ADSORPTION AND DESORPTION TECHNIQUE IN PREDICTING OUTBURST OF GAS AND COAL

By

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ABSTRACT

The paper describes the studies conducted to date on the short term adsorption/desorption of gases in coal from the point of view of developing techniques to predict imminent outbursting conditions in coal mines. A number of different parameters such as ΔP express, K' and $\Delta V_{0/60}$ etc. which have been effectively used overseas were studied on samples of coal from Westcliff and Leichhardt Colliery. Results indicate that these do not seem to be valid indices for predicting an outbursting condition.

Based upon desorption isotherms, a new index defined as "L_2''" has been developed which shows promising results. This index is in a position to differentiate the changes in the structures of coal and its proness to outbursts. The "L_2''" value determinations and its usefulness opens a new field where it would be possible to determine outbursting conditions from existing drill cores obtained during exploration studies or from long holes drilled in advance from underground workings. The index is more or less independent of the time elapsed between the extraction of a sample and the conduct of the test. The test for "L_2''" can be conducted on site or in the laboratory. The test is simple, easy to carry out and the "L_2''" value for a sample can be calculated in less than 20 minutes. It could be adapted as a routine test for monitoring outburst conditions in mines.

INTRODUCTION

The phenomenon of outbursts occurs worldwide both in coal and salt mines as well as in excavations driven in rocks of coal measure strata. In Australia it occurs in a number of collieries in N.S.W. and Queensland. The gases associated with outbursts under Australian conditions are mostly CH_4 (Leichhardt, Moura, West Cliff, Corrimal and Appin Collieries) or mostly CO_2 (Collinsville and Metropolitan Collieries) or a mixture of the two with small amounts of other gases such as nitrogen, hydrogen, hydrogen sulphide, etc. Studies worldwide have shown that for this phenomenon to occur one or more of the following conditions must be fulfilled:

1. The quantity of gas present in the coal seams must exceed a certain limit e.g. >10 m^3/tonne of coal in the case of CH_4 or >7 m^3/tonne of coal in the case of CO_2.
2. Comparatively low strength of coal compared to the stresses acting in the seams. A depth of 100 m is sufficient when geological disturbances such as shear zones are present. In the absence of a shear zone, a depth approaching 500 m is required.
3. Coal varies from medium to high rank where outbursts occur. It usually has a fine crack (cleat or cleavage) structure with possibly low permeability and high adsorption capacity.

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4. There must be some initiating factors present such as vibrations from a machine, blast initiation, withdrawal or setting of supports, drilling holes etc.

The location of outbursts also indicates that they are probably associated with regions of high geological activity on a regional level such as compressional forces causing mountain building and regional uplift (Czechoslovakia, Yugoslavia, Turkey, India, Japan), large erosion and marked changes in the topography (Canada, U.S.A., Poland) or high localised compression as in salt mines in Germany and Poland. These indicate the possibly high lateral stresses associated with outbursts of gas and coal.

The period of occurrence of an outburst can vary from a fraction of a second to several tens of seconds and sometimes up to 2.5 minutes (U.S.S.R., 1964). The initial impulse of lower magnitude presents itself usually about 0.5 s before the start of the major event (de Vergeron and Belin, 1966). Investigations show that microseismic noise levels increase and then drop almost from a few seconds to a few minutes before the major event.

The quantity of material thrown out may vary from a few tonnes to thousands of tonnes with millions of cubic metres of gas released into the ventilation stream of the mine (Lama, 1980). This creates extremely dangerous mining conditions and has led to losses of lives and equipment, destruction of mine structures, gas explosions followed by dust explosions and even closures of a mine section or the whole mine.

In Australia, this problem is becoming very important as the depth of mines increases. In the Bowen Basin it seems that 180 m is almost the critical depth at which outbursts would occur if coal was saturated with CO_2 (Collinsville State No. 2 Colliery). At Leichhardt almost 200 outbursts have occurred at about 400 m depth. It is expected that gas outbursts are likely to occur in future underground mining operations at depth in the whole of the Bowen Basin, since the deeper underground mines in the northern, south western and eastern regions of the Basin are already experiencing this phenomenon.

In the N.S.W. mines located in the Southern Coalfields this problem could occur increasingly as the excavations move further away from the escarpment. An increased volume of gas in newly opened mines away from their outcrops (West Cliff and Appin colliery leases) and at greater depths has already been indicated.

Two basic theories have been put forward to explain the phenomenon of outbursts. The most commonly accepted is the dynamic theory (Skocinski, 1954, Khodot, 1961 and 1964). According to this theory both rock pressure and gas play an equal role. Rock pressure causes fracturing and release of a large volume of gas which is instrumental in the displacement of coal. A number of research workers in Russia, France, Belgium and Germany support this concept.

The second theory was put forward by Ruff (1930) and is known as the "nest" theory. According to this theory, nests or pockets of low strength (already crushed) coal are saturated with gas. If one of the localised pockets is suddenly punctured with advance of face, a large volume of almost adhesionless coal particles floating in gas is displaced, with a dynamic effect.

Jarlier (1936) rigorously opposed this theory on the basis that no changes could be established in the composition of the materials at places where outbursts have occurred or where these have been absent. Looking closely at both theories, one can suppose that all such areas or zones where coal is weak and fractured, such as shear zones and zones of high stresses caused by local changes in geological structure or mining conditions are in fact "nests", and as such these two theories can be combined. The occurrence of more severe and higher frequency of outbursts in mines when CO_2 is present in coal seams would suggest that such nests should be more frequent in these coal seams. There is, however, no evidence to confirm this.

There are other features associated with outbursts. For example, in certain mines both in Australia (Leichhardt Colliery, Gemini Seam, Queensland, and Metropolitan Colliery, Bulli Seam, N.S.W.) and overseas (Cevennes, Fontanes Seam, France) outbursts have occurred independent of the direction of drivage of roadways. In Leichhardt, the direction of drivage of roadways has played a decisive role only in location of outbursts. However, most of the outbursts that occur around the world are associated with geological disturbances. The question of severity of the outbursts and their frequency in association with such geological disturbances must however be sought in the decreased strength of coal and possibly (but not always) zones of high stress gradients (not necessarily high field stresses) associated with it.

The presence of CO_2 gas associated with higher intensity and frequency of outbursts has to be considered from two points of view. Firstly, the adsorption capacity of a coal sample for CO_2 gas is far higher than for CH_4 gas. The amount of CO_2 adsorbed is almost 2 - 3 times that of CH_4. Secondly, the desorption rate of CO_2 from coal is much slower compared with CH_4 (keeping in mind the total quantities of gas present). The reasons for the latter are (i) higher viscosity of CO_2 (148×10^{-6} g/cm for CO_2 and 108×10^{-6} g/cm for CH_4 at 1 bar pressure and 20°C, (ii) larger molecular cross section area of CO_2 (39.2 A^2 for CO_2, 17.8 A^2 for CH_4). This would mean that all conditions remaining constant, pressure gradients would be higher when CO_2 is present and as such it would favour ease of fracturing.

METHODS OF PREDICTING OUTBURSTS USING ADSORPTION/DESORPTION OF GASES

A number of methods using the adsorption/desorption technique have been developed and successfully applied to predict imminent outbursting conditions. These methods rely on the basic assumption that gas plays a major role in the phenomenon of outbursts.

The method of utilizing desorption of gas is based upon determining the amount of gas present in a given sample of coal under controlled field conditions. The measure of gas could be either the amount of gas liberated over a given time (ΔV) (Hargraves, 1962, Tarnowski, 1966) or pressure (ΔP) developed in the chamber containing the sample (Tarnowski, 1970, de Vergeron & Belin, 1966) or the rate of desorption known as K value (Janas & Winter,1977).

These methods have the disadvantage that the samples have to be taken at definite intervals and from a specified distance from the face. These hinder extraction and production cannot be continued till the results of tests are known so as to avoid any occurrence of a sudden outburst.

The various factors that influence the test results are dependent upon rate of advance of face, location of sample from the face, fraction size, time elapsed between sampling and testing, permeability of coal, initial gas content, temperature and moisture content etc. The critical values of various indices (ΔV, ΔP or K) are, therefore, different. However, there are two basic points which stand out quite prominently. Firstly, the critical value of any outburst index (ΔP or ΔV) is higher when methane is associated with outbursts than when carbon dioxide is present. Secondly, the higher the value of desorption (ΔP or ΔV), the greater the danger of outbursts. (Cynheidra, Wales is an exception -Davis and Jenkins, 1978

Success in predicting imminent outbursts has been varied (from 0 - 90%). Most investigators believe that a number of indices should be used together. In these investigations two methods have been investigated: these are the ΔP-express method, based upon adsorption of gas, and the K index, based upon desorption of gas.

ΔP-EXPRESS METHOD (ADSORPTION METHOD)

ΔP-express method is a modification of the original Ettinger's method (Ettinger and Zupachina, 1954) and has been used by Inicher to determine $\Delta P_{0/60}$ values (Vandeloise, 1964). A relationship has been established between the $\Delta P_{0/60}$ value and the ΔP-express value (Fig. 1).

The ΔP-express method is simple and easy to conduct in the field. It is independent of depth of sampling and time of sampling. The time required to conduct a test does not take more than 10-12 minutes. The method could be suitable for use under Australian mining conditions with fast advancing headings, it was the first method chosen for testing.

Figure 2 shows the setup and Figure 3 gives the schematic layout. The sample container (4) has a volume of 250 cm^3 and contains a gauze wire cylinder resting on a hollow washer stand. The container is connected to a 4-way rotary valve. The 4 positions on the rotary valve switch connect the sample container to vacuum pump (2) at position (1), to vacuum gauge (7) at position (2), to the gas bottle (1) at position (3) and to the pressure gauge (6) at position (4).

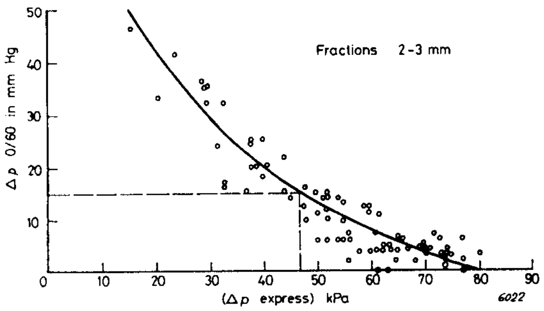

Fig. 1.- $\Delta P_{0/60}$ and ΔP-express values for anthractite coal.

A 50 g sample in the fraction range of -0.5 mm to + 0.25 mm is placed in the sample container. The sample container is then connected to the evacuating pump and the sample is evacuated for 300 seconds. Gas from the gas cylinder is then introduced into the sample container by opening the container to a steady stream of gas at a present pressure for a period of 2 seconds.

The purge time of 2 seconds was decided upon by taking measurements on the rate of build-up of pressure in the chamber containing the coal sample. This depends upon the input supply pressure, the diameter of the connecting pipe, length of the pipe, the volume of the sample chamber, and the adsorption rate of coal. Tests were conducted in the laboratory using two different gases and for different input pressures. Figures 4 and 5 show the influence of input pressure on the build-up of pressure in the sample chamber containing a 50 g sample of coal (fraction size -0.5 to + 0.25 mm) for both CO_2 and CH_4. These measurements showed that the build up of pressure in the chamber containing a coal sample takes about 0.8 - 1.15 seconds for CH_4 and 1.65 - 2 seconds for CO_2 depending upon the input pressures. Build-up of pressure in the chamber is only slightly influenced by the presence or absence of the coal sample in the chamber. After input of gas to the sample container, it is then isolated and the drop in pressure is monitored for the next 600 seconds using the gauge (6) or the pressure transducer (5) depending upon whether the test is conducted in the field or in the laboratory. Under laboratory conditions, output from the pressure transducer was recorded both on the X-Y plotter and a digital oscilloscope.

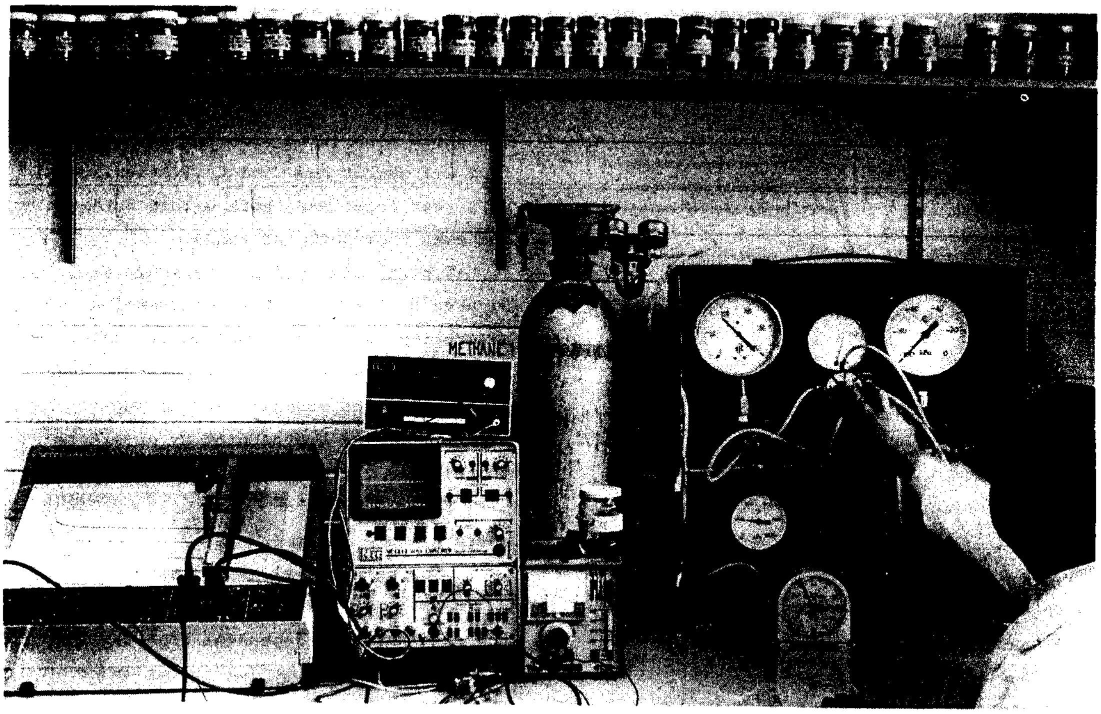

Fig. 2.- General set-up of equipment for adsorption/desorption studies on coal samples.

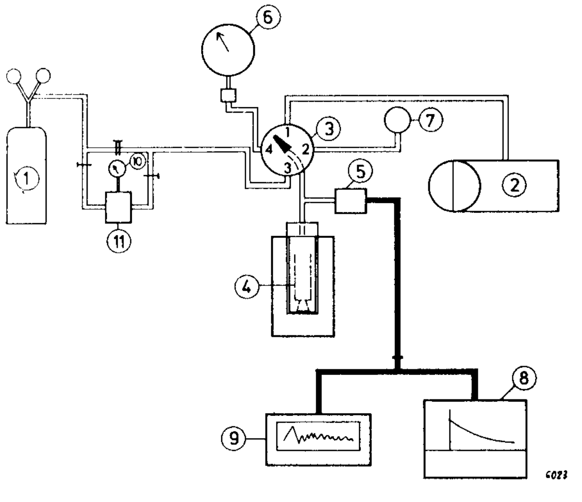

Fig. 3.- Schematic diagram of gas adsorption/desorption equipment.

(1) Gas reservoir, (2) vacuum pump, (3) 4-way rotary valve, (4) coal sample, (5) pressure transducer, (6) pressure gauge, (7) vacuum gauge, (10) pressure gauge, (11) container.

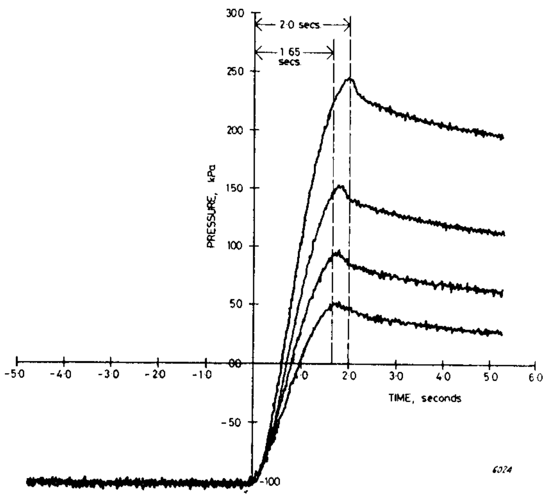

Fig. 4.- Influence of pressure build-up in the sample chamber as a function of input pressure (CO_2, 50g sample of coal Leichhardt Colliery, Site 4, fraction size -0.5 to +0.25 mm).

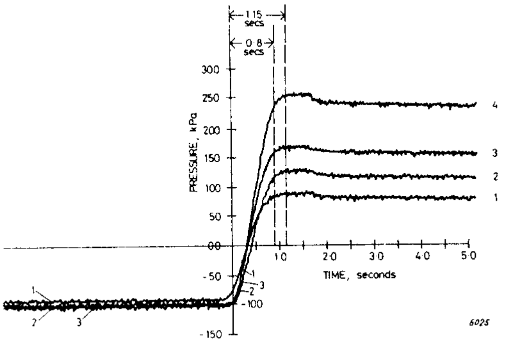

Fig. 5.- Influence of pressure build-up in sample chamber as a function of input pressure (CH_4, 50g sample of coal, Leichhardt Colliery, Site 4, fraction size -0.5 to +0.25 mm).

Three different gases were used during adsorption studies. Nitrous oxide was used so as to have results comparable with those obtained by German investigators (Paul, 1977). Carbon dioxide and methane were used to establish the adsorption parameters of these gases on coal samples depending upon the association of these gases in Australian mines

Samples were collected from four location at West Cliff Colliery. All samples were collected by drilling holes to a depth of 3 m and cuttings were collected as drilling was continued for 2.7 m to 3.0 m. The samples were sieved and fractions in the range of -0.5 mm to +0.25 mm were collected in glass bottles. Except when tests were conducted immediately, bottles were sealed with wax covering the complete area of the plastic cap. Ten samples were collected from 10 different holes drilled in various sections.

Site 1 for sample collection is an area where no outbursts have occurred. Site 2 lies close to a shear zone (~10 m) and where some bumping was experienced, possibly due to higher stresses. Site 3 is the location of shear zone. At this site holes were drilled directly into the shear zone. The cuttings from this shear zone are much finer and have a silky touch, indicating very highly ground material. Samples from this site had much higher fractions of -0.25 mm. Site 4 lies at a distance of 5 m from the shear zone (Site 3). Samples were collected from Leichhardt and Cook Collieries from different locations, both within outburst zones and away from outburst zones.

Typical adsorption curves are given in Figures 6, 7 and 8. The phenomenon of gas adsorption in a porous medium is analogous to heat flow. For a spherical particle under test conditions, the pressure at the end of a given time, t, can be represented by an exponential function of the form (Lama, 1980):

$$Pt = Po - APo\, e^{-Bt} \qquad (1)$$

where A & B = constant

Po = initial gas pressure

Pt = pressure at a given time, t

The constant A is dependent upon the sorption capacity of coal, the initial pressure, Po, and the radius of the particles. The constant B is dependent upon the diffusivitity of the coal particles and the radius of the particles. It will decrease with increase in the radius of the particle.

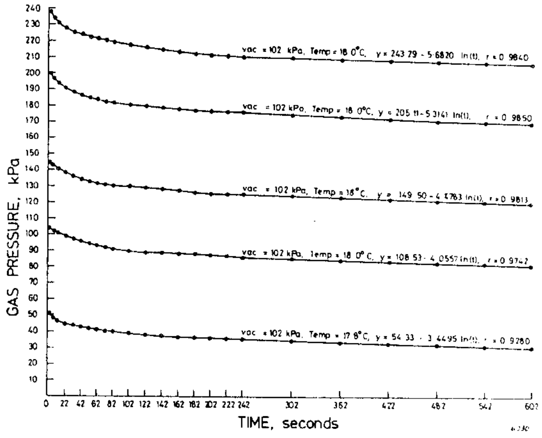

Fig. 6.- Adsorption of CH_4 in coal, sample 29, West Cliff Colliery

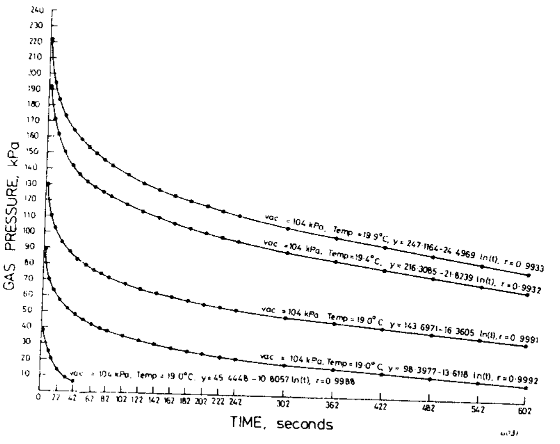

Fig. 7.- Adsorption of CO_2 in coal, sample 29, West Cliff Colliery.

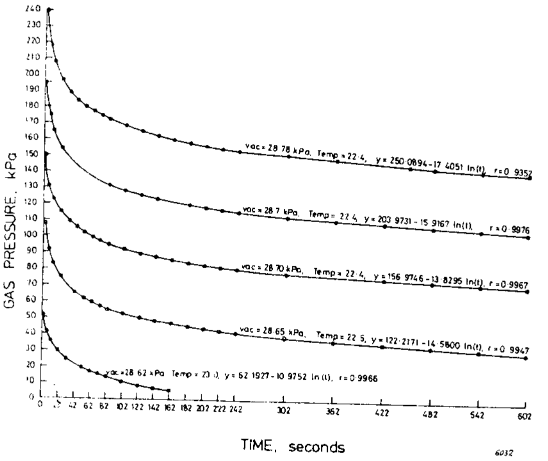

Fig. 8.- Adsorption of N_2O in coal, sample 29, West Cliff Colliery.

Results by different investigators do not agree with the above exponential relationship. Most investigators report adsorption as a function of time as a power law (Zupachina and Ustinov, 1967; Janas and Winter, 1977). These investigations showed that adsorption best fits a logarithmic law, though correlation coefficients using an exponential law are sufficiently high (0.9). The general relationship can be represented by the equation:

$$Pt = Po - CPo^D \ln(t+1) \qquad (2)$$

The value of the constants C and D for the samples using CH_4, CO_2 and N_2O are given in Figure 9. The values of C and D are lower for CH_4 than for CO_2 and N_2O. This reflects the smaller amount of CH_4 adsorbed, compared to CO_2 and N_2O. These constants differ from sample to sample, but the amount of gas adsorbed at any given time in a sample does not vary very much.

The ΔP express values using Po = 200, t = 60s and using nitrous oxide have been calculated for the different samples, and mean values for the 4 sites are given in Table 1. These values have been corrected for the sample weight to make them comparable to those obtained by Paul (1977). ΔP express values calculated using

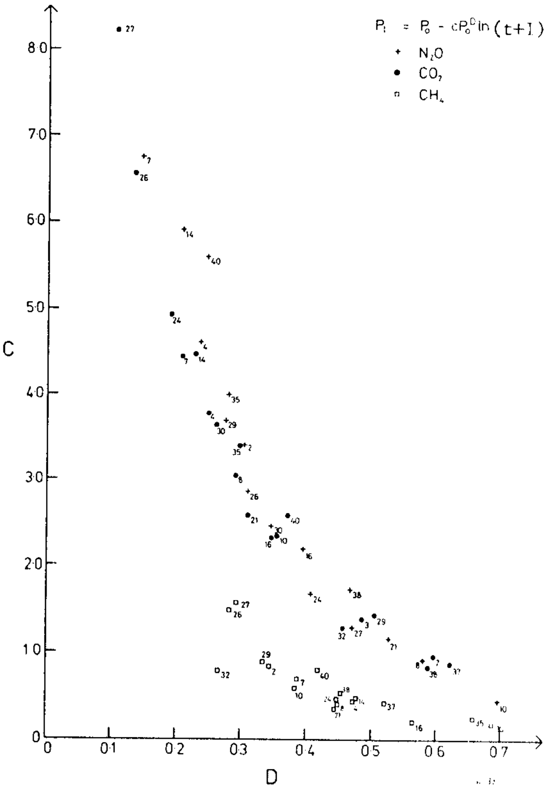

Fig. 9.- Values of adsorption coefficients C & D for different gases.

Table 1A

ΔP express values using N_2O (West Cliff Colliery)

$P_t = P_o - CP_o^d \ell n(t+1)$ P_o = 200 kPa

Site	Sample No.	C	D	P_t (kPa) t=60 seconds	ΔP Express Values, kPa (P_tx0.6526)
1	2	-3.389	0.3030	131	85.5
	3	-3.342	0.2974	133	86.8
	4	-4.614	0.2347	134	87.5
	5	-3.835	0.2895	127	82.9
	6	-1.188	0.5094	127	82.9
	7	-6.750	0.1449	140	91.4
	8	-0.910	0.5782	120	78.3
	9	-4.245	0.239	138	90.1
	10	-0.449	0.6965	126	82.2
	11	-0.941	0.5544	127	83.0
				Mean $\overline{\Delta P}_{60}$	85.06
				σ	3.98)
2	12	1.7097	0.4340	130	84.8
	13	2.0806	0.4185	122	79.6
	14	5.9154	0.2260	120	78.3
	15	1.7789	0.4532	120	78.3
	16	2.1930	0.3954	127	82.9
	17	3.0686	0.3216	131	85.5
	18	2.4557	0.3727	128	83.5
	19	1.9396	0.4023	133	86.8
	20	3.2420	0.3374	121	79.0
	21	1.1678	0.5270	122	79.6
				Mean $\overline{\Delta P}_{60}$	82.12
				σ	3.28)
3	22	2.0451	0.3940	132	86.1
	23	2.8218	0.3063	141	82.0
	24	1.6821	0.4065	141	92.0
	25	2.0823	0.3636	141	92.0
	26	2.8540	0.3097	140	91.0
	27	1.2823	0.4705	136	89.0
	28	1.5486	0.4152	143	93.0
	29	3.6981	0.2753	135	90.0

Cont.

Table 1A Cont.

Site	Sample No.	C	D	P_t (kPa) t=60 seconds	ΔP Express Values, kPa (P_tx0.6526)
3 (cont.)	30	2.4538	0.3462	137	89.0
	31	4.0763	0.2462	138	90.0
				Mean $\overline{\Delta P}_{60}$	89.5
				σ	3.03)
4	32	2.664	0.3327	136.4	89.0
	33	3.897	0.2616	136.2	88.9
	34	3.413	0.3091	128.1	83.6
	35	3.994	0.2791	128.2	83.7
	36	1.683	0.4811	111.8	72.9
	37	2.275	0.4023	121.5	79.3
	38	1.729	0.4658	116.5	76.0
	39	2.417	0.3755	127.6	83.0
	40	5.601	0.2426	117.1	76.4
				Mean $\overline{\Delta P}_{60}$	81.5
				σ	5.68)

$$\Delta P \text{ express} = \frac{P_t \times 50 \times 180}{70 \times 197}$$

$$= P_{60} \times 0.6526$$

Table 1B

ΔP express values using CO_2 (West Cliff Colliery)

$P_t = P_o - CP_o\ \ell n\ (t+1)$

Site	Sample No.	C	D	P_t t=60	ΔP express
1	2	0.9522	0.5957	108.45	70.87
	3	1.3920	0.4861	125.12	81.65
	4	3.7757	0.2803	141.77	92.53
	7	4.4471	0.2086	145.01	94.64
	8	3.0446	0.2909	141.78	92.53
	10	2.3461	0.3557	136.76	89.26

Cont.

Table 1B Cont.

Site	Sample No.	C	D	P_t t=60	ΔP express
			Mean $\overline{\Delta P}_{60}$	133.15	86.90
			(σ)	(13.98)	(9.12)
2	14	4.4755	0.2295	138.18	90.18
	16	2.3249	0.3469	140.18	91.49
	21	2.5850	0.3110	145.01	94.64
			Mean $\overline{\Delta P}_{60}$	141.11	92.03
			(σ)	(3.54)	(2.31)
3	24	4.9427	0.1913	144.24	94.14
	26	6.4607	0.1339	145.39	94.89
	27	8.2251	0.1069	140.67	91.81
	29	1.4335	0.5039	115.26	75.22
	30	3.6398	0.2612	140.53	91.72
			Mean $\overline{\Delta P}_{60}$	137.22	89.55
			(σ)	(12.46)	(8.13)
4	32	1.2876	0.4578	140.38	91.62
	35	3.3887	0.2980	132.71	86.61
	37	0.8593	0.6220	105.03	68.53
	38	0.8373	0.5875	122.92	80.22
	40	2.5797	0.3706	124.75	81.42
			Mean $\overline{\Delta P}_{60}$	125.16	81.68
			(σ)	(13.22)	(8.63)

$$\Delta P \text{ express} = \frac{P_t \times 50 \times 180}{70 \times 197}$$

$$= P_{60} \times 0.6526$$

Table 1C

ΔP express values using CH_4 (West Cliff Colliery)

$P_t = P_o - CP_o \ell n(t=1)$

Site	Sample No.	C	D	P_t t=60	ΔP express
1	2	0.8668	0.3438	178.06	116.21
	4	0.455	0.4721	177.27	115.69
	7	0.6971	0.3869	177.82	116.05
	8	0.4117	0.4491	181.80	118.65
	10	0.5882	0.3843	181.55	118.49
			Mean $\bar{\Delta}P_{60}$	179.72	114.68
			σ	(2.19)	(1.43)
2	14	0.4709	0.4781	175.72	114.68
	16	0.2115	0.5643	182.78	119.29
	21	0.3721	0.4478	183.66	119.87
			Mean $\bar{\Delta}P_{60}$	180.72	117.95
			σ	(4.35)	(2.84)
3	24	0.4716	0.4493	179.13	116.91
(outburst	26	1.4963	0.2853	172.22	112.40
site)	27	1.5789	0.2935	169.39	110.55
	29	0.8771	0.3346	178.86	116.73
	30	0.1927	0.6890	169.63	110.71
			Mean $\bar{\Delta}P_{60}$	173.85	113.46
			σ	(4.83)	3.15)
4	32	0.7891	0.2657	186.80	121.91
	35	0.2474	0.6571	167.07	109.03
	37	0.4258	0.5214	172.38	112.50
	38	0.5267	0.4554	175.92	114.81
	40	0.799	0.4179	170.05	110.98
			Mean $\bar{\Delta}P_{60}$	174.44	113.85
			σ	(7.63)	(4.98)

$$\Delta P \text{ express} = \frac{\Delta P_{60} \times 50 \times 180}{70 \times 197}$$

$$= P_{60} \times 0.6526$$

Table 1D

ΔP express using N_2O,

Cook and Leichhardt Collieries

Colliery	Site	Sample No.	ΔP express
Cook Colliery	1	2	71.13
	1	3	79.56
	2	1	78.32
Leichhardt Colliery	1	2 (Vitrain)	74.99
	2	1 (Derain)	74.99
	3	1 (Vitrain)	69.12
	4	1 (Derain)	80.28
	Cone 8	outside	79.90
	Cone 8	inside	41.35*
	Cone 8	inside	41.62*
	Cone 3	outside	44.00*
	Cone 3	inside	42.65*

*calculated from 25g samples.

methane and carbon dioxide are also given in Table 1, along with results for Leichhardt and Cook Collieries. These values are lower by 20 - 40% compared to those obtained by using nitrous oxide. ΔP-express values for samples from Leichhardt are about 15% lower than those of West Cliff Colliery, indicating higher probability of an outburst. These also indicate the different nature of the two coals. Tests on samples from Leichhardt and Cook Collieries were conducted after a lapse of about 18 months from the time of collection of samples. It is reported that desorption capacity drops with the elapse of time. The drop in the ΔP-express value over a period of 18 months could be as much as 40% (Paul, 1977). However, it depends upon the storage conditions of the samples. In this case samples were stored in glass bottles. It is hoped that these values are not so much affected as reported.

The ΔP-express values could not differentiate between outbursting and non-outbursting sites. This showed its inadequacy as an index, at least under Australian conditions.

"L_1" INDEX (ADSORPTION METHOD)

A modified index based upon long term adsorption of coal, called the "L_1" index, has been developed by the author. The adsorption curve, representing pressure against time, can be divided into three regions. The first part of the curve, represented by a very small interval of time (say up to 0-5 s), represents the filling of the coarse pores and adsorption of gas on the surface of these pores. The next phase, up to 100 s, represents adsorption of gas in the surface of a medium sized pore, and after 300 s most adsorption takes place on the surface of the finer pores. In any mining practice, when a face is exposed, the influence of the exposure is to drain the gas quite in advance of the face. Under medium rates of advance, the effect of exposure would be to influence an area up to 30 - 40 m ahead of the face. The gas which is present in cracks and large size pores must escape much faster. The gas that is adsorbed on the finer pores will need much longer to escape. If the rate of advance of face is high, so that for a particular site the rate of drop in gas pressure is slower, this would result in building up of a high gas pressure gradient closer and closer to the face. As a result, a dangerous situation could occur when this high pressure zone suddently reached a stage of critical equilibrium, and even a shock or loss of constraint could result in its explosive

Table 2

L_1" Values as a Function of Size Fraction and Initial Pressure P_o

Colliery	Site	P_o kPa	Fraction Size mm	CO_2 Adsorption "L_1" Value	CH_4 Adsorption "L_1" Value
Leichhardt	1	200	25-9.5	0.0271	0.0132
	1	200	4-2	0.0260	0.0087
	1	200	0.5-0.25	0.0351	0.0103
	1	200	< 0.063	0.0338	0.022
Leichhardt	1	100	0.5-0.25	0.0286	0.0077
	1	150	0.5-0.25	0.0334	0.0091
	1	200	0.5-0.25	0.0351	0.0092
	1	250	0.5-0.25	0.0375	0.0113

Table 3

L_1" Value of Coal Samples

From West Cliff, Leichhardt and Cook Collieries

		L_1" Value		
Colliery	Site	N_2O Adsorption	CO_2 Adsorption	CH_4 Adsorption (standard deviation)
West Cliff	1	0.0397 (0.0025)	0.0376	0.0117 (0.0012)
	2	0.0416 (0.0025)	0.0332	0.0107 (0.0025)
(Outburst site)	3	0.0349 (0.0018)	0.0371	0.0153 (0.0027)
	4	0.0420 (0.0047)	0.0414	0.0144 (0.0043)
Leichhardt	1	0.0483	0.0351	0.0103
	2	0.0480	0.0378	0.0158
	3	0.0541	0.0403	0.0196
(Outburst site)	4	0.0564	0.0395	0.0204

Cont.

Table 3 Cont.

Colliery	Site	N_2O Adsorption	CO_2 Adsorption	CH_4 Adsorption (standard deviation)
Cook	1	0.0513		
	1A	0.0400		
	2	0.0450		

disruption. Obviously, therefore, the rate of release of gas after extended intervals of time is a measure of the permeability of coal, and could represent outburst proness of coal.

Working on the above hypothesis a new index, "L_1", is introduced here, called the gradient of the pressure adsorption curve after 300 seconds. This index is calculated using the relationship

$$"L_1" = \frac{P_{300} - P_{600}}{300} \qquad (3)$$

where P_{300} = pressure, kPa, after 300 seconds with initial pressure of 200 kPa

P_{300} = pressure, kPa, after 600 seconds with initial pressure of 200 kPa.

The value of "L_1" effectively represents the rate of adsorption (or release) of gas from the sample. Its value will depend upon the viscosity, critical temperature and pressure of gas, tortuosity of the material, and pore size. The values of "L_1" will vary from gas to gas and will depend upon the molecular cross-section in relation to pore size.

Investigations showed that, other conditions remaining constant, the input pressure (P_o) does influence the value of "L_1" even for the range of initial pressures (P_o) from 100 kPa and 250 kPa (Table 2). At lower pressures the value is slightly lower. The "L_1" values are also sensitive to fraction size. Proper sieving therefore is essential. The "L_1" values of coal samples from West Cliff, Leichhardt and Cook Collieries are given in Table 3. Methane adsorption of the "L_1" value varies more widely than CO_2 or N_2O desorption "L_1" values. For West Cliff samples, the increase in the value of "L_1" for the outbursting coal (Site 3) is almost 50% higher compared to Site 2. At a distance of 5 m from the shear zone (Site 4), the value is about 40% higher compared to Site 2. Site 1 is about 25 m away from a similar shear zone which is a potential outburst site and the value is about 10% higher than Site 2.

In the case of Leichhardt the "L_1" values for CH_4 for Site 4 compared to Site 1 are almost 100% higher. Site 2 at Leichhardt Colliery lies in an area where outbursts had occurred and as such this value should be close to the critical value. This is also very close to the "L_1" value obtained on West Cliff coal samples.

"L_1" values obtained using CO_2 and N_2O gas show a trend similar to methane.

The "L_1" value clearly indicates the difference in the nature of coal from an outbursting point of view. Tests were conducted to determine whether this index was in a position to differentiate between coal close to an approaching shear zone. If so, it would give a possibility of predicting a shear zone and hence locating an outburst position precisely, particularly at West Cliff Colliery. Sixteen samples were collected from Panel 203 at various distances from the shear zone, sampling always the same ply. The "L_1" values are given in Figure 10. It seems that this index cannot differentiate minor changes occurring close to a shear zone though it can differentiate easily between a pulverised coal due to shearing and a nonpulverised coal.

The changes in "L_1" value from different sites however do indicate changes in the nature of coal. In the area where Site 4 is located (West Cliff Colliery) the "L_1" values are higher compared to Sites 1 and 2 and so also outbursts have been more severe. Also, higher values associated with Sites 2 and 3 compared with Site 1 at Leichhardt indicate greater possibilities of outbursts in these areas.

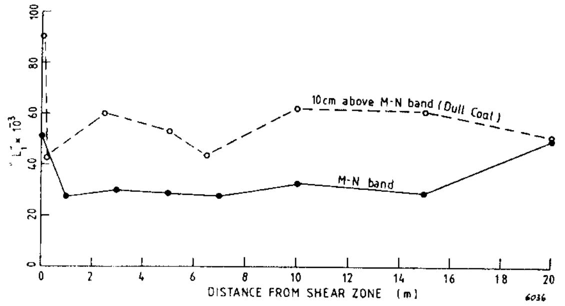

Fig. 10.- Changes in "L_1" values approaching a shear zone.

K AND "L_2" INDEX (DESORPTION METHOD)

Studies on the desorption of gas from coal samples in field conditions have indicated that sufficient quantity of gas is still present in the coal sample if the sample is collected from a point lying sufficiently deep and ahead of an advancing face. Short term studies have indicated that the desorption of gas from such samples can be taken as an index of proneness of outbursts. In the standard test, a sample of coal is collected from the advancing face and sieved. A definite fraction (~0.65 mm) is collected in a container and the rate of release of gas is measured. The rate of release of gas plotted against time over a period of say 2 to 10 minutes has been expressed as a power law (Vandeloise, 1964). The slope of the curve is called the K-value. This can be represented by

$$K = \frac{\ell n(\dot{V}_a) - \ell n(\dot{V}_b)}{\ell n(t_b) - \ell n(t_a)} \qquad (4)$$

where $\dot{V}_a$ and $\dot{V}_b$ = desorption rates, $cm^3/min/kg$ at times t_a and t_b.

If the value of $K \leqslant 0.645 \pm 0.035$, it represents a non-outbursting coal. If the value exceeds 0.75, the condition represents an outbursting coal (Vandeloise, 1964).

In practice, this value of K will vary from point to point and from section to section. The criterion for an outbursting condition therefore must take into consideration the statistically determined average value.

These tests must be conducted on a working face. Due to obvious difficulties, laboratory procedure was adopted when a sample of coal was evacuated for 90 minutes as in ΔP-express method, and subjected to gas pressure for a period of 90 minutes. The desorption of gas was measured over a period of 30 minutes using volumetric techniques.

Typical desorption curves are shown in Figure 11. The K values calculated for samples taken from different distances away from the shear zone are given in Figure 12. The samples were collected from the same ply to eliminate errors due to variability of plys. In spite of the care taken these values cannot clearly differentiate an approaching outburst zone. The range of values however indicates that the area could be classified as an outburst prone area.

One of the reasons for the failure of this test seems to be the sensitivity of the K value to subjective errors. Besides, the desorption rates do not truly follow the power law and hence do not give a straight line fit as expected by Equation (4). Graphical determination of values introduces errors. The emission of gas from the samples seem to come in bursts and not in a continuous stream, and this results in fluctuations in the values of K calculated from the volume of gas desorbed.

The desorption curve has been interpreted in a slightly different way by taking into consideration not the desorption rates (as above) but the total quantity desorbed (Fig. 11). The gradient (L_2) of the log-log plot of volume desorbed against time was calculated for samples taken from different distances from the shear zone. The gradients have been calculated for the interval between 30 and 600 seconds. Tests were conducted on both bright and dull coal and in fractions and solid coal (+6 mm). The results of tests are given in Figure 13. These results indicate that the L_2 index is a better indication of an approaching shear zone. The L_2 value tends to increase from almost 20 m away from the shear zone and reaches its maximum at a distance of about 10 m, where it drops again. Samples 51 and 52 (Fig. 14) were taken from close to a normal fault far away (over 500 m) from the shear zone. The L_2 values for those samples are lower and correspond to the general value for the coal not influenced by the shear zone.

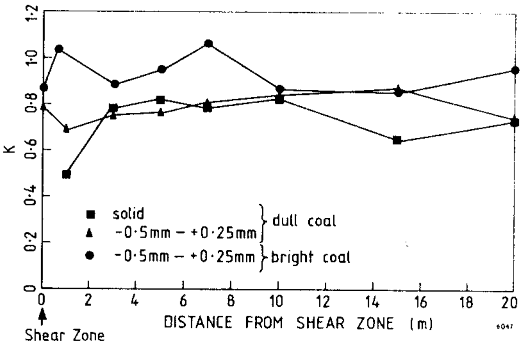

Fig.12.- Variation in K value on approaching

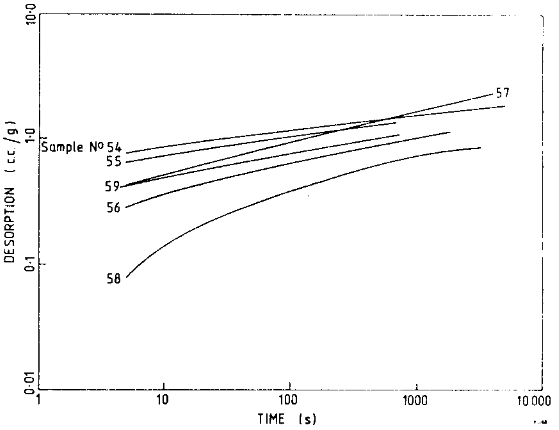

Fig.13.- Desorption of methane from coal samples (Fractions -0.5 - + 0.25 mm, dull coal, Bulli Seam, West Cliff Colliery).

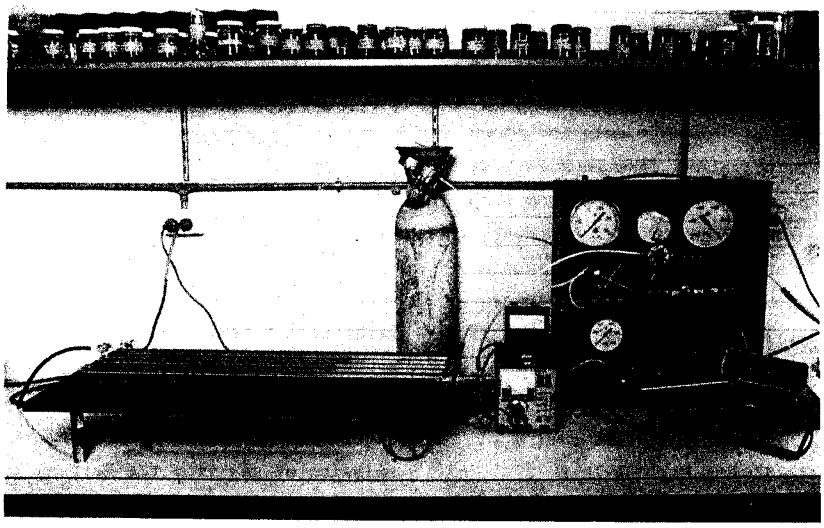

Fig. 11.- Equipment for measurement of gas desorbed using volumetric method.

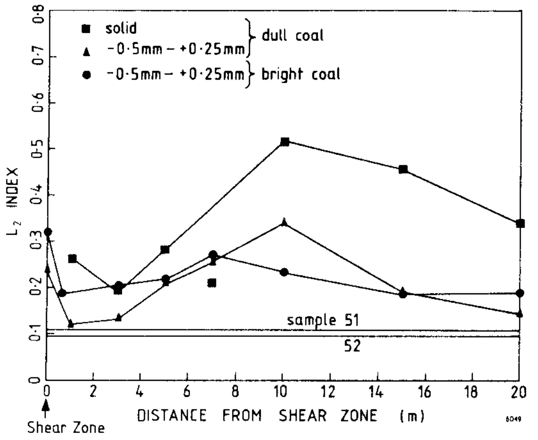

Fig. 14.- Variations in L_2 value in approaching a shear zone (samples 61-68 M-N band, fraction -0.5 to + 0.25 mm; samples 52-60, dull coal, solid +6 mm and fractions -0.5 to + 0.25 mm, Bulli Seam, West Cliff Colliery).

The differentiation between the values is better for solid samples than for fractions and dull coals are better suited for this test. It is hoped that, using the L_2 index, it should be possible not only to predict an imminent outburst but also to predict the closeness of the shear zone. It may be pointed out that this index may not be able to differentiate when outbursts are not associated with shear zones.

The use of the L_2 index has the advantage that it is not dependent upon drilling in advance for collection of samples. Samples can be collected from the face using a pick and can be limited to a well defined band, thereby eliminating errors due to variability of coal. Changes up to 10 m ahead of an approaching shear zone can be picked up, and appropriate steps can be taken before intersecting the shear zone. A distance of 10 m is a sufficient barrier to prevent outbursts from triggering and also permit drainage of gas using advance drilling.

CONCLUSIONS

These studies indicate that adsorption and desorption isotherms can be used to predict an outburst condition. The ΔP express method and the K value used overseas does not seem to be suitable for predicting an outbursting condition in Australia. This could be because of the difference in the physical properties of the coal, but in the absence of more detailed studies, it is difficult to make any definite conclusions on these indices.

Two new indices called "L_1" and "L_2" have been developed which look very promising. The "L_1" index is a quick way of differentiating between different zones where outbursting conditions may change. The "L_2" index can be used as a practical means not only of indicating an outburst condition, but also changes in the structural properties of coal, and predicting in advance up to a distance of 10 m - 15 m an approaching shear zone.

The "L" value determinations and its usefulness opens up a new field where it would be possible to determine outbursting conditions from existing drill cores obtained during exploration studies or from long drill holes from underground. The index does not require tests to be conducted on site immediately after extracting a sample. The test is simple, easy to carry out, and can be easily adopted as a routine method of predicting outburst conditions in mines.

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