the pure methane flow also increases depends on the quality of the boreholes. Isolating or regulating a borehole increases the system resistance. As a result, suction pressure increases, mixture flow decreases, but purity and hence pure flow, may increase as more suction is applied to the remaining more productive boreholes.

Manufacturers' pump curves indicate volume flow at the operating pressure under conditions of standard temperature and pressure. A fall in pump performance is expected due to age and wear.

The duty of the gas extraction system can vary considerably over time depending on the number of old districts, barometric conditions, coal production rates, number of operational faces and the degassing effects of previous mining.

Methane concentrations (purities) in drained gas can range from a few per cent to in excess of 90% in exceptional circumstances. Some control on purity is achievable. Increasing suction in an effort to increase gas flow will introduce more air and hence reduce the gas purity. Conversely, reducing suction (e.g. by stopping a methane pump) will reduce the total mixture flow but improve gas purity. The balance between gas flow and purity is achieved either by manual adjustment or by an automatic control system at the methane drainage plant. Gas purity is controlled by adjusting a by-pass valve, switching pumps off or on, and by regulating flows from sealed off waste areas underground.

Gassy UK coal mines can achieve satisfactory gas control using a combination of ventilation and cross measures gas drainage techniques.

Gas management

Safety legislation defines precautions to be adopted in the design, selection of equipment and operation of gas drainage and utilisation plant at collieries. Typical requirements are for monitoring of methane concentration in and around the plant, provision of flame traps and automatic shut down systems if methane concentrations fall below a minimum safe concentration, typically 30%. Current utilisation schemes introduced by UK Coal, linked to the surface gas extraction scheme, are capable of using gas with a methane purity of 27%. The systems have been design to include effective risk control.

Guidance has recently been prepared, on behalf of the UK Health and Safety Executive mines inspectorate, on methane drainage practice and management for UK coal mines (Creedy, 2001). This guidance indicates how effective gas management systems can be developed to ensure compliance with health and safety legislation and best practice. It may contain some useful lessons for mines in China.

4.2 China technology and methods

The study has identified that by the end of 2001 some 184 mines practised methane drainage with 10 Mining Groups draining more than 10 million m^3 of methane. Figures for 2002 show this has increased to 193 mines in 53 Coal Mining Groups capturing some 1.1 billion m^3 of methane, an increase of 16% over the previous year.

Key statistics on gas control and gas drainage practice in China (2000) imply low serviceability of equipment and poor drainage performance:

- 793 drill rigs reported although only 452 in use
- 647 methane drainage pumps reported although only 383 in use
- the length of draining borehole per tonne of coal is 0.4m
- average drained gas concentration is 32%
- average gas drainage efficiency is 22.5%
- 312 mines equipped with monitoring and control systems (2001)
- 337 mines equipped with monitoring and control systems (2002).

A number of gas drainage methods have been developed to suit the varying geological and mining conditions encountered in China. These include both pre and post drainage using surface and underground methods. Advanced underground in-seam guided drilling techniques have been demonstrated by foreign contractors and are being applied with some success at a Sino-US joint venture coal mining operation in Shanxi Province.

Pre-drainage in-seam drilling
The technique is used where coal seams are outburst prone and/or permeability of the coal is sufficient to allow pre-drainage of the coal in advance of mining operations. In-seam gas drainage is used for both mine development and coal production. Some mines, particularly those prone to outbursts require boreholes to be drilled in advance of the development drivage (Figure 1). While this creates a restriction in development rates it allows the roadway to be constructed in a safe manner.

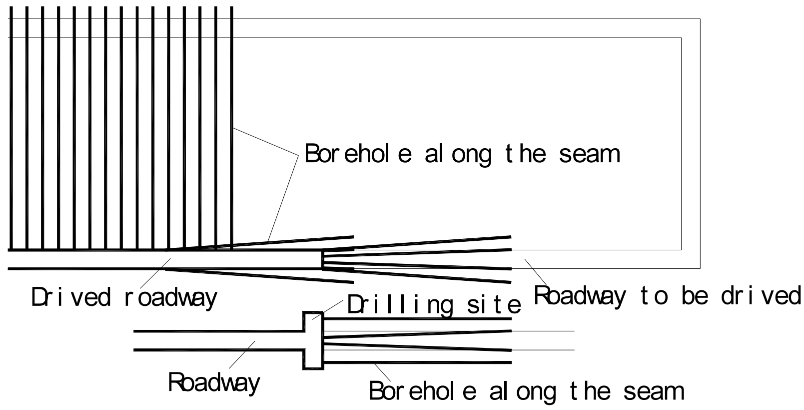

Figure 1. Schematic layout of in-seam drilling options

Where the coal seam permeability is sufficient to allow gas to be drained from the unmined coal boreholes can be drilled in-seam before mining is carried out. The time frame between drilling and coal production will vary on the initial gas content, gas content identified for safe mining to be carried out is, number and spacing of boreholes, borehole design and coal permeability. The technique involves drilling boreholes across a coal panel (typically up to 200m as shown in Figure 3). At present boreholes are drilled with conventional rotary systems but the application of more advanced guided drilling systems that allow the borehole to be steered in the coal have been tried. Results of such technology suggest mixed success due to:

- inappropriate and unsuitable geological setting for the application of technology
- application of advanced technology without training and support
- inexperienced operators
- inadequate provision for maintenance costs.

Characteristics of coal seams in China are highly variable, egg, very soft, high gas pressure and rock stress. These characteristics can create difficult drilling conditions