Available online at www.sciencedirect.com
ScienceDirect
International Journal of Coal Geology 69 (2007) 253 – 266
International Journal of COAL GEOLOGY
www.elsevier.com/locate/ijcoalgeo

Control and prevention of gas outbursts in coal mines, Riosa–Olloniego coalfield, Spain

María B. Díaz Aguado *, C. González Nicieza

Department of Mining Exploitation, University of Oviedo, School of Mines, Independencia, 13, 33004 Oviedo, Spain

Received 25 March 2005; accepted 12 May 2006
Available online 4 August 2006

Abstract

Underground coal mines have always had to control the presence of different gases in the mining environment. Among these gases, methane is the most important one, since it is inherent to coal. Despite of the technical developments in recent decades, methane hazards have not yet been fully avoided. This is partly due to the increasing depths of modern mines, where methane emissions are higher, and also to other mining-related circumstances, such as the increase in production rates and its consequences: difficulties in controlling the increasing methane levels, increasing mechanization, the use of explosives and not paying close attention to methane control systems.

The main purposes of this paper are to establish site measurements using some critical parameters that are not part of the standard mining-control methods for risk assessment and to analyze the gas behavior of subvertical coal seams in deep mines in order to prevent gas incidents from occurring. The ultimate goal is the improvement in mining conditions and therefore in safety conditions.

For this purpose, two different mines were instrumented for mine control and monitoring. Both mines belong to the Riosa–Olloniego coalfield, in the Asturias Central Basin, Spain and the areas instrumented are mined via subhorizontal sublevels at an actual depth of around 1000 m under the overburden of Mount Lusorio.

During this research, a property favoring gas outbursts was site measured for the first time in an outburst-prone coal (8th Coalbed), gas pressure and its variations, which contributed to complete the data available from previous characterizations and to set some guidelines for assessing the potential outburst-prone areas. A gas-measurement-tube set has been designed for measuring gas pressure as well as its variation over time as a result of nearby workings and to calculate permeability.

The paper establishes the effect of overlapping of works, but it also shows the efficacy of two preventive measures to be applied: high pressure water infusion and the exploitation of a protective coal seam (7th Coalbed), that must be mined preferably two complete sublevels before commencing the advance in the outburst-prone coalbed. Both measures constitute an improvement in the mining sequence and therefore in safety, and should be completed with a systematic measurement to control the risk: gas pressure in the 8th Coalbed in the area of influence of other workings, to establish the most suitable moment to renew the advance. Further researches could focus on ascertaining the permeability, not only in mined areas but also in areas of the mine that are still not affected by mining work and on tuning more finely the ranges of influence of overstress time and overlap distance of the workings of the 7th Coalbed in the 8th Coalbed.

Keywords: Coal mine; Coalbed methane; Gas pressure; Permeability; Gas outburst

* Corresponding author. Tel.: +34 985 10 42 66; fax: +34 985 10 42 65.
E-mail address: miny@git.uniovi.es (M.B. Díaz Aguado).

0166-5162/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.coal.2006.05.004

1. Introduction

Coalbed and coal mine methane research is thriving due to the fact that power generation from coal mine methane will continue to be a growing industry over the coming years in certain countries. For instance, China, where 790 Mm^3 of CH_4 were drained off in 1999 (Huang, 2000), has 30 Tm^3 of estimated CBM potential in the developed mining areas (Zhu, 2000). The estimate by Tyler et al. (1992) of the in-place gas in the United States is about 19 Tm^3, while Germany's total estimated coalbed methane resources are 3 Tm^3, very similar to Polish or English resources (World Coal Institute, 1998).

This increase in the CBM commerce has opened up new lines of research and has allowed the scientific community to increase its knowledge of some of the properties of coal and of methane gas, above all with respect to the properties that determine gas flow, which until now had not been sufficiently analyzed. Some of these parameters are the same ones that affect the occurrence of coal mining hazards, as methane has the potential to become a source of different fatal or non-fatal disastrous events.

Since the famous mining catastrophe with over 1000 fatalities in Courrières, France, in March 1906, the list of dead and injured miners in modern mining has grown progressively, but growth in Western countries is at a decreasing rate. Fourteen miners died in the 8th Coalbed at San Nicolás mine on 31 August 1995, the worst mining accident in recent years in Spain. Major concern was aroused in the region with respect to mining-related safety problems.

The fatal accident in the 8th Coalbed at San Nicolás mine has led to different research studies (such as the "Research project of the 8th Coalbed in the 863 area", 2003, between the University of Oviedo and Hunosa; "Research of Prevention of Gas Outbursts", 2003, by the Department of Safety of Hunosa; "Research of the 8th Coalbed in San Nicolás and Montsacro", 2004, between the University of Oviedo and the Regional Industry, Commerce and Tourism Ministry of Asturias) for achieving a better knowledge of this coalbed and its behavior in order to improve safety conditions and thus to minimize future risks. As Flores (1998) suggested, there is a relationship between gas outbursts (mine safety) and production in underground mines (efficiency of mine operations and mine economics). Since the 8th Coalbed is economical, the management has not considered the option of ending mining operations in it.

The 8th Coalbed is mined via two mines: the aforementioned San Nicolás, in Ablaña (Mieres) and Montsacro, in Riosa. This research study has taken place in both mines and has an unquestionable importance in order to fulfill some gaps: to quantify some unknown parameters of the 8th Coalbed very related to mining hazards (such as gas pressure), to improve the mining sequence in the sublevel method (a factor very related, after Thielemann et al., 2001, with the risk of sudden outbursts), to establish the accuracy of some of the prevention measurements applied or to delimit the hazardous areas.

2. Description of the Asturian Central basin and of the 8th Coalbed

The 8th Coalbed of the Riosa–Olloniego unit, located in the Southwest of the Asturian Central Coal Basin (the largest coal basin in the Cantabrian Mountains, IGME, 1985), has CBM potential of about 4.81 Gm^3. This is around 19.8% of the estimated resources of the Asturian Central Basin and 12.8 % of the total assessed CBM resources in Spain (Zapatero et al., 2004). 3.84 Gm^3 of the CBM potential of the 8th Coalbed belongs to San Nicolás and Montsacro: 1.08 Gm^3 to San Nicolás area and 2.76 Gm^3 to Riosa, down to the −800 m level (IGME, 2002).

The minable coalbeds of this unit are concentrated in Westphalian continental sediments (Suárez-Ruiz and Jiménez, 2004). The Riosa–Olloniego geological unit consists of three seams series: Esperanza, with a total thickness of 350 m, contains 3–6 coalbeds with a cumulative coal thickness of 3.5 to 6.5 m; Pudingas, which is 700 m thick, has 3–5 coalbeds with a thickness of 5–7 m; whereas the Canales series, the most important one, is 800 m thick, with 8–12 coalbeds that sum up to 12–15 m thick. This series, which contains the 8th Coalbed, the coalbed of interest in this study, has a total thickness of 10.26 m at San Nicolás and 15.13 m at Montsacro (Pendás et al., 2004). Fig. 1 shows the geological map of the two coal mines, whereas Fig. 2 represents a front view of both mines and the location of the instrumented areas. In this particular study, the 8th Coalbed is situated at a depth of between 993 and 1017 m, in an area of low seismic intensity.

Instantaneous outbursts pose a hazard to safe, productive extraction of coal in both mines. The mechanisms of gas outbursts are still unresolved but include the effect of stress, gas content and properties of the coal. Other factors such as geological features, mining methods, bord and pillar workings or increase in rate of advance may combine to exacerbate the problem (Beamish and Crosdale, 1998). Some of the main properties of the 8th Coalbed favoring gas outbursts (Creedy and Garner, 2001; Díaz Aguado, 2004) had been previously studied by the mining company, in their internal reports

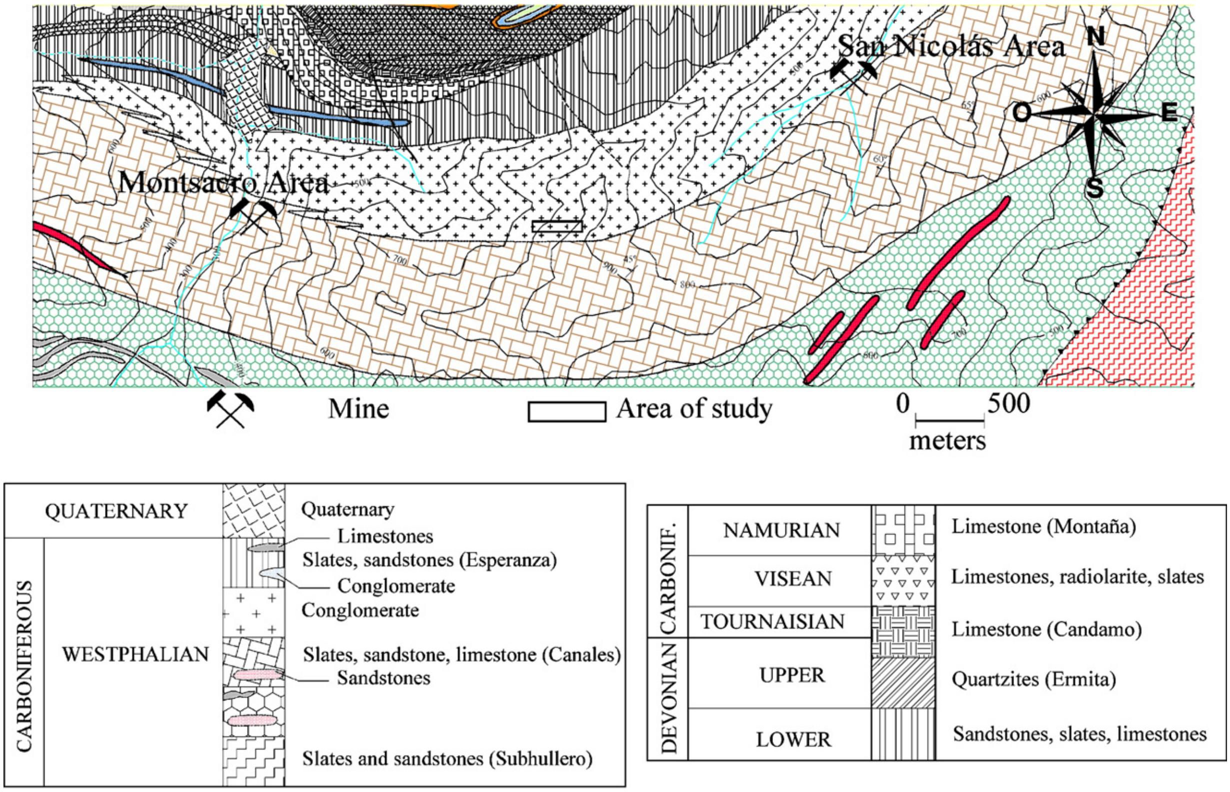

Fig. 1. Geological map.

as well as in the different research studies cited in Section 1: the geological structure of the basin, the stress state of the coalbed and its surrounding wall rock and some properties of both coal-bearing strata and the coalbed itself. The next paragraphs summarize the state of the research when this project started.

Many researchers have studied relationships between coal outbursts and geological factors. Cao et al. (2001), found that, in the four mining districts analyzed, outbursts occurred within tectonically altered zones surrounding reverse faults; this could help to delimit outburst-prone zones. In the 8th Coalbed, some minor outbursts in the past could be related to faults or changes in coal seam thickness. Hence, general geological inspections are carried out systematically, as well as daily monitoring of any possible anomalies. But, in any case, some other outbursts could be related neither to local nor general faults.

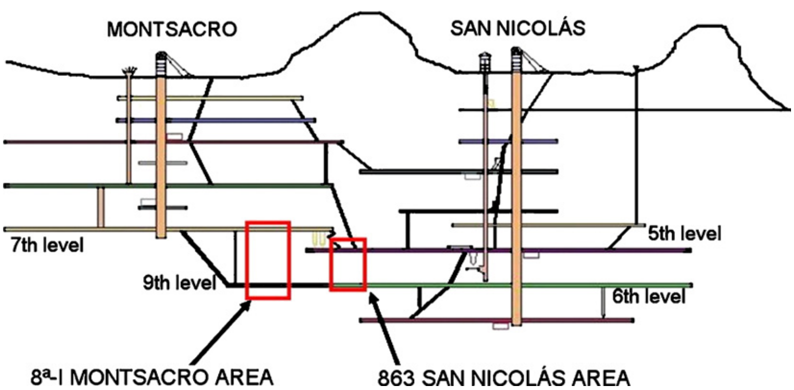

Fig. 2. General location of the study area.

For some years now, the technical experts in charge of the mine have been studying the stress state of the coalbed by means of theoretical calculations of face end or residual rock mass projections that indicated potential risk areas, based on Russian standards (Safety Regulations for Coal and Oil Shale Miners, 1973). Assuming that there was an initial approach to the stress state, this parameter was therefore not included in the research study presented in this paper.

In the Central Asturian Coal Basin, both the porosity and permeability of the coal-bearing strata are very low, the cleat structure is poorly developed and cleats are usually water-filled or even mineralized. Consequently, the only paths for methane flow are open fractures.

Coal gas content is one of the main parameters that had been previously analyzed. The methane concentration in the Central Asturian Basin varies between 4 and 14 m^3/t of coal (Suárez Fernández, 1998). Particularly, in the Riosa–Olloniego unit, the gas content varies from 3.79 to 9.89 m^3/t of coal (Pendás et al., 2004). During the research, the measured values in the area of study have varied between 4.95 and 8.10 m^3/t, with an average value of 5.10 m^3/t. In some countries, such as Australia (Beamish and Crosdale, 1998) or Germany, a gas outburst risk value has been established when methane concentration exceeds 9 m^3/t (although close to areas of over-pressure, this risk value descends to 5.5 m^3/t). As the average gas contents in the coalbed are comparable with those of the Ruhr Basin (which according to Freudenberg et al., 1996, vary from 0 to 15 m^3/t), the values in the 8th Coalbed would be close to the risk values.

Desorption rate was considered the most important parameter by Williams and Weissmann (1995), in conjunction with the gas pressure gradient ahead of the face. Gas desorption rate (V_1) has been defined as the volume of methane, expressed in cm^3, that is desorbed from a 10 g coal sample, with a grain size between 0.5 and 0.8 mm, during a period of time of 35 s (from second 35 to 70 of the test). Desorption rates have been calculated from samples taken at 2 m, 3 m and 7 m, following the proceedings of the Technical Specification 0307-2-92 of the Spanish Ministry of Industry. The average values obtained during the research are: 0.3 $cm^3/(10\ g \cdot 35\ s)$ at 2 m depth, 0.5 $cm^3/(10\ g \cdot 35\ s)$ at 3 m and 1.6 $cm^3/(10\ g \cdot 35\ s)$ at 7 m. Maximum values were of 1.7 $cm^3/(10\ g \cdot 35\ s)$ at 2 m depth, 3.3 at 3 m and up to 4.3 $cm^3/(10\ g \cdot 35\ s)$ at 7 m. The initial critical safety value to avoid gas outbursts in the 8th Coalbed was 2 $cm^3/(10\ g \cdot 35\ s)$. Due to incidents detected during this research study, the limit value was reduced to 1.5 $cm^3/(10\ g \cdot 35\ s)$.

But other properties, such as coal gas pressure, the structure of the coal itself and permeability, had been insufficiently characterized in the Riosa–Olloniego unit before this research study.

Two methods had been previously employed to determine the gas pressure in the mine: the Russian theoretical calculations for the analysis of the stress state and the indirect measurements of the gas pressure obtained by applying criteria developed for the coalbeds of the Ruhr Basin (Germany), Poland and the former Soviet Union. These indirect measurements were the Jahns or borehole fines test (Braüner, 1994), which establishes a potential hazard when the fines exceed a limiting value. Although there are tabulated values for the coalbeds of the Ruhr Basin, it is not the case for the coals of the Riosa–Olloniego unit. Therefore, in this paper an improvement to the gas pressure measurement technique is proposed by developing a method and a device capable of directly measuring *in situ* pressures.

The 8th Coalbed is a friable bituminous coal, high in vitrinite content, locally transformed into foliated fabrics which, when subjected to abutment pressure, block methane migration into working faces (Alpern, 1970). With low-volatile content, it was formed during the later stages of coalification and, as stated by Flores (1998) this corresponds to a large amount of methane generated. Moreover, the coal is subject to sudden variations in thickness (that result in unpredictable mining conditions) and to bed-parallel shearing within the coalbed, that has been considered an influence on gas outbursts (Li, 2001). Its permeability had never been quantified before in this mining area. Thus, during research in the 8th Coalbed it was decided to perform *in situ* tests to measure pressure transients, to obtain site values that will allow future calculations of site permeability, in order to verify if it is less than 5 mD, limit value which, after Lama and Bodziony (1998), makes a coalbed liable to outbursts.

Therefore, in this study we attempted to characterize gas pressure and pressure transients, for their importance in the occurrence of gas outbursts or events in which a violent coal outburst occurs due to the sudden release of energy, accompanied by the release of significant amount of gas (González Nicieza et al., 2001), either in breaking or in development of the coalbed (Hardgraves, 1983).

3. Control of gas outbursts

Gas outbursts are not totally understood with respect to the coal/gas system and prediction techniques continue to be unreliable, as stated by Beamish and Crosdale (1998); unexpected outbursts are a major concern for coal operations. Due to the complexity of the causative mechanisms, Cao et al. (2001) report the

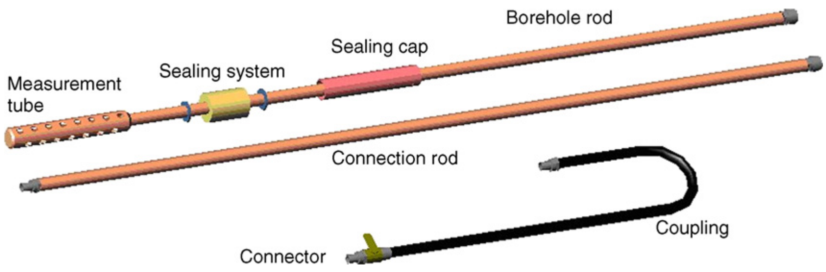

Fig. 3. Schematic diagram of a gas-pressure-measurement tube set.

closure of some mines with intense outburst hazard in China, because no effective methods could be found to predict or prevent outbursts. However, some general diagnosis and prevention measures may be proposed, as well as some protection methods.

Potential hazard may be diagnosed by determining over-pressured areas and measuring gas desorption rates and gas content. Other researchers (Alexeev et al., 2004) propose apparatuses such as the true triaxial loading (TTAL) to reproduce outburst type fracture mode. Also, suitable models have been provided for the prediction of gas emissions, but most of them are site specific (Noack, 1998).

The main prevention measures are: gas dilution by ventilation, drainage boreholes (Flores, 1998; Noack, 1998), water infusion and exploitation of a protective coal seam (González Nicieza and Díaz Aguado, 2001). A protective seam is a seam which is minable without bursting, so that the burst-prone coalbed can be over- or undermined (Braüner, 1994).

When hazards have not been avoided, some useful protection methods are protection barriers, the use of self-rescue breathers and areas of group safety (Struminski and Madejam, 2001).

4. Site measurements

This paper sets out the monitoring carried out in the 8th Coalbed on the basis of the analyses conducted. During the research, coal gas content and desorption rate continued to be measured, as they presented variations that were at times significant from one area of the mine to another and whose abnormal values should in themselves constitute a warning signal.

But the current research focussed on the measurement of the gas pressure (both in the coalbed and during water injection as a preventative method), and pressure transients. The following sections describe the research carried out for these specific measurements.

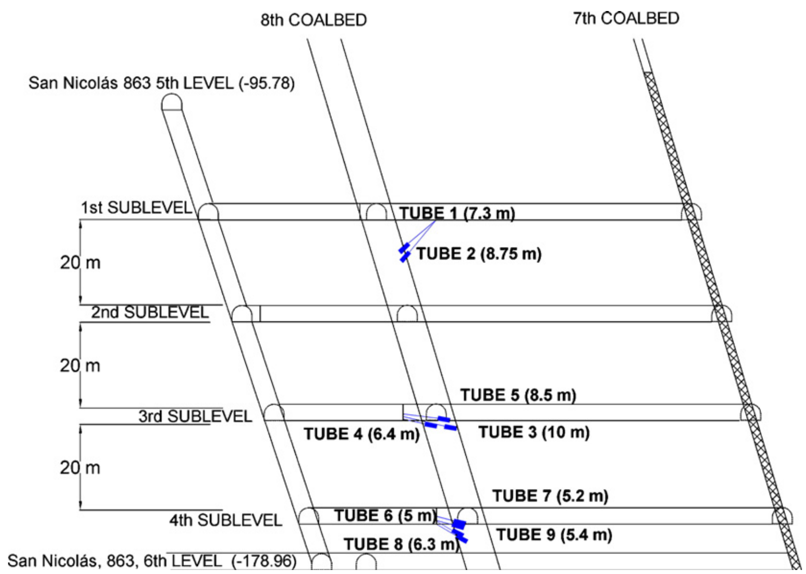

Fig. 4. Gas measurement tubes at San Nicolás (front view).

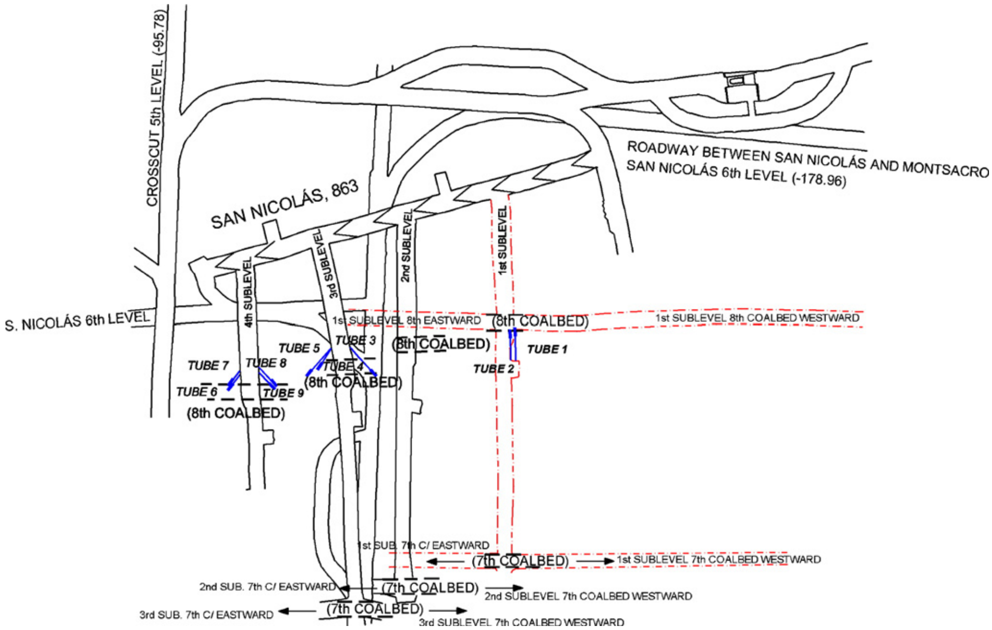

Fig. 5. Gas measurement tubes at San Nicolás (plan view).

4.1. Gas pressure measurements

To measure the gas pressure, the Ground Engineering Group at the University of Oviedo has designed and manufactured the gas-measurement-tube set shown in Fig. 3. This measurement tube allows the methane pressure to be determined accurately at different depths and at different points in the coalbed.

The gas-pressure-measurement-tube set is made up of a rigid copper tube for capturing the coal gas, with 40 holes of 5 mm diameter. The rod is equipped with a sealing system, which expands within the measurement tube to impede the flow of coal gas, when activated from the surface. A manometer, equipped with a pointer, is coupled to the connector, allowing the maximum gas pressure occurring between two data reading dates to be registered.

A total of nineteen measurement tube sets were installed in the two mines at different levels that were being mined. Of these, thirteen were installed at San Nicolás and six at Montsacro. Some of them were installed before passing through the target coalbed, from a crosscut in the rock and others after having passed through the coalbed. Figs. 4 and 5 show the location of nine of the measurement tubes at San Nicolás; measurement tubes TUBE 10, TUBE 11, TUBE 12 and TUBE 13 were located at a greater depth (some 150 m from those on the first sublevel) on the seventh level of San Nicolás. They were situated before passing through the 8th Coalbed from the advance face of a crosscut, with the layout shown in a plan view in Fig. 6.

Table 1 shows the values of the initial pressure (pressure provided by the gas measurement tube), the maximum stabilized pressure (maximum value of the instantaneous pressure or pressure read on the manometer at the moment of collecting data) and the maximum pressure (maximum value registered by the manometer, which in turn corresponds to a peak in the pressure between two reading dates) for all the measurement tubes installed at San Nicolás, as well as the actual installation depth of each set.

The highest initial pressures were registered at the deepest measurement tubes, TUBE 12 and TUBE 13. When analyzing TUBES 10 to 13, a difference was observed between the equilibrium pressures measured at each side of the crosscut, due to the existence of a fault. This fault provoked greater fracturing and therefore a

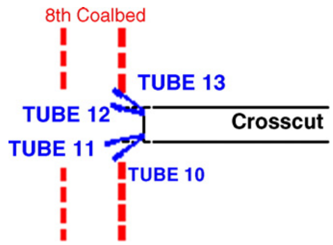

Fig. 6. Gas measurement tubes situated on the 7th level at San Nicolás (plan view).

Table 1
Gas pressure values at San Nicolás

TUBE	Installation depth (m)	Initial pressure (kPa)	Stabilized pressure (kPa)	Maximum pressure (kPa)
TUBE 1	996	14	22	22
TUBE 2	998	45	415	530
TUBE 3	1028	0	0	110
TUBE 4	1028	12	42	319
TUBE 5	1027	200	240	318
TUBE 6	1046	125	125	575
TUBE 7	1046	4	215	360
TUBE 8	1048	0	35	95
TUBE 9	1049	5	15	40
TUBE 10	1141	60	100	500
TUBE 11	1141	40	50	660
TUBE 12	1141	250	250	480
TUBE 13	1141	220	220	340

degasification of the left part, whereas in the area on the right (Fig. 6) it was possible to measure the “virgin” pressure of the coal on the 7th level, with an average value of 410 kPa.

The maximum pressure increases with depth, as its average value was 264 kPa between the 5th and 6th level (for an average depth of 1029 m), whereas it is notably higher on the 7th level, at 495 kPa and 1141 m depth.

Figs. 7 and 8 correspond to the measurement tubes installed at Montsacro and Table 2 summarizes the measurements in this area.

The pressure ranges are smaller in magnitude than those of San Nicolás, where the gas measurement tubes are some 122 to 206 m deeper. The average maximum pressure for the first sublevel was 126 kPa, while 40 m deeper, in the 3rd sublevel, it rises to 207 kPa.

The measurement tubes show that, once installed, pressure increases progressively, due to gas recharging into the tubes until equilibrium pressure in the coal. This recharging time, usually around two weeks, is variable and it is affected by the effect of closeness of longwall caving in the 7th Coalbed on the pressures. The equilibrium pressure varies between San Nicolás and Montsacro and even depends on the specific area tested within each mine.

Another important consideration is the analysis of the maximum pressure values that may be produced, which may even be threefold the value of the equilibrium pressure. These increases are basically due to the influence of the longwall caving in the 7th Coalbed on the gas pressure in the 8th Coalbed. The degree of influence increases as the face approaches to the measurement tube set location i.e. when the longwall caving is close to its conclusion or is recently finished.

The results of one of the measurement tubes, TUBE 2, installed on the first sublevel of San Nicolás are presented and analyzed in Fig. 9, whose legend is summarized in Table 3. The positioning of this tube was ideal for observing the influence of the workings of the 7th and 8th Coalbeds on the gas pressure.

The meters advanced start at the zero metric point of advance, the initial situation on the main crosscut (the intersection of the transversal of the coalbed with the advancing sublevel) and as time passes, the said advance increases until the final advanced length. As regards the longwall cavings, since we are dealing with retreat longwall cavings, the workings always commence at the final advanced length. As time passes, they approach meter zero (the main crosscut). Finally, the graph also shows

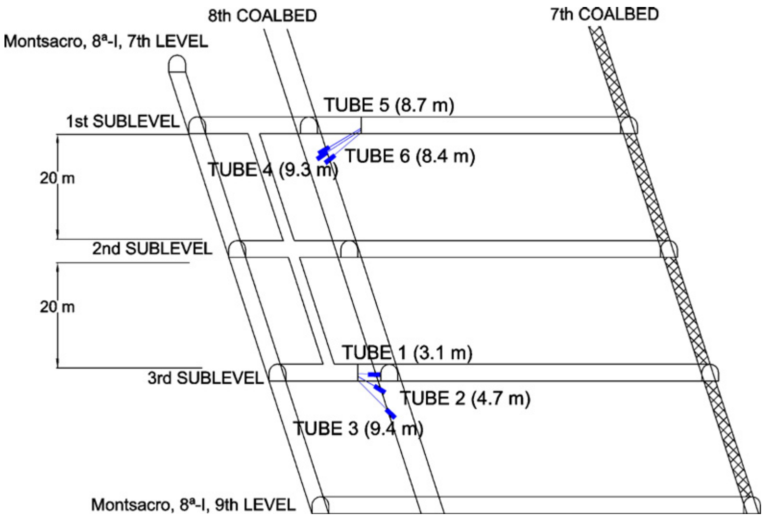

Fig. 7. Gas measurement tubes at Montsacro (front view).

the most important gas outbursts that took place during mining work, both eastward (G.O. C/8th E) and westward (G.O. C/8th W) directions.

The initial pressure at the moment of installing the test measurement tube was 45 kPa, although this was recharged until reaching 380 kPa over two weeks. However, this relatively high value of equilibrium pressure of the coal might be influenced by the approaching longwall caving on the first sublevel of the 7th Coalbed. From the end of this caving, the pressure presents a descending trend down to 180 kPa, in a distention period that lasts about three months. The gas pressure in the coalbed subsequently increases, due to the influence of the 1st W longwall caving in the 7th Coalbed on the gas pressure of the 8th Coalbed. A pressure of 530 kPa was registered (maximum pressure measured by TUBE 2) just when this westward longwall caving finalizes in the 7th Coalbed.

As occurred subsequent to the longwall caving of the first sublevel in the 7th Coalbed, the pressure once more descends progressively over a distention period estimated at around two and a half months. However, during this period of time, various pressure peaks were registered that reached 280 kPa, because of the caving that had commenced westward on the 2nd sublevel of the 7th Coalbed.

Eastward advance was initiated on the first sublevel of the 8th Coalbed. From the advance of the workings, the gas pressure shows an ascending trend with various pressure peaks around 300 kPa. Specifically, a gas outburst (marked with the first round point on Fig. 9) took place when 24 m had been advanced on the 8th level. The outburst affected 10 m of the advance, although the workers managed to run away. This corresponded with an overlapping of workings between the end of longwall caving of the 7th Coalbed and the commencement of the advance of the 8th Coalbed, which affects the gas pressure (by increasing its value almost four times) and favors the occurrence of gas outbursts. After this incident, the company decided to stop this advance and to initiate it in the opposite direction, i.e. westward. But at the beginning of this advance, another gas outburst took place, during water injection.

After 396 days, the gas pressure presents various peaks that coincide with the progression of the westward advance on the first sublevel of the 8th Coalbed and with the eastward longwall caving on the 2nd sublevel of 7th Coalbed. The maximum pressure thereafter is 300 kPa

Table 2
Gas pressure values at Montsacro

TUBE	Installation depth (m)	Initial pressure (kPa)	Stabilized pressure (kPa)	Maximum pressure (kPa)
TUBE 1	874	110	140	260
TUBE 2	878	200	220	230
TUBE 3	883	30	80	130
TUBE 4	836	10	55	80−+
TUBE 5	835	17	160	220
TUBE 6	837	10	40	80

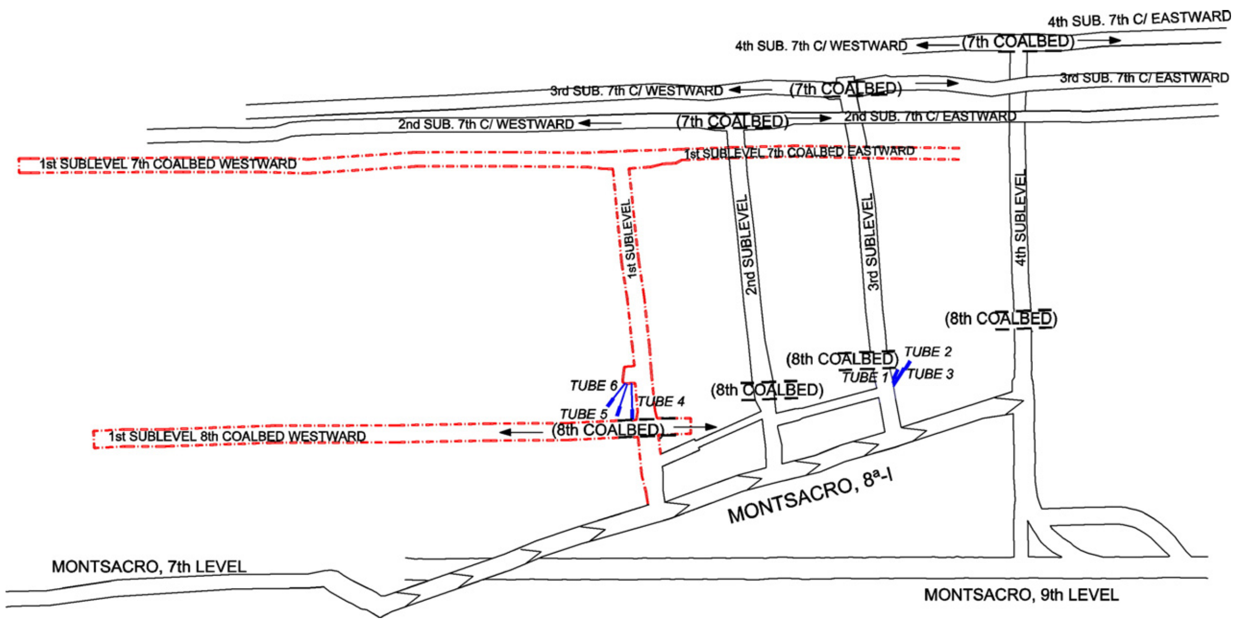

Fig. 8. Gas measurement tubes at Montsacro (plan view).

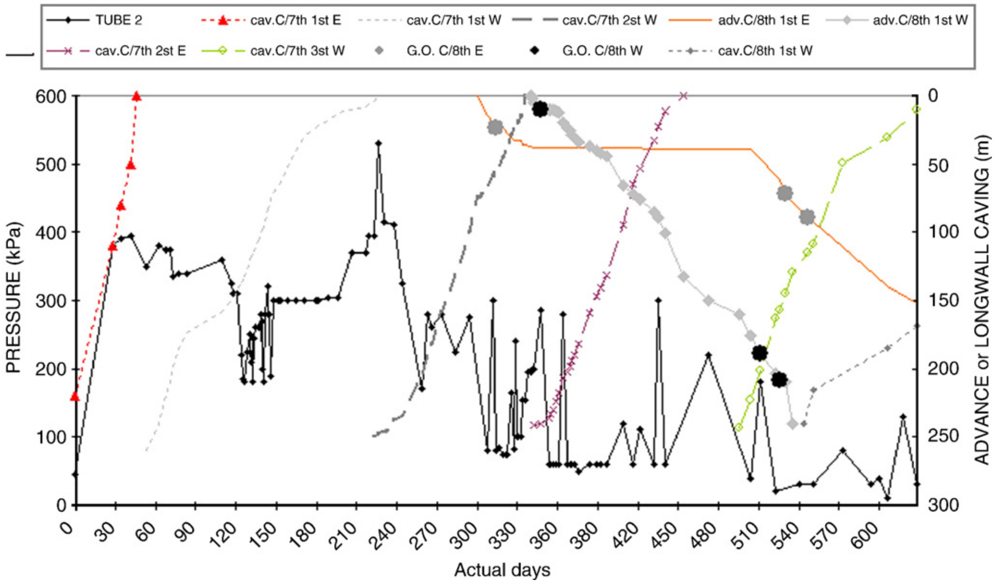

Fig. 9. Gas pressure measurements of TUBE 2 at San Nicolás.

after 435 days, coinciding once more with the overlapping of workings.

Moreover, advance was started up again on the first sublevel of the 8th Coalbed eastward, as well as the caving on the 3rd sublevel westward. The four remaining gas outbursts also coincide with pressure peaks and with the overlapping of workings, as can be observed on Fig. 9. During advance, these outbursts were normally preceded by successive knocks in the coal, as reported by the miners and personally observed by the authors in the mine.

From the analysis of all the measurement tubes, some results can be obtained. After longwall caving, distressing occurs over a period that is estimated at around 2–3 months, the moment at which it seems that the pressure has decreased substantially and that it might be adequate to start up workings in the 8th Coalbed. These advance workings should never commence if the pressure of the gas is increasing due to the influence of nearby workings, because then the coalbed would be prone to outbursts.

It should be noteworthy that the benefit of a period of distressing is not increased by detaining the workings indefinitely. The coalbed needs a period of time after being affected by the longwall caving to recover its prior state (or even improve on this, at times) but, after a certain amount of distention, the pressure no longer decreases.

Another aspect to be taken into account is the overlapping of workings. Its negative influence on the gas

Table 3
Legend of Fig. 9

Legend	Value measured	Axis
	Pressure measurements, expressed in kPa	Main *y*-axis
Actual days	Days from installation	*x*-axis
	Advance of the 1st sublevel of the 8th Coalbed Eastward, in m	Secondary *y*-axis (continuous line)
	Advance of the 1st sublevel of the 8th Coalbed Westward, in m	Secondary *y*-axis (continuous line)
	Caving of the 1st sublevel of the 7th Coalbed Eastward, in m	Secondary *y*-axis (broken line)
	Caving of the 1st sublevel of the 7th Coalbed Westward, in m	Secondary *y*-axis (broken line)
	Caving of the 2nd sublevel of the 7th Coalbed Westward, in m	Secondary *y*-axis (broken line)
	Caving of the 2nd sublevel of the 7th Coalbed Eastward, in m	Secondary *y*-axis (broken line)
	Caving of the 3rd sublevel of the 7th Coalbed Westward, in m	Secondary *y*-axis (broken line)
	Caving of the 1st sublevel of the 8th Coalbed Westward, in m	Secondary *y*-axis (broken line)
	Gas outburst during mining work in the 8th Coalbed Eastward	Round point
	Gas outburst during mining work in the 8th Coalbed Westward	Round point

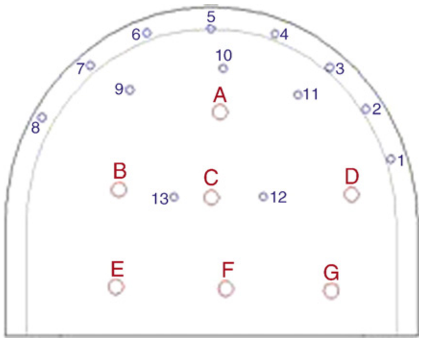

Fig. 10. Injection boreholes and degasification boreholes.

pressure was established by means of the installed measurement tubes, giving rise to considerable peaks in pressure. Moreover, the overlapping of workings was observed to coincide with gas outbursts. One way of evaluating the risk of the occurrence of an outburst would be the implementation of local measurements in the 8th Coalbed when there is overlapping of workings. A systematic control that is compatible with mining work is proposed: to detain the advance of the 8th Coalbed temporarily, installing gas measurement tubes in the face, which together with the values obtained from gas concentration tests, would provide sufficient data to control the gas conditions of the coalbed and establish what moment would be suitable to renew the advance.

On the basis of the results obtained, the overlap distance between workings might be established at around 55–60 m (when the longwall caving of the 7th Coalbed is some 55–60 m from the face of the 8th Coalbed), though logically this influence is greater as the longwall caving of the 7th Coalbed gets closer.

The above proposed systematic control would allow the values of the range of influence and of the overstress time in the 8th Coalbed to be more finely tuned. It is therefore initially proposed that the aforementioned distances and times be applied and that these values may be adjusted with the results from day-to-day work.

It should also be noted that, due to the long interval of time measured at some of the pressure measurement tube installations, an “ageing” of these installations might have taken place (increase in fracturing, loss of properties of the sealing material, loss of airtightness in the coupling seals of the measurement tubes, etc.). Therefore, the absolute values of pressure after several months might be higher than those actually measured via the measurement tubes.

Finally, as a result of comparing the workings in both mines, the most favorable situation for commencing the advance in the 8th Coalbed appears to be that of carrying out longwall caving of two complete sublevels in the 7th Coalbed. Thus, at the Montsacro area (which, when the advance in the 8th Coalbed commenced, had completed longwall caving of the entire first and second sublevels in the 7th Coalbed, in both directions, eastward and westward), the pressures were lower than at San Nicolás and so were the pressure peaks obtained. In this latter mine, the advance of the 8th Coalbed began when only one caving had been completed and caving was still being carried out on retreat on the second sublevel.

4.2. Gas pressure during water infusion

Water injection has been used as a method of controlling instantaneous outbursts in some countries (Jackson, 1984). Its main purposes are to saturate the cleats and fractures so that methane emission can be hindered in the infused area, to divert the gas away from the face and to fracture the coal and partially relax the stresses that the coalbed is subjected to.

These tests were being systematically employed in the mine as a mean of preventing gas outbursts. They consist in injecting high-pressure water (up to 25 MPa) into thirteen injection boreholes previously bored into the face (numbered 1 to 13 in Fig. 10); the water mixed with coal

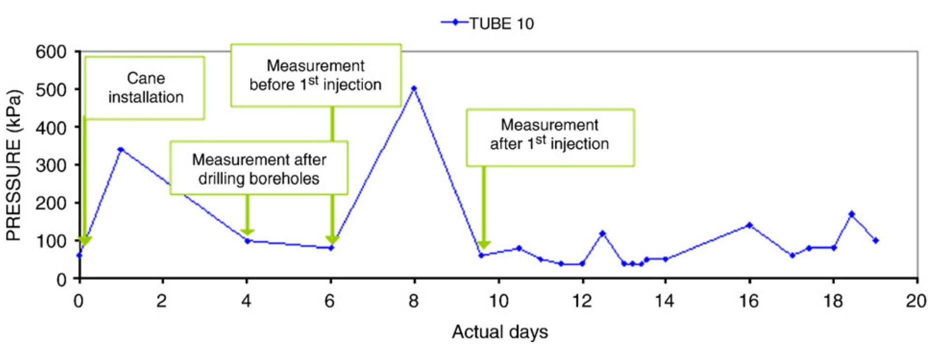

Fig. 11. Gas pressure measurements during an injection test.

and gas subsequently exits through seven degasification boreholes (lettered A to G in the figure). Injection was stopped when the borehole admitted water at a pressure smaller than 4 MPa.

Four measurement tubes were used to establish the efficacy of injection during this analysis (TUBES 10 to 13), with the layout shown in Fig. 6. The data of TUBE 10 was plotted in Fig. 11, as an example.

After installation (70 kPa) recharging occurred until the equilibrium pressure (340 kPa), but when drilling the injection boreholes, the pressure descends to 80 kPa. It is then observed that a maximum of 500 kPa is registered during the water injection process, since the injection of water pushes the gas towards the area where the measurement tube is situated. Immediately after injection, the pressure descended to 60 kPa.

The registers of the following week, during which water continued to be injected, are around 80 kPa, with some peaks lower than 170 kPa.

These results show the efficacy of injection as a preventative measure, since it manages to reduce the value of the initial pressure four- or sixfold to pressures that make more suitable to pass through the coalbed. But when the infusion is stopped the process reverses, so the effects of infusion are not long lasting (Beamish and Crosdale, 1998). Also, it is important to ensure good coalbed coverage and to assess the borehole location with respect to possible changing coalbed lithology.

During the infusion process itself, however, an increase in the pressure value of between 100 and 640 kPa is produced, which could increase the risk of the occurrence of rapid degassing or gas outbursts during the course of these injection tests. This possible occurrence of incidents during injection, corroborated during mining practice, must be taken into account when carrying out this measure. It is necessary to maintain the safety distance, to employ protective boarding and adequate ventilation, and to have trained, well-prepared personnel ready for any eventuality. Nevertheless, these outbursts are to be expected and therefore would not constitute the unforeseen, surprise factor of gas outbursts, although this does not mean that they are hazard free.

4.3. Gas pressure transient between two gas measurement tubes

The variation of the coal gas pressure due to methane flow was estimated *in situ* by means of a specific test developed by the Ground Engineering Group at the University of Oviedo, using the gas pressure measurement tube described above.

The test is carried out between two measurement tubes situated at the same depth (5 m) and at a specific distance from one another (1 to 1.5 m), measuring the variation in pressure over time in one of these when the other one is under atmospheric pressure.

Twenty-one valid tests were carried out in all between the two mines. A statistical analysis was carried out with these data with a Student's *t*-test. The minimum number of values needed to obtain an average value was calculated, assuming a level of confidence of 0.95 (95%): sixteen values. The doubtful values from the tests were iteratively eliminated on the basis of the rejection criteria employed. At the end of the process, a total of eighteen

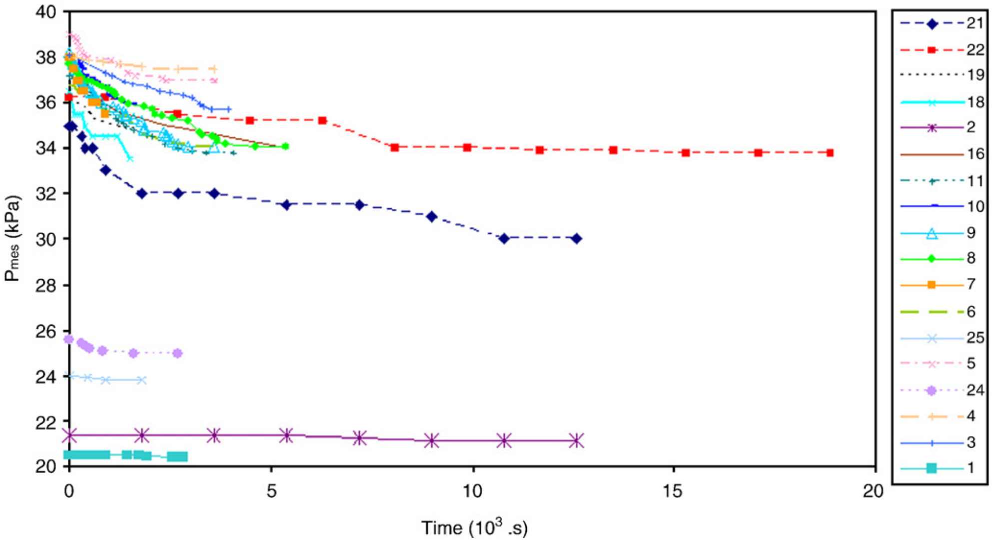

Fig. 12. Gas pressure variation tests.

Table 4
Gas pressure variation tests

Mine	S N	S N	S N	S N	S N	S N	S N	S N	S N	S N	S N	M	M	M	M	M	M	M
Test	1	2	3	4	5	6	7	8	9	10	11	16	18	19	21	22	24	25
t	3.72	12.6	3.96	3.6	3.64	3.84	0.9	5.4	3.6	1.53	4.08	5.34	1.5	1.8	12.6	18.9	2.7	1.8
P_i	20.48	21.31	36.54	37.76	37.96	35.39	36.96	35.91	36.07	36.90	35.53	36.27	35.05	35.42	35.00	34.63	25.23	23.88
ΔP	0.08	0.11	0.84	0.26	0.96	1.29	1.46	1.81	1.97	1.00	1.73	2.27	1.55	0.62	5.00	0.83	0.23	0.08

data remained that obeyed a Law of Normal Distribution. These eighteen tests are represented in Fig. 12, where P_{mes} is the pressure in kPa measured in a measurement tube (variation in pressure with time) and time is expressed in 10^3 s.

Table 4 shows the duration of each test (t, in 10^3 s), the initial pressure (P_i) and the pressure transient (ΔP), in kPa, for the tests conducted in San Nicolás (S N) and Montsacro (M).

The average initial pressure is 33.71 kPa for San Nicolás, with a variation of 1.05 kPa and 32.21 kPa for Montsacro, with 1.51 kPa of variation. Therefore, conditions are better in Montsacro (with a better mining sequence regarding the risk of outbursts), with lower initial pressure and higher gas flow, which favors degassing of the coalbed. These results coincide with those obtained from gas pressure measurements (Section 4.1).

It would be important to continue this research, to calculate permeability using numerical models. Low permeability values are expected, since the permeability of coal is significantly affected by its stress state (Durucan and Edwards, 1986) and in deep coalbeds, where the coal is subjected to high stresses, this permeability is usually low. However, the flow of gas and the permeability suffer variations due to the changes in stress in the mine, and the permeability varies depending on the distance to the face at which it is measured and the mining sequence followed (Ren and Edwards, 2000).

Nonetheless, it would be very interesting to ascertain the permeability not only in the zone of study, but also in the areas of the mine that are still not affected by mining work, which might constitute a further research study.

5. Conclusions

Coalbed is still a major hazard affecting safety and productivity in some underground coal mines. This paper highlights the propensity of the 8th Coalbed to give rise to gas outbursts, due to fulfilling a series of risk factors, that have been quantified for 8th Coalbed for the first time and that are very related to mining hazards: gas pressure and its variation, with high values measured in the coalbed, obtaining lower registers at Montsacro than at San Nicolás (where 480 kPa were reached in the gas pressure measurements at the greatest depth). These parameters, together with the systematic measurement of concentration and desorption rate that were already being carried out by the mine staff, require monitoring and control.

A gas-measurement-tube set was designed, for measuring gas pressure and its variations as well as the influence of nearby workings to determine outburst-prone areas. The efficacy of injection as a preventative measure was shown by means of these measurement tubes. Injection decreases the gas pressure in the coalbed, although the test must be conducted maximizing all the precautionary measures, because gas outbursts may occur during the process itself.

The instrumentation results indicated the convenience of mining the 7th Coalbed at least one sublevel ahead of the 8th Coalbed. This means having completed longwall caving of the corresponding sublevel both eastward and westward, and having allowed the necessary time to elapse for distention to take effect. This distention time was estimated between two and three months.

The constructed instrumentation likewise allowed the effect of overlapping of workings to be measured: as the longwall caving of the coalbed situated to the roof of the instrumented coalbed approaches the area of advance of the 8th Coalbed, an increase in the pressure of the gas is produced in the 8th Coalbed. This may even triplicate the pressure of the gas and is more pronounced as the longwall caving approaches the position of the measuring equipment. A spatial range of the influence of longwall caving of some 55–60 m was estimated and a time duration of 2–3 months.

The main contribution of this article resides in the proposal of measures of control and risk of gas outbursts that complement the systematic measurements in the mine itself, with the aim of improving safety in mining work. This proposal, apart from certain practical improvements in mining work, above all regarding the exploitation sequence, would involve the installation of gas measurement tubes before initiating the advance or at the overlap of workings. It would consist in temporarily detaining the advance in the 8th Coalbed when an overlap of workings may occur or prior to the commencement of an advance in the 8th Coalbed, installing measurement tubes in the face. The values and the trend of the measured gas pressures, together with the values obtained from gas concentration tests, would enable control of the conditions of the coalbed and the establishing of what moment would be appropriate to renew the advance. The gas measurement tubes would hence be a reliable, economic control and evaluation measure of the risk of gas outbursts.

Furthermore, this equipment would enable the opening of other lines of research, both for calibrating the time and range of influence of mining work in each advance, as well as for calculating the permeability of the coal. By means of the designed test (gas flow between two gas-measurement-tube sets), permeability could be estimated by numerical models calibrated with site data, both in areas of the mine that have still to be affected by mining work and in those already subject to mining works. These calibrations would also allow the variation in permeability with the depth of the coalbed itself to be analyzed.

Acknowledgements

The authors wish to express their gratitude to HUNOSA (Spain), and especially to the staff of the San Nicolás and Montsacro Pits and the Department of Gas Dynamic Phenomena.

References

Alexeev, A.D., Revva, V.N., Alyshev, N.A., Zhitlyonok, D.M., 2004. True triaxial loading apparatus and its application to coal outburst prediction. Int. J. Coal Geol. 58, 245–250.

Alpern, B., 1970. Tectonics and gas deposit in coalfields: a bibliographical study and examples of application. Int. J. Rock Mech. Min. Sci. 7, 67–76.

Beamish, B.B., Crosdale, J.P., 1998. Instantaneous outbursts in underground coal mines: an overview and association with coal type. Int. J. Coal Geol. 35, 27–55.

Braüner, G., 1994. Rockbursts in Coal Mines and Their Prevention. Balkema, Rotterdam, Netherlands. 137 pp.

Cao, Y., He, D., Glick, D.C., 2001. Coal and gas outbursts in footwalls of reverse faults. Int. J. Coal Geol. 48, 47–63.

Creedy, D., Garner, K., 2001. UK-China Coalbed Technology Transfer. Report N° Coal R207 DTI/Pub URN 01/584, 24 pp.

Díaz Aguado, M.B., 2004. Análisis, Control y Evaluación de Riesgo de Fenómenos Gaseodinámicos en Minas de Carbón, PhD Thesis, University of Oviedo (Spain) Publishing Service, I.S.B.N.: 84-8317-434-0, 301 pp. (in Spanish, with English Abstract).

Durucan, S., Edwards, J.S., 1986. The effects of stress and fracturing on permeability of coal. Min. Sci. Technol. 3, 205–216.

Flores, R.M., 1998. Coalbed methane: from hazard to resource. Int. J. Coal Geol. 35, 3–26.

Freudenberg, U., Lou, S., Shlütter, R., Schütz, K., Thomas, K., 1996. Main factors controlling coalbed methane distribution in the Ruhr district, Germany. Coalbed Methane Coal Geol. 109, 67–88.

González Nicieza, C., Díaz Aguado, M.B., 2001. Gaseodynamic behaviour of a methane hazardous coal bed mined by sublevels. Proceedings of the 29th International Conference of Safety in Mines Research Institutes, Poland, vol. 1, pp. 7–17.

González Nicieza, C., Díaz Aguado, M.B., Álvarez, I., 2001. El gas en la mina. Eur. Minera 36, 60–65.

Hardgraves, A.J., 1983. Instantaneous outbursts of coal and gas: a review. Proc. Australas. Inst. Min. Metall. 285 (3), 1–37.

Huang, S., 2000. The investment perspective of coal mine methane projects in China. UK-China CBM Technology Workshop-Resources Development and Commercialization, Hua Qiao Da Sha, Beijing, November 2000.

IGME, 1985. Actualización del inventario de recursos nacionales de carbón. IGME, Series Mineral Resources, Madrid. 217 pp.

IGME, 2002. Exploración, evaluación y explotación del metano en capas de carbón. IGME, Series Mineral Resources, Madrid. 224 pp.

Jackson, L.J., 1984. Outbursts in coal mines. Tech. Rept. No. ICTIS/TR25. Int. Energy Agency Coal Res., London. 55 pp.

Lama, R.D., Bodziony, J., 1998. Management of outburst in underground coal mines. Int. J. Coal Geol. 35, 83–115.

Li, H., 2001. Major and minor structural features of a bedding shear zone along a coal seam and related gas outburst, Pingdingshan coalfield, northern China. Int. J. Coal Geol. 47, 101–113.

Noack, K., 1998. Control of gas emissions in underground coal mines. Int. J. Coal Geol. 35, 57–82.

Pendás, F., Loredo, J., Cienfuegos, P., Fernández, J.J., 2004. Posibilidades de almacenamiento de CO_2 en capas de carbón en la Cuenca Carbonífera Central Asturiana. Proceedings of the Scientific Technical Meeting on methane exploitation and CO_2 sequestration in coal beds, Department of Mining Exploitation and Exploration of the University of Oviedo and Geological Mining Institute of Spain (IGME), Oviedo June 2004, Conference 2.7. 36 pp.

Ren, T.X., Edwards, J.S., 2000. Three-dimensional computational fluid dynamics modelling of methane flow through permeable strata around a longwall face. Trans. Inst. Min. Metall., A. Min. Ind., Sect. A: Min. Tech. 109, 41–48.

Safety Regulations for Coal and Oil Shale Miners, 1973. Instructions for Safe Mining Operations when Mining Burst-Prone Seams. Nedra, Moscow. 255 pp.

Struminski, A., Madejam, B., 2001. Optimization of the withdraw roads for the mine staff during the underground fire. Proceedings of the 29th International Conference of Safety in Mines Research Institutes, Poland, vol. 2, pp. 125–132.

Suárez Fernández, M.J., 1998. Evaluación de riesgo de desprendimiento instantáneo mediante un sistema experto borroso. pHD Thesis. University of Oviedo, 286 pp. (in Spanish, with English Abstract).

Suárez-Ruiz, I., Jiménez, A., 2004. Coal facies studies in Spain. Int. J. Coal Geol. 58, 31–39.

Thielemann, T., Krooss, B.M., Littke, R., Welte, D.H., 2001. Does coal mining induce methane emissions through the lithosphere/atmosphere boundary in the Ruhr Basin, Germany? J. Geochem. Explor. 74, 219–231.

Tyler, R., Kaiser, W.R., Ambrose, W.A., Laubach, A.R., Ayers, W.B., 1992. Coalbed methane characteristics in the foreland of the Cordilleran Thrust belt, western United States. In: Beamish, B.B., Gamson, P.D. (Eds.), Symposium on Coalbed Methane Research and Development in Australia, vol. 4(2). James Cook Univ. of No. Queensland, pp. 11–32.

Williams, R.J., Weissmann, J.J., 1995. Gas emission and outburst assessment in mixed CO_2 and CH_4 environments. Proc. ACIRL Underground Mining Sem. Australian Coal Industry Res. Lab., North Ryde. 12 pp.

World Coal Institute, 1998. Ecoal. The Quarterly Newsletter of the World Coal Institute, 28.

Zapatero, M.A., Martínez, R., Suárez, I., Mansilla, H., Arenillas, A., 2004. Inventario de recursos de CBM-CMM en España. Proceedings of the Scientific Technical Meeting on methane exploitation and CO_2 sequestration in coal beds, Department of Mining Exploitation and Exploration of the University of Oviedo and Geological Mining Institute of Spain (IGME), Oviedo June 2004, Conference 1.1. 39 pp.

Zhu, X., 2000. China's policies for CBM development and utilization: today and tomorrow. Proceedings of Second International Methane Mitigation Conference, Novosibirsk, Russia, pp. 565–570. June 2000.