REDUCING THE ENVIRONMENTAL IMPACTS OF ABANDONED COAL MINES IN CHINA

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ABSTRACT

Coal mines release methane and other hydrocarbons from coal seams disturbed during the extraction process. Even after coal mining has ceased, emissions will continue but they will slowly decay. Flooding will eventually prevent further emissions. If the mine entries are sealed, the gas emission rate can be reduced significantly but then risks of uncontrolled emissions can arise. In some circumstances, there is sufficient gas remaining in the unmined coal seams within the strata disturbed by mining to represent a significant reservoir. Methods for estimating abandoned mine methane (AMM) reserves and resources have been developed and technologies for extracting and using methane from abandoned mines are available.

A project funded by the UK government has demonstrated that greenhouse gas emissions from abandoned mines in China can be reduced substantially by capturing and using the gas and also by streamlining the mine closure process. The possible risks to the public, and to re-developed coalfield areas, from uncontrolled migration of gas from closed mines are not yet recognised in China and warrant further investigation.

Closing small coal mines and replacing capacity with large mines may have significantly increased greenhouse gas emissions attributable to coal mining in China.

An Abandoned Mine Methane Project Advice Centre (AMMPAC) has been established at CCII in Beijing to provide a service to the coal industry. AMMPAC disseminates technical information to the coalfields and seeks to identify promising project sites and promote their development. Specialists from Wardell Armstrong and AEAT in the UK assisted the establishing of the centre, providing training and technical support to enhance the capability of CCII. This process has potential for replication in other coal mining countries, developing countries in particular, where AMM technology has not yet been introduced and the environmental impacts of coal mine closure are not fully appreciated.

1.0 INTRODUCTION

Methane release to the atmosphere is detrimental to the environment because of its high global warming potential. Methane occurs naturally in coal seams and is released as a result of coal mining. When mining ceases, the emissions continue but at a decreasing rate. Considerable efforts have been made to encourage capture and use of gas at working coal mines in China but, prior to this project, little emphasis has been placed on reducing emissions from closed mines.

Abandoned mine methane (AMM) is the gas remaining in abandoned coal mines in coal seams that have been disturbed by longwall mining. The quantity of AMM released depends on various factors including the volume of un-worked coal in the strata disturbed by mining, the residual gas content of the coal still in place and the rate of flooding of the workings. Gas leakages to the surface from old mines can also create serious hazards to the public.

1.1 ABANDONED MINE METHANE PROJECT ADVICE CENTRE

An abandoned mine methane project advice centre (AMMPAC) has been established at the China Coal Information Institute (CCII) in Beijing. The primary aim of AMMPAC is to identify and promote means for reducing greenhouse gas emissions from abandoned coal mines in China with particular emphasis on introducing technologies for capturing and exploiting methane. This one-year project was supported financially by the UK Foreign and Commonwealth Office (FCO) through its Climate Change Challenge Fund.

Primary project tasks were to build the capacity of CCII to provide an information service to mining enterprises and project developers through in-house training courses, site visits and personal coaching. Additional tasks were to identify organisations able to provide design, testing and engineering support services for AMM projects, to provide links to potential investors and technical specialists and to seek support for the continuation of AMMPAC.

AMMPAC has disseminated research results and technical information through various media including the internet, exhibitions, conferences, workshops, papers, guidance documents and training courses. Information sheets and technical guidance notes were prepared by the UK specialists for translation into Chinese and posting on CCII's web site, in addition to being made available on request from AMMPAC. Topics covered include environmental, engineering, financial and promotional issues.

Training courses and seminars have formed a major and successful input to the FCO funded AMMPAC project. These courses have covered technical, managerial and commercial topics and have formed part of the overall AMMPAC development and dissemination activities. A wide cross section of delegates participated in the training from government, engineering, safety and academic organisations in addition to CCII staff.

Funding for AMMPAC is being sought to support its continuation for a further two years after which it should become self-sufficient as AMM projects are established.

1.2 BENEFITS OF AMM EXTRACTION AND USE

Capture and utilisation of methane from abandoned coal mines provides several benefits including clean energy from a waste material, reducing the release of a potent greenhouse gas and potential financial gain under emissions trading and the Kyoto Clean Development Mechanism (CDM). Of importance to local governments in China is that AMM schemes could provide

some employment following mine closure and assist the regeneration of former mine sites.

If use of abandoned mine methane displaced the use of coal locally then this would have a beneficial effect on both air and water quality and thus positive human health benefits.

Commercial AMM extraction and utilisation schemes with an installed capacity of some 60MW_e equivalent are operating in the UK. Schemes are also operating in Germany, France, Czech Republic and the USA. Most of the schemes either generate electricity or provide fuel gas to industrial customers. There is potential for applying similar technologies in China.

1.3 ABANDONED MINE GAS SOURCES

Methane is formed during the natural coalification process and the coal mining operation releases some of this methane from the coal being worked and from surrounding de-stressed coal measures. The gas remaining in the disturbed coal seams after mining has ceased comprises the AMM reservoir. Robust computer models have been developed and software is available for estimating this AMM resource. British Coal Corporation research suggests that coal seams up to 150m to 200m above the worked seam and 40m to 70m below may emit gas into working longwalls. All of China's State-owned mines (SOCMs) use longwall or other caving methods of mining that will release gas from coal seams in adjacent strata. Most of the small coal mines in China use room-and-pillar methods of working. Here most of the gas emitted comes from the worked seam as little disturbance is transmitted into the surrounding strata and thus there is little methane emission following closure.

1.4 PRODUCTION OF AMM

The AMM production process relies on gas desorbing from primary coal seam sources entering goaf areas (worked-out longwall panels) and migrating along underground roadways to the surface extraction point. This is achieved by using surface extraction pumps to apply a suction pressure to the mine. The quantity of gas recoverable will depend on the magnitude of the source and how much suction pressure can be applied. Mine-water may accumulate in goaf areas and displace methane into roadways and shallower seam workings. Once a goaf area has been flooded, the associated primary gas sources can no longer release gas into the workings. The resource is not lost but de-watering will be required before the desorption processes can be re-established.

1.5 ENVIRONMENTAL ISSUES

Release of methane to the atmosphere incurs a significant environmental penalty because of its high GWP. The extent of methane release from coal mines after closure will depend on several factors. These include the volume and gas content of un-mined coal that has been disturbed by mining, whether or not the mine has been sealed and whether or not the workings have become flooded.

Gas leakages from old mines can also create serious hazards to the public. In the UK, for reasons of public safety, passive vents are often installed in abandoned shafts, drifts or surface boreholes drilled into the workings to provide a low resistance leakage path to the surface. Thus, as the workings fill with water, displaced gases will vent freely to the atmosphere. In most cases the gas passively vented represents a small proportion of the resource remaining in a mine. The environmental emission is considered to be acceptable in the light of the surface emission risk. Situations have been observed in China where surface emission hazards may be occurring but there is no awareness of the potential problems and no data are available.

2.0 COAL MINE CLOSURES IN CHINA

The coal mining sector in China has undergone substantial re-structuring in recent years and this process is ongoing. Mine closure is an inevitable consequence of changing from a command and control system to a market system. Mines also have a finite life due to depletion of coal reserves.

The government of China has implemented mine closure policies to address two separate issues:

- Closing and bankrupting of more than 120 SOCMs with depleted resources and no commercial future
- Closing of Town and Village coal mines (TVCMs) that fail to meet safety, licensing and resource access criteria to prevent over production and price instability. In recent years more than 30,000 TVCMs have been closed.

Gassy SOCMs are potential targets for AMM schemes. Extraction and use of AMM from say 50 mines, at an average production rate of 200l/s pure (equivalent to approximately 7MW thermal), would produce a mitigation benefit of about 4.4Mt of CO_2 equivalent per year.

2.1 IMPLICATIONS OF CHINA'S MINE CLOSURE STRATEGY FOR GREENHOUSE GAS EMISSIONS

As longwall mines tend to emit more methane after closure compared with room-and-pillar mines, China government policy to move to larger longwall mining operations is therefore likely to result in an increase in methane emissions. Improved gas drainage and utilisation in the large mines during working could mitigate the effect to some extent. Extraction of AMM after mine closure could mitigate emissions further.

The total methane emissions from both SOCMs and TVCMs can be estimated to assess the possible impact of the above changes. First order estimates shown in Table 1, neglect any gas emission reduction due to increased gas utilisation from 1997 to 2001 and assume an average specific emission of $1m^3/t$ for TVCMs and $10m^3/t$ for SOCMs. The table is based on official coal production statistics, and there is some evidence to suggest that TVCM production may have been understated. An estimated annual increase in

methane emissions of 1.6 billion m^3 (22Mt CO_2 equivalent) has occurred from 1997 to 2001 while total coal production has fallen.

Table 1. Estimated methane emissions from working coal mines in China

Year	Total coal production Mt	SOCMs coal production Mt	TVCMs coal production Mt	billion m^3 methane
1997	1325	705	620	7.7
2001	1106	906	200	9.3

Recent legislation requires all gassy mines to practise methane drainage. Provided uses can be found for the gas there is scope for reducing emissions substantially.

3.0 REDUCING EMISSIONS FROM ABANDONED MINES

Research, discussions and visits to abandoned mine sites at Fushun (Liaoning Province), Tongchuan near Xi'an (Shaanxi Province), Xinyi at Hegang (Heilongjiang Province) and Mulin near Jixi (Heilongjiang Province) provided an insight into mine closure procedures and methods revealing some aspects of environmental note. These visits were made during a UK Department for Trade and Industry sponsored technology transfer project to stimulate interest in the energy generation potential of AMM schemes. Under the auspices of AMMPAC a visit was made to Yangquan mining group, Shanxi, to view an embryonic AMM project.

De-watering of coal mine workings is sometimes continued after closure. Reasons for this may include protection of adjacent underground workings, to enable equipment salvage, the prospect of re establishing operations and the protection of surface water quality. De-watering maintains access to the underground reservoirs from which methane emanates and finds its way to the surface. If AMM extraction and use is not feasible, allowing early, controlled flooding would rapidly suppress methane emissions.

The low concentration of methane in the ventilation airflow, typically less than 1%, will preclude a commercial recovery and utilisation option using currently available technology. The ventilation air will also reduce the partial pressure of methane and lead to a greater rate of emission than if ventilation was halted. During the closure period significant volumes of greenhouse gases may be vented. At one site an estimated 420 million m^3 per year of methane was emitted from a closed working which was partially ventilated. The main coal production had ceased three years ago and still no treatment was planned.

Protracted mine closure leads to increased costs, additional safety risks and prolonged methane emissions.

4.0 IDENTIFICATION AND DEVELOPMENT OF POTENTIAL AMM SITES

AMMPAC has identified some prospective site areas and these now need further investigation.

4.1 DATA COLLECTION AND ANALYSIS

A questionnaire was sent out to 100 Coal Mining Enterprises. Responses were not expected from all of them as some enterprises operate low gas mines and thus have no interest in AMM. Information was requested including numbers of mines closed and identified for closure, sealing and flooding status, areas disturbed by mining, gas content, gas drainage and ventilation data.

Replies were obtained from 17 enterprises and the information entered by CCII into a database. Follow-up enquiries were made to identify potential project site areas. It is now for the respective enterprises, or independent developers, to conduct investigations. The role of AMMPAC will be to provide guidance as required.

4.2 POSSIBLE AMM SITE AREAS

The data were filtered and site areas eliminated if one or more of the following conditions applied: gas contents were low, the closed mines were flooded, a small area of mining, no mines have been closed or are due for closure within three years. Sites of possible interest were subsequently identified in the provinces of Shanxi (Yangquan Group), Ningxia (former Taixi Group), Jiangxi, (Fengcheng, Yinggangling), Hunan (Zixing, Lianshao) and Liaoning (Benxi, Fushun, Fuxin).

Systematic site appraisals and feasibility studies are now required to determine the potential of AMM resources in China. The best prospects are likely to be the mines that are due to close but are still accessible to allow for detailed inspection of plans and underground preparations prior to closure.

Fengcheng and Ningxia Groups have a history of coal mine methane (CMM) drainage and utilisation. The Fushun closed mines are located close to a CMM pipeline in an area with an established mine gas demand. It should be noted that the three major coal mining enterprises in Ningxia have been amalgamated into the Ningxia Mining Industry Group.

Yangquan Mining Group has probably the first AMM scheme in China. Albeit small, the abandoned mine supplies gas to help meet peak demands from a CMM scheme during winter.

4.3 AMM PROJECT DEVELOPMENT

Currently available information indicates there are some potential AMM project sites but most are likely to be commercially marginal and probably too small to attract financing unless clustered. However, AMM could offer benefits when integrated with coal mine methane (CMM) schemes as a source of gas to meet peak demands and a reservoir to store gas during low demand.

Many of the commercial factors which influence the viability of CMM utilisation schemes will similarly affect AMM schemes. The main difference is that AMM extraction can be controlled to suit demand whereas gas drainage in a working mine is operated to protect the underground workforce as a first priority.

CDM may offer a potential financing route to assist development of AMM and CMM schemes subject to establishing protocols. Flaring might be an option for small AMM schemes subject to CDM acceptability as a financing mechanism.

Current methods of sealing mine entries in China are inadequate for abandoned mine methane (AMM) schemes and AMMPAC has prepared a technical guidance note outlining the necessary requirements.

5.0 CONCLUSIONS AND RECOMMENDATIONS

An advisory centre has been successfully established in Beijing to promote and support AMM developments with the aim of reducing greenhouse gas emissions from closed mines in China. It has enabled experience of project development, technology and management from the UK to be transferred to China.

The most effective approaches to reducing methane emissions after mine closure are:

- Extraction and utilisation of methane from the mine after sealing
- Allowing the mine workings to flood as soon as possible after cessation of coal production (provided there are no significant inrush hazards to neighbouring mines or major groundwater pollution risks), thus preventing gas release and migration

The best AMM project prospects are likely to be large SOCMs that will close soon but are still accessible. Thus, the necessary underground engineering works can be undertaken to ensure an effective gas extraction scheme can be developed. Of the mines currently identified for closure, not all will be gassy or necessarily suitable for AMM extraction. In order to achieve commercial scale, AMM projects may need to be linked with coal mine methane schemes at working mines.

An unexpected result of the research is the finding that re-structuring of the coal mining sector in China by replacing small mine capacity with large mines could have increased annual coal mine sector emissions by as much as 22Mt CO_2 equivalent. More gas extraction and utilisation schemes at working mines are urgently needed to reduce this emission. As coal production is concentrated in larger mines, AMM will become increasingly important in the future.

The time elapsed between cessation of coal production and mine abandonment in China is protracted. Coal mine closure procedures should be

accelerated to ensure gas emissions are reduced as soon as possible by either introducing AMM utilisation schemes where feasible, or allowing flooding, provided there are no significant inrush hazards to neighbouring mines or major groundwater pollution risks.

Any underground salvage operation which delays the introduction of an AMM scheme or final closure should be financially justifiable. An environment appraisal should be undertaken to assess surface stability, gas emission and mine water recovery aspects including the identification of any necessary control measures. The schedule should demonstrate that the closure and sealing will be undertaken systematically and swiftly. Thus, financial resources can be directed towards providing re-training, and legitimate job creation schemes.

Prior to closure of a gassy mine, the feasibility of constructing an AMM extraction and utilisation scheme should be undertaken. The guidance notes prepared by AMMPAC highlight the key factors to be considered and outline the necessary engineering works.

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