THE CASE FOR METHANE DRAINAGE

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ABSTRACT

Everyone connected with underground coal mining is familiar with the phenomena of methane emission and of the efforts to remove this gas safely using ventilation air. Another method of removal is the practice of methane drainage and this paper gives some background to its invention, application and refinement. It also illustrates the current situation in the UK industry following the move towards concentration of output.

Based on the simple premise that the methane drainage capture is directly proportional to coal production increases, the value of the extra coal won is calculated and compared to the theoretical extra cost of equivalent ventilation air requirements if drainage was not used. The value of the captured methane is also analysed, in terms of emissions trading credits, as is its energy value for electrical power production.

Methane drainage is shown to play a major role in meeting the challenges increased rates of mining have recently created, which when linked to surface utilisation, offers a proven, robust system to combat methane emission from underground coal mining.

Some trends are forecast and methods of improving methane drainage are outlined. Possible alternatives are offered, finalising with underground coal gasification (UCG) being viewed as the ultimate solution to the current coalmine methane emission problem.

1.0.) <u>INTRODUCTION</u>

Methane release from coal mining is a phenomenon that has dogged the industry right from its very beginnings. Before the invention of methane drainage and with fan engineering in its infancy, it would have been hard to deal with this gas and numerous solutions were devised.

One such solution was the “fireman”, who would be wrapped in wet rags and sent to remove methane from working places. He would do this by literally burning it away, using a lighted brand, thrust into the layers of accumulated methane. This was considered the lesser of two evils, the other being the risk of an un-controlled, unexpected ignition occurring, when many other, more vulnerable men might have been working in that area of the mine.

This method could have been termed “in-situ chemical conversion” and apart from a rather spectacular rate of reaction, it definitely had merits. The process was quick, cheap to apply and was very efficient. Although unknown at the time, it was also environmentally friendly too, although the fireman would probably not have cared that much, understandably having more immediate worries of his own! Unfortunately, the products of combustion from this process, although relatively benign to the environment, would have been rich in carbon monoxide and devoid of oxygen and it was probably the case that enthusiasm for this practice died off at much the same rate as its proponents.

2.0.) FROM WHERE AND HOW IS METHANE RELEASED?

Methane, produced during coal formation is adsorbed onto its internal surfaces and it is notable that just 1 tonne of coal will have an internal surface area of around 90 million m^3, onto which this, and other gases can congregate in a molecule thin layer. Once there it is packed as dense as a liquid and volumes held this way can exceed 30 m^3 per tonne of coal.

Along with other factors, the burial pressure mechanism, which helps form a coal will also dictate how much gas a coal might still hold today and most coal basins illustrate a gas gradient where increasing depth generally shows corresponding increases in gas content. Free gas can be held within a coals' open pore system in this way at pressures exceeding 5 MPa (725 psi). Any free gas within the coal interacts with the adsorbed gas and a state of equilibrium is created.

Coals around the world exhibit different levels of permeability. In the UK hardly any coal is considered permeable and methane remains trapped in seams until disturbed by mining, whereas coal in countries such as Australia or the US can have permeabilities 3 or 4 orders of magnitude greater, allowing active transport of gas into their mines' roadways even before the massive disturbance of longwall mining occurs.

Permeable or not, once a longwall face cutting machine has passed, around 40% of the worked coal seams' gas is reckoned to be liberated onto the face immediately. However, the greatest source of gas release onto a longwall is generally from seams above and below the worked seam. These are disturbed by the extraction process and depending on their proximity and thickness, will give off varying amounts of methane, commensurate with mining rate. Unchecked, all of this gas will eventually be liberated underground, as once undermined, seams become permanently connected to the mine via a myriad of vertical fissures and de-stressing increases their permeabilities by up to 3 orders of magnitude.

Long after a mine has closed, gas will continue to be desorbed, venting straight to the surface through open shafts, or building up pressure in the mine roadway system, before escaping through subsidence fissures or by traversing permeable rocks to the surface. The only mechanism, which appears to curtail this activity, is to allow the mine to become flooded with water, which re-creates equilibrium within the coal once the hydrostatic head matches the remaining gas pressure.

3.0.) WHAT CAN BE DONE ONCE METHANE ESCAPES FROM COAL?

With the advent of modern fans, many mines having low gas content coal can now dilute methane using ventilation alone and running costs for fans to provide these low volumes of air are comparatively cheap. All of the gas escaping from the coalface and seams above and below will percolate through the fractures in the waste and simply be carried away through the surface fan.

In permeable coal, which has raised gas content, Australia and the U.S. have perfected the art of pre-draining the worked seam, drilling long horizontal holes into the coal. Low flows of high purity methane can be drained from the seam in this way over a number of months. At the beginning of any pre-drainage regime however, a mine would have to work hard to get in advance with its developments and this would involve a once only cost of typically some 4000 m of roadways in order to get ahead of itself. In the US, the technique of drilling and fraccing vertical Coal Bed Methane (CBM) holes from the surface to commercially gather gas from permeable coals is also useful for pre-draining seams, prior to longwall mining.

In coal that has a raised gas content but is less permeable, gob wells drilled from the surface or underground cross measures boreholes can be employed. Gob wells are favoured in countries where mines are remote, relatively shallow and with little water bearing rock present above the worked seam, whilst cross measures drilling, eminently suited to the deep, wet rock mines, often under built up areas is predominant in the UK.

When longwall panels have been mined out methane continues to desorb from the disturbed coals and although they are supposedly sealed off from the ventilation circuit, these are rarely gas tight. Often, exaggerated during times of falling atmospheric pressure due to Boyle’s Law, this gas flow can become too great to be diluted safely by the ventilation air so many mines in the UK have devised means to drain gas into the methane drainage network. Gob wells can also be used in this way too; draining gas long after the mined area has been sealed off underground.

On a much larger scale, the same phenomena existing in abandoned mines and in 1998, Alkane Energy pioneered the capture of methane from vents left in many UK mines during sealing. Gas has also been captured from purportedly sealed mines by drilling holes up to 300 mm diameter at up to 720 m depth in order to intersect underground roadways. Pressures in excess of 240 kPa gauge (35 psi) have been found, void sizes have often indicated little flooding and enormous reserves of high quality gas are known to be accumulating in these mines. Alkane have so far drained and utilised over 200 million m^3 of mines gas at approximately 50% methane purity from 5 of their closed mines, in 26 $MW_{(e)}$ of electricity generation, boilers and furnaces.

Tower Colliery in the UK performed a similar operation in 2000, but from underground, when they had to drill 65m upwards into an old mine to relieve pressure and drain off gas before they could progress any further in safety. The old mine above gave up an initial 11 million m^3 at around 90% pure methane at an initial pressure of around 100 kPa gauge, some of which was used in an $8MW_{(e)}$ generation scheme operating at that mine. It is notable that this old mine is still giving up considerable volumes, some 3 years on and assists the generation plant considerably, by acting as a buffer reserve during face changeover periods.

4.0.) ONCE CAPTURED, WHAT IS DONE WITH THE METHANE?

If methane is just diluted in the ventilation air, then rather than letting it go to the atmosphere, it is theoretically still possible to burn off the methane. One solution tried in the UK, has been the experimental, ultra-low concentration methane combustion sandbox, at Thoresby Colliery in the early 1990's, whilst Appin Mine in Australia feed it into their mines gas powered, generating engines' air intakes, which incinerates the methane and increases energy input too.

Once properly captured in a drainage system however, methane can easily be easily flared off or otherwise burned for a more useful purpose. In the UK around 40 MW of electricity is generated at working mines using combined cycle turbines and a number of reciprocating engines. Some mines flare off the excess and methane is also used in boilers to heat buildings and water.

Hatfield mine in the UK have recently won government approval for a 430 $MW_{(e)}$ coal gasification power station and the methane from drainage and the mine air could easily be designed to be fed into this plant in the future.

5.0.) UK EXPERIENCE

Methane was being drained for heating and lighting even before 1900 in the UK, albeit on a very small scale, but as coal mining in the UK became more mechanised during the early to mid 1900's, fan design was perfected and the industry gained from the introduction of large, efficient, radial fans, which could often adequately ventilate mines without the need for drainage.

At first, UK mine design included shallow seams, many openings, total extraction and the wastes were supported by packs. There would have been plenty of air in a mine and comparatively less gas emitted per district than towards the end of this period, when total caving longwall mining was adopted. Then in some mines, 3 or 4 of these longwall panels would often have to be worked simultaneously, so, as one would become "gassed off", production could be switched to the other units, leaving it to recover.

Looking for a solution to the increased gas emissions from these caved longwalls and following successful experiments in Germany at Mansfeld Colliery in the Ruhr in 1943, cross measure methane drainage was adopted in the UK after the war. By 1950, 6 mines had started cross measures methane drainage, with 1 mine utilising the captured gas. By 1954, 17 mines were practicing, with 5 mines utilising. By 1958, 60 mines in the UK were cross-measure methane draining and draining gas from worked out areas. Total extraction was around 4,000 litres/sec pure methane, with 15 of those mines utilising a combined rate of around 2,000 litres/sec pure methane. Total deep mine coal production at this time was around 200 million tonnes p.a.

Up until the mid 1980's, methane drainage was viewed primarily as a contribution to safety, by raising gas horizons and so helping to prevent peaks of methane concentration occurring in the airflow. Cross measure drainage was easy to manage and there was plenty of time and space available to drill. Captured gas was seen as a nuisance and mostly just vented to atmosphere.

At the beginning of the 1990's however, concentration of output onto single retreat faces started to raise serious problems. Mine ventilation resistances became enormously tight and time and again old, large volume but low pressure surface fans were found to be unsuitable for these new duties. Booster fans had to be installed in most mines and recently, at two mines, even more booster fans inbye of those ones have been required.

This was because the new style of mining meant more coal would be produced off a single face than had been previously been got off 3 or 4 advancing faces and to dilute this gas to the previous levels thus meant three or four times the ventilation was required. Unfortunately, because of the ventilation laws, this would have required up to 4^3 or 64 times increase in ventilation airpower. Even with the introduction of multiple booster fans this would have rarely been practicable as even where it could be improved, about 45 m^3/s across a face is considered the practicable limit before dust problems start to become a major issue.

Methane drainage, was re-designed to ensure high quality cross-measure drilling could take place behind the face in the drawn off roadway. Modifications to retreat mining support and methane drilling have quickly evolved and almost all UK mines now drill safely and effectively using a robust support method using wood cribs, with a cloth partition for ventilation.

Deep mines in the UK now produce around 17 million tonnes per annum saleable and drain a total of 5480 litres/sec pure methane, utilising 2620 litres/sec of this. It can be seen that although there has been little change in the drained/utilisation ratio at around 50%, the amount drained per tonne of coal mined has increased substantially from 0.63 m^3 per tonne in 1958 to 10.17 m^3 per tonne today. This is has not been by choice – but by necessity, as remaining mines have gone deeper, concentrated output onto single retreat faces and mined at much faster rates, all serving to otherwise burden the ventilation system.

6.0.) <u>BENEFITS OF METHANE DRAINAGE IN THE UK</u>

UK experience has shown that in mines having a specific methane emission greater than around 10 m^3/tonne, introduction or improvement of methane drainage has become a very cheap alternative to otherwise having to increase the ventilation pro-rata for any increase in mining rate.

The primary benefit of methane drainage is that it allows much greater production from mines adopting concentration of output and it is estimated that about a third of all coal mined in the UK is attributed to methane drainage, having an approximate value of £160 million per year.

Mine Name	2003 targets (saleable tonnes /week)	Approximate Saleable tonnes p.a. (@43 wks to account for face gaps)	Typical CH4 content of worked seam m^3/t	Typical Specific Emission m^3/t	Methane drainage capture effy%	Tonnes p.a. assisted by drainage	Est £/tonne	Value of coal assisted by methane drainage £ p.a.
Ellington	25,000	1,075,000	0.2	0.3	n/a	0	25	0
Daw Mill	50,000	2,150,000	1.6	1.7	n/a	0	25	0
Wistow	30,000	1,290,000	3.2	7.0	n/a	0	25	0
Hatfield	10,000	430,000	4.3	8.0	n/a	0	25	0
Welbeck	35,000	1,505,000	5.6	10.0	45	677,250	25	16,931,250
Rossington	30,000	1,290,000	5.2	12.0	42	541,800	25	13,545,000
Riccall	32,000	1,376,000	3.8	12.0	48	660,480	25	16,512,000
Thoresby	35,000	1,505,000	5.4	12.0	38	571,900	25	14,297,500
Kellingley	36,000	1,548,000	5.1	15.0	60	928,800	25	23,220,000
Stillingfleet	32,000	1,376,000	4.8	17.0	40	550,400	25	13,760,000
Maltby	35,000	1,505,000	6.4	18.0	50	752,500	25	18,812,500
Harworth	33,000	1,419,000	7.4	22.0	65	922,350	25	23,058,750
Tower	11,000	473,000	15.0	75.0	80	378,400	50	18,920,000
TOTALS		16,942,000						159,057,000

Table 1. Approximate 2003 UK tonnages and potential value of coal assisted by methane drainage.

Mine Name	saleable Tonnes p.a. (@43 wks to account for face gaps)	Total effective airpower on mine kW(air)	Est. total power cost $kW_{(e)}$	Est. Cost £ p.a. (at 4.5 p/kwh)	Est. vent. costs £ per tonne	Theoretical % extra air required if there was no drainage	Theoretical new cost of ventilation £ p.a	Theoretical Increase in ventilation cost (factor)
Ellington	1,075,000	874	1,165	459,164	0.43	0	459,164	1.0
Daw Mill	2,150,000	594	839	330,918	0.15	0	330,918	1.0
Wistow	1,290,000	1,050	1,400	551,880	0.43	0	551,880	1.0
Hatfield	430,000	656	875	344,794	0.80	0	344,794	1.0
Welbeck	1,505,000	2,068	3,005	1,184,571	0.79	82	7,119,886	6.0
Rossington	1,290,000	1,276	1,734	683,727	0.53	72	3,504,278	5.1
Riccall	1,376,000	1,094	1,459	575,217	0.42	92	4,090,924	7.1
Thoresby	1,505,000	2,371	3,401	1,340,661	0.89	61	5,625,277	4.2
Kellingley	1,548,000	1,175	1,692	666,855	0.43	150	10,419,609	15.6
Stillingfleet	1,376,000	1,592	2,159	851,052	0.62	67	3,940,053	4.6
Maltby	1,505,000	2,223	3,105	1,223,991	0.81	100	9,791,928	8.0
Harworth	1,419,000	2,889	4,212	1,660,370	1.17	186	38,725,840	23.3
Tower	473,000	1,051	1,640	646,646	1.37	400	80,830,710	125.0
TOTALS	16,942,000			10,519,845	0.62			

Table 2. Total airpower installed at mines; Ventilation cost per tonne saleable and theoretical cost if tonnage had to be mined without drainage (This calculation is very simplistic and uses cost $\propto Q^3$ on the whole mine network).

Alternatively, it could be viewed that methane drainage is a substitute for ventilation and in theory, using cost $\propto Q^3$, methane drainage is potentially offsetting incredible costs of some £75 million per year (excluding Tower at £80m alone which would be absolutely impossible to dilute by ventilation at present production rates). Obviously a gross simplification, as engineers would no doubt be able to make some economies on outbye roadway flow demands or would redesign roadway infrastructure, this estimate nonetheless serves to illustrate the point about the true value of methane drainage.

Some mines have got Carbon Credits through the UK Emission Trading Scheme, by introducing methane utilisation schemes and recently, UK Coal secured approximately £5 million p.a. over a 4-year period. Once their generation targets are met, even simply flaring-off excess captured methane is considered quite legitimate, as this still mitigates the GWP of methane by 87%.

When a mine utilises methane in electricity generating schemes, it will also benefit from the power generated, either by selling to the grid or by consuming this electricity "free of charge", which at least offsets their ventilation power costs.

Mine Name	**generating capacity installed ($MW_{(e)}$)**	**Potential generation from methane (@ 48 weeks p.a. availability) (MWh)**	**Lower UK market value at typically £24/MWh (£)**	**Value if able to offset purchase at £45/MWh (£)**
Ellington	0.00	0	0	0
Daw Mill	0.00	0	0	0
Wistow	0.00	0	0	0
Hatfield	0.00	0	0	0
Welbeck	2.83	22,821	547,707	1,026,950
Rossington	0.00	0	0	0
Riccall	0.00	0	0	0
Thoresby	2.83	22,821	547,707	1,026,950
Kellingley	2.83	22,821	547,707	1,026,950
Stillingfleet	4.25	34,272	822,528	1,542,240
Maltby	4.25	34,272	822,528	1,542,240
Harworth	14.00	112,896	2,709,504	5,080,320
Tower	8.10	65,318	1,567,642	2,939,328
TOTALS	39.09		7,565,322	14,184,979

Table 3. Generation of Electricity from UK Working Coal Mine Methane

As shown above, the UK currently generates around 39 $MW_{(e)}$ from working mines and this has a value of between £7.5 to £14 million p.a.

Methane drainage tends to make mines far safer, as methane emissions become much more predictable when gas horizons are raised. Roofholes effectively introduce a third dimension to the pressure regime on longwall faces, which removes gas up and away from the working plane where disruptive pressure effects can often occur, whilst in compliment, floorholes also relieve any floor gas pressure build up in a safe, controlled manner.

7.0) FUTURE TRENDS AND POSSIBLE DRAINAGE IMPROVEMENTS

Because mining equipment is becoming ever more reliable and robust and longwalls are now at a minimum number of 1, output may now have to be improved by increasing hours of operation. From a present 75 hours a week, by introducing 4 shift “hot seat changeovers” and 7 days a week working, faces could eventually be doing around 150 hours a week, effectively doubling current production rates and therefore doubling gas release rates.

Ventilation is already the primary limiting factor and would offer little room for improvement, so it is considered that methane drainage would once again be called upon to help expand the boundaries of production if this was adopted.

Tower is a good example in the UK of the eventual limits to which methane drainage can be taken, where, because of restrictive airways, there is now four times more methane being carried in the pipes, than is handled by the ventilation. Roofholes are drilled continually, the roadways are literally full of drainage pipes and the surface plant is the largest in the UK and is continually run, at full duty. Although the mine is very successful in achieving its tonnage week-on-week, everything is now at full stretch and the mine drainage runs at an average 80% capture efficiency and has recently been measured at 88%!

To achieve improvements in cross measure methane drainage:

- Holes could be drilled at a closer spacing than previously.
- Improved standpipe seals and increased length are a possible option.
- More or bigger drainage pipes are required if increasing gas flows
- Extraction plant must be made larger to handle more throughput
- Design to provide a healthy vacuum of at least 10 kPa at the borehole.
- Undertake borehole design work to maximise yield and minimise effort.

Once the boundaries of this technique are reached, to achieve further improvements in methane removal or mitigation, fundamental changes to mining may need to be implemented. Realistic options may include:

- Adoption of narrower longwalls or Board and Pillar working, so as to disturb fewer seams above (but may well slow down production).
- Possibly being able to drain whole sealed off previously mined seams above the worked seam by either mine fan pressure re-distribution or by methane plant suction (only an option in specific instances where previous mining has occurred above– works as a “vertical sewer gate”).
- The adoption of multi-entry longwalls and trunks, which are favoured in US and Australia (longwalls would be easy to do, but trunk roads would involve major infrastructure changes at all UK mines).
- Reversal of the concentration of output trend by working multiple longwalls simultaneously (could allow cheaper ventilation).
- Gobwells, either independent or as a supplement to cross measures (not really viable in the UK because of depth, planning issues and aquifer rocks).
- Introduction of sewer gates (Risky if coal is prone to spontaneous combustion; gas is diluted by air further outbye, but remains in mine)

Options worth investigation for the future may be:

- Horizontal in-seam pre-drainage by Australian Tight Radius Drilling (TRD) from the surface, then using the holes as gobwells afterwards (not really viable in the UK – impermeable coal).
- Some form of controlled chemical conversion and removal by chemical or catalytic means (high volumes of low concentration methane in air would need to be processed) . . . full circle – back to the fireman?

The ultimate solution however is considered to be:

- Underground coal gasification (UCG), which would enable extraction of energy from coal without need for any ventilation at all. 100% of the original in-situ methane would be captured along with products of gasification (CH_4, CO, H_2 and CO_2). Strata disturbance would be minimised and the risk of having men underground would be removed.

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