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Sergazy Baimukhametov
ArcelorMittal Coal Mining

Yuriy Stefluk
ArcelorMittal Coal Mining

Maarten Velzeboer
ArcelorMittal Coal Mining

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DEVELOPMENT AND MINING OF HIGH GAS LOW PERMEABILITY COAL SEAMS IN THE KARAGANDA COAL FIELD-KAZAKHSTAN

Sergazy Baimukhametov¹, Yuriy Stefluk² and Maarten D Velzeboer³

ABSTRACT: The seams being mined in the Karaganda coalfield in Kazakhstan are very gassy and have low permeability, so called tight coals. In addition, the coalfield is dry, which means that "traditional" predrainage, through a two phase gas liberation process, by first dewatering, is not possible. Outbursts in development particularly in the D₆ seam are still a major concern and technologies to allow better prediction of geological anomalies are being tried. Managing gas levels during the longwall extraction calls for special applications to be adopted. These have resulted in improved volumetric underground gas capture and purity, which allows the resultant drained gas to be utilised for local power generation. The methods developed and those foreseen in the future to achieve more effective predrainage and more effective operational gas management are described.

INTRODUCTION

The Karaganda coalfield, in Kazakhstan, was first developed during the early part of last century, with major mine exploration and new mine developments during the post war period. Mining currently takes place from some 15 mines, eight of which are underground and belong to "ArcelorMittal", Coal Division.

Most operating underground mines date from the second half of last century and these are more or less of standard Soviet design, with a nominal annual shaft hoisting capacity of 1.5-2 Mt (ROM) and using full caving longwall extraction.

Over the last five years the accident rate within mines has improved significantly, through a focussed programme of investment, modernisation and operational mind set changes. Many technical challenges still remain to be fully mastered, high gas and low permeability coal being one of them.

GEOLOGICAL SETTING

The Karaganda basin is located in the area of the same name near central Kazakhstan. Within the Karaganda region, the coal bearing areas occupy some 2000 km² at a total thickness of 4000 m. The basin is characterised by three main synclinal structures. The productive coal mines go down to depths 700-1200 m, the working series contain up to 30 coal seams, varying from <1 m to 7 m in thickness, consisting of high quality energy coal and prime metallurgical coal. Total coal resources of the Karaganda basin up to the depth of 1800 m have been estimated at 41.3 bt with a total coal thickness of over 40 m.

The main target seams for extraction are the K and D seams. Both seams are outburst prone at depth and liable to spontaneous combustion. Dips in the coalfield vary between 8 to 35 plus degrees. Near verticality is observed at the sub-crops. Minor faulting and associated dip changes are not infrequent.

The D₆ seam is a thick high quality coking coal, with a very distinct shear zone (0.2-1.2 m) in the bottom section. The D₆ seam has been found to be extremely outburst prone, particularly the bottom section. The permeability of the seam is extremely low, and wet drilling through the bottom section zone has to date been found to be most challenging, probably because of the fine coal within the shear zone and swelling clays within the seam itself. The diffusion coefficient of the bottom section has also been found to be several orders of magnitude greater than the top section of the seam.

¹ Technical director of Modernisation for the Coal Division of ArcelorMittal Coal Mining, Karaganda, Kazakhstan;

² Technical director coal division of ArcelorMittal Coal Mining, Karaganda, Kazakhstan;

³ Principal MD Mining, London, part time advisor to ArcelorMittal Mining in Kazakhstan, email: m.velzeboer@mdmining.com.

GAS ENVIRONMENT

The Karaganda basin is considered a high gas content resource area. The gas content intensity of the seams increases from the beginning of the methane zone at 400-500 m to gas levels of 15-20 m³/t at current working depths and stabilising at 800-1200 m depth to limits of 22-27 m³/t. The depth of the methane free zone from the surface varies over the range of 60-250 m and depends on local geologic and structural features.

Operational challenges

As the underground workings get deeper the gas content within the main seams increases and the permeability of the seams decreases, as illustrated in Table 1:

Table 1 - Variations in depth and permeability (Baimukhametov, 2006; Sigra, 2009)

Seam series	Depth / m	Permeability /10 ⁻² mD
K ₁₀ -K ₁₂	400	1.51-2.77
	600	0.19-0.35
	800	0.05-0.09
D ₁ -D ₆	400	5.85-3.89
	600	0.75-0.50
	800	0.19-0.13
D ₆ (measured 2009)	600	0.3

In response to containing mining costs, and benefitting from the higher production rates of modern mining equipment, increased productivity is being sought.

All three factors potentially lead to a contradictory mix.

- Increased gas contents require more effective pre drainage, or more time to drain;
- Lower permeability relies on more effective permeability enhancement, and/or requires more drainage time;
- Higher productivity demands for increased development and extraction rates, which is only possible in "safely" drained areas of extraction.

GAS

The efficiency of coal seam degassing has relied on increasing the gas permeability of the coal bed by creation of induced fractures and by allowing for an increase of the degassing period.

In order to achieve an acceptable gas content reduction the following actions have been taken:

- Permeability enhancement has been adopted from vertical surface predrainage wells which have been subjected to in-seam water fracking, with possible reworking at a later stage;
- In the underground situation, undermining (or overmining) the target seam, thereby allowing it to be extracted in the "de-stressed" zone. So called "protection" extraction has proven quite successful. Increasingly the potential "protection seam" is outside the distress zone, or not viable (too thin) in a mining sense, so alternatives have to be developed;
- Pre mining longwall block drainage is extensively used, with mixed results, mainly because of low in seam permeability, and the lack of natural permeability enhancement as part of the activity. Where the coals are water saturated, pumping leads to relaxation, which allows gas flow to follow the drainage through pumping. This two phase mechanism is not available in a dry coalfield. Artificial permeability enhancement, has to be engineered, such as hydrofracking;
- Drainage within the approaching face front abutment (60-80 m), is a technique under consideration, as the permeability's of <0.01 increases to over 10 mD. The gas evacuation time is very limited because of the advancing face and the capacity control of the (vacuum) drainage system will need to be re-dimensioned;

- Post mining and goaf drainage is quite advanced in application. This has been described in some detail by Mukhamedzhanov *et al.* (2009). These techniques range from surface drainage boreholes, above seam drainage sewers and underground goaf drainage holes on vacuum and are well developed and applied where relevant. Selective directional drilling and eventual “reservoir” modelling will add to the available tools and capabilities in this sphere.

Typical degassing performance efficiencies are given in the following Table 2

Table 2- degassing performance (Baimukhametov, 2006)

Degassing method	Typical capture performance/%	Efficiency/%
Pre drainage	3.75	12
Development face drainage	0.75	10
Pre mining block drainage	2.2	33
Goaf/LW block drainage		
Vertical wells from surface	35.4	38.2
Drilled goaf wells	9.5	9.7
Goaf drainage	14.0	14.4
Face ventilation	34.4	37.7

Due to gas management and operational safety concerns in the past, current production rates from “gas rich” longwalls have been restricted to 4000 t/day, which is well below the face equipment capability.

A limiting factor is also the face ventilation, where the air velocity along the face is restricted to <4 m/s. By applying Y ventilation, the face velocity may be reduced, by increasing the quantity of air over the tailgate. By reducing the seam gas content before longwall mining to a value of <4 m³/t, the face ventilation constraint and spontaneous combustion exposure become more manageable.

OUTBURST MANAGEMENT

Unlike Australia, no universally compatible threshold value (the “8/12” rule) is currently applied in Kazakhstan underground coal mining. Current practice is based on the Russian standards. Whilst these are robust in their nature, there is a case to be made to reconsider the existing “outburst probability” determination, and consider the redefinition of a scientifically sustainable Norm. The Norm must find its origin in the characteristics and behaviour of the seam conditions of the Karaganda coals. Typical development rates are 25-40 m/month, in the high gas, outburst prone seams such as the D₆. In addition developments roadways are driven in stone, 10m below the future gate roads, to allow seam drainage to be carried out. In an economic future such development rates and stone drive efficiencies, need to be improved significantly to remain financially viable and allow for social and economic advancement of the operations.

GAS MANAGEMENT FOR EXTRACTION

Issues need to be addressed include the following:

Pre drainage from surface

During the early ‘60’s hydro and nitrogen fracking, from vertical boreholes, was tested in the K₁₂ seam, with good results. Further tests proved successful for seams down to 500 m, with a reported gas reduction of 3.3-3.8 m³/t and when including the in-seam (vacuum) extraction an overall reduction of 8-9 m³/t has been reported. In addition the outburst hazard was found to be below the critical limit.

Tests carried out at deeper horizons, 700-800 m, proved very disappointing. It was concluded that below 500-550 m, the deterioration of well productivity reduced significantly (e.g. 1.1 m³/min at 400 m, 0.5 m³/min at 550 m and <0.2 m³/min at 750 m depth) because of failure to keep the fractures open at depth.

In early ‘80’s an area of the D₆ seam at Lenina mine was drilled and fracked from the surface, with water and other chemical active agents. By pre-draining over a period of ten years, it was possible to reduce the gas levels by 6-9 m³/t. An interesting observation was made at the time, in that the fine coal from

the shear zone, caused a fine coal plug to be formed, which effectively sealed the well, necessitating re-cleaning. Similar plug sealing has been experienced with wet underground drilling trials from the stone heading 10 m under the seam. It is postulated that clays within the seam react with the drilling fluid (water) and the super fine coal from the shear zone to form a plug. Using (vegetable) oil or gas/air as the fracking medium should overcome the swelling clay problem. Figure 1 shows a coal plug being cleaned out.



Figure 1 - Coal fines plug being cleared from hole, shown as a black jet flowing from the borehole as it is opened up after hydrofrac-pumping

Based on the positive results during the '80's, pre-drainage from vertical boreholes, spaced at 250 m is standard practice for the D₆ and other high gas seams. The gas from the seam is flared off on surface, where there is no natural gas flow; this is assisted by pumping out the frack-water with a donkey pump. Figure 2 shows a surface donkey pump installation with flare. Because there is no real water make, within the seam, there is no need to provide drainage infrastructure.



Figure 2 - Nodding donkey pump, with gas flare, with mine Kazakhstanskaya boundary shaft in background

More recently in seam gas make tests have been carried out at Kazakhstanskaya mine, also in the D₆ seam, as the pre-drain area is being developed for mining. Of the wells shown, most were re-stimulated after three to four years of operation, to maximise the degassing. The effectiveness of the pre-drainage is shown in Table 3.

Table 3- Effectiveness of pre-drainage

BH number	Drainage time /months	Gas extracted to date/Mm ³	Seam gas content reduction/(m ³ /t)	Well characteristic
23	126	0.93	4.02	Self flow
24	126	1.27	6.32	Self flow
25	120	1.09	5.44	Donkey pump
30	106	0.56	2.80	Donkey pump
31	103	0.60	5,46	Self flow
37	80	0.80	4.01	Donkey pump

The longwall blocks of such pre-drained areas are currently being developed. Because of the high outburst risk in development of the D₆ seam, the initial development takes place in stone, 10 m below the seam. During the development of these stone drives, the gas make of the overlying seam has been measured. The gas makes have been recorded in the zones as indicated in T, and in the section of the mine plan shown in Figure 3.

Table 4- Gas make data

Zone	Average gas make (m ³ /min) for zone	Max gas make	Min gas make
A	0.02	0.05	0
B	0.005	0.03	0
C	0.04	0.09	0.01
D	0.07	0.16	0.02

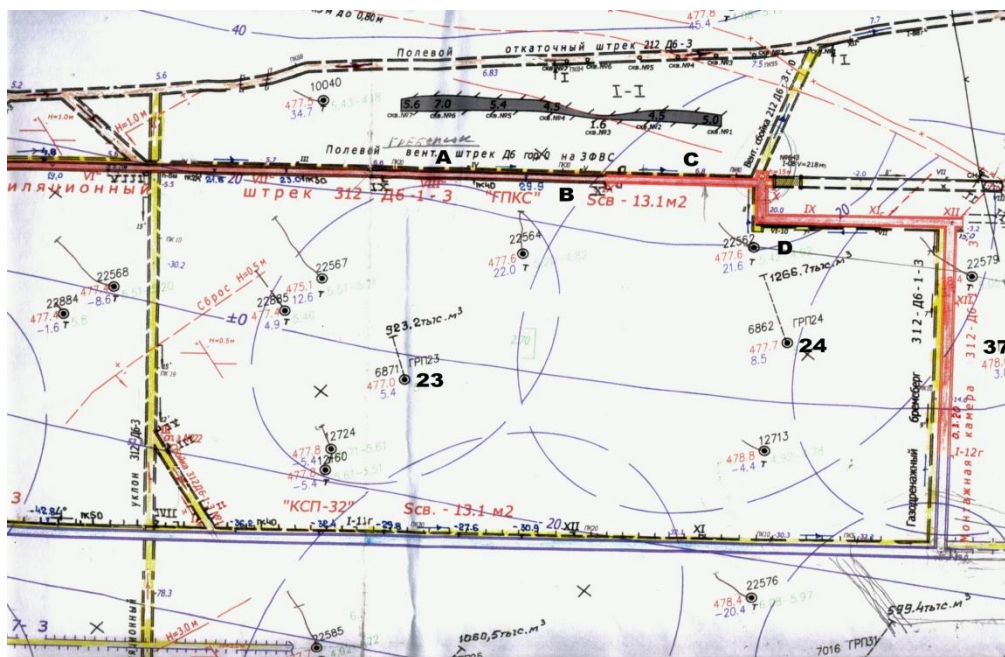


Figure 3 - Mine Kazakhstanskaya pre drainage holes (23, 24 and 37), and zones of measured UG gas production (A, B, C and D)

Pre drainage from underground

It is observed that for an initial gas content of say 20 m³/t, a reduction of up to 6 m³/t from the surface pre-drainage still results in a challenging underground gas environment. In-seam techniques and permeability enhancements are required to achieve desired operationally safe gas content levels.

Two aspects of pre-drainage from underground are important. The first relates to achieving safe background gas levels, to avoid outbursts during development. The second relates to avoiding being gassed out at the longwall face during production.

Drainage during development

The gas testing and pre-drainage within in-seam development headings is well regulated by the Kazakhstan Authorities. This essentially consists of drilling 17 m ahead of the face, in an overlap fashion. Outburst proneness detection is then undertaken and if it was considered safe, mining may proceed to within 5 m of the end of the holes. Unfortunately still too many near misses and outburst accidents occur. All outbursts appear to be associated with geological features.

Plans are in hand to trial underground remote sensing techniques to better pinpoint geological disturbances, abnormal gas accumulations or high diffusion rated zones. Trials with surface techniques have also been carried out.

In the most highly outburst prone areas, D_6 in particular, the future roadway development locations are degassed by driving stone roadways 10 m under the seam, and drilling degassing holes, up into the seam as shown in Figure 4. Typically a fan of five holes is drilled into the seam from the roof of the roadway below at 4 m spacing, which are put on vacuum, up into the seam. Once a safe threshold (time or gas content related) has been achieved, within the seam, in-seam gate road development will take place.

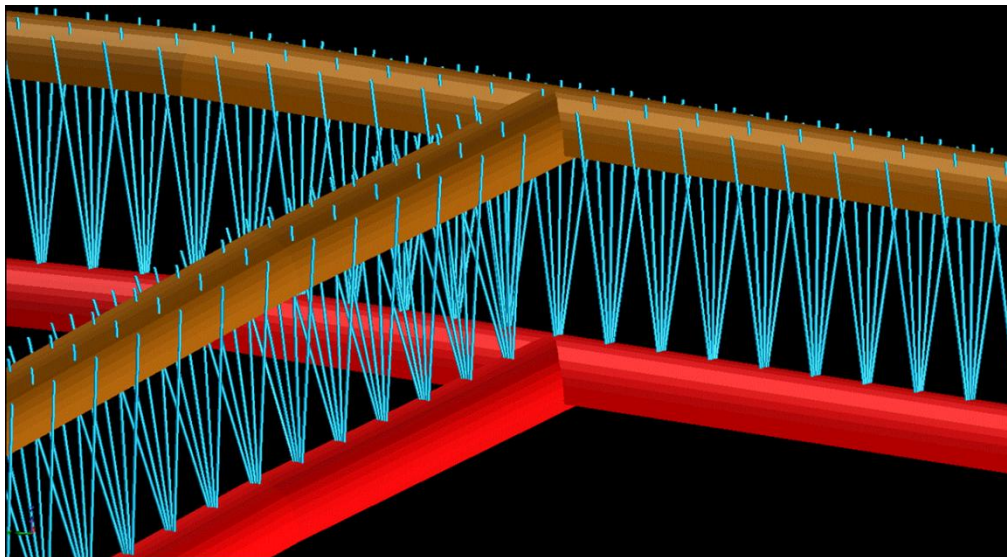


Figure 4 - 3D visualisation of in stone development (red) and degassing holes for in seam gate roads (brown)

Drainage of longwall block

Drainage of the longwall block is accomplished by drilling a series of long parallel in-seam holes across the block. The spacing of these holes is about 4 m, but trials of 2 m spacing have been carried out. The existing drilling equipment is only capable of efficiently drilling 100-120 m auger air-flush holes within the seam. Hole wander has also been found to be a major constraint when advocating longer in-seam holes. The unsatisfactory trials of wet drilling have already been mentioned.

Little difference in drainage efficiency has been noted, when drilling parallel or at an angle towards/away from the face line. The beneficial effect of cleat direction does not appear to have been considered, or found to play a part.

Most benefit has been achieved by better sealing of the borehole collars and being able to regulate the vacuum attached to the hole. This has resulted in a doubling of the gas purity and subsequent greater effective extraction of methane gas as shown in Figure 5.

Trials with directional longhole drilling are planned and in-hole survey tool applications are foreseen. The availability of a simple IS survey tool for hole depths of up to 100 m has proven to be challenging.

Vacuum influence at methane-air mix concentration at experimental site and compared site

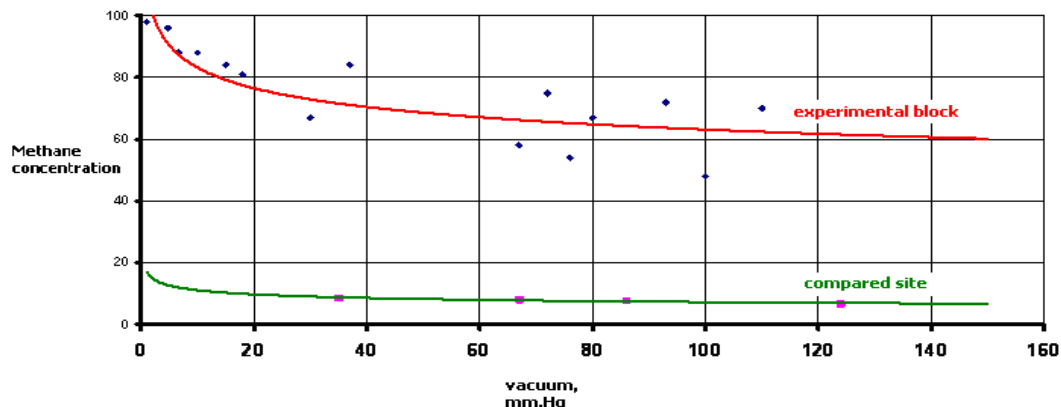


Figure 5 - The effectiveness of drainage collar sealing, on purity and therefore also gas extraction rate

Destressing

The most effective method of increasing the seam permeability is by undermining, (within 50-70 m) or to a lesser extent over mining, (within 30 m) of the target seam. When undermining, no drainage of the target seam is required, which is consistent with experience in Germany, Russia and elsewhere. Such an approach is common when mining the K_{12} seam, by taking the underlying K_{10} first. The added advantage in this instance is that the mining conditions for the K_{10} are also better, as the seam has lower gas and outburst characteristics.

The zone within the front abutment of the longwall is marked by having a high permeability. This potentially allows increased gas extraction from this zone by the in seam drainage holes. Careful vacuum management is required, as there will be the changes in the drainage dimensions, However there is a future opportunity for interactive purity and suction instrumentation and automation.

Permeability enhancement

Due to the absence of water within the seam, gas liberation is essentially a single phase process. This process is probably a balancing act between the seam pressure, the sorption pressure and the resultant effective pressure envelope with induced coal shrinkage.

Limited shrinkage tests have been carried out on the D_6 seam, and although found to be present, the results were inconclusive, possibly because of inadequate sample quality.

In practice, over time, may be years, sufficient gas liberation may come about. This clearly is not an option in a mining environment. Some method of managing the time-frame or artificially enhancing the permeability is sought. A mechanism of "kicking off" a self-sustaining gas release is required, such as by creating an above critical enhanced permeability volume, or stress condition, which induces permeability increase through shrinkage by way of releasing the initial gas volume and pressure. This needs to be the focus into the future.

CONCLUSIONS

Developments within the Karaganda coalfield have moved forward and there is a clear focus on the work that still needs to be done. It is hoped that this work will lead to mastering the safe mining of high gas and low permeability coal seams in an efficient and safe manner.

It is interesting to note that increasingly Australian mines are planning to work low permeability seams, or "difficult to drain" areas. There is a common desire to cracking the problems and achieving a safer working environment underground.

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