THE PERMEABILITY OF SOME AUSTRALIAN COALS

By

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ABSTRACT

As a prelude to studying the sorption-desorption and permeability behaviour of coal cores in a triaxial stressing rig using sorbable gases, the air permeability of typical cores was measured. Lump coal samples were obtained from three gas-troubled collieries in Queensland and New South Wales. These were cored in the laboratory and a simple laboratory permeameter employed which accepted 38 x 40 mm cores in a thick rubber sheath. Air pressure of 500 kPa was applied outside the sheath to provide suitable sealing between the rubber and the coal.

Differential driving pressures up to 100 kPa were employed and the air flow measured by displacement of water columns in inverted graduated cylinders. Flow measurements accurate to $\pm$ 2% could thereby be achieved. Coal lumps were cored both parallel and perpendicular to the bedding plane, and were observed prior to measurement for any notable features, in particular for the presence of fissures. Between samples an overall variation of from < 0.1 to > 100 milliDarcy was found in Appin, Westcliff and Leichhardt coals. Significant variation was observed both from section to section of a core and between regions of a colliery, but no significant difference was found between cores cut parallel and perpendicular to the bedding plane. With colliery the permeability of the coals increased in the order Westcliff: Appin: Leichhardt. The results also exhibit sensitivity both to handling of the cores and to external sheath pressure.

As the permeability was measured at low confining stress relative to in-situ stresses underground, the dynamic elastic modulus was measured for the cores using an acoustic method. This showed that coal compressibility increased between collieries in the same order as for permeability, suggesting the possibility that in-situ permeability differentials might be less than measured here.

Coal from a location immediately adjacent to the outbursting mylonite zone in the Westcliff colliery exhibited higher permeability than coal from the pit bottom.

INTRODUCTION

The present study was prompted by the need for permeability data on typical gassy Australian coals to provide input to a feasibility study of a proposed investigation of the sorption/desorption capacities and permeability of coal cores in a triaxial stressing rig. Coal core permeability can be related to diffusional unit size by geometrical modelling of the assumed fissure networks. Taken together with the diffusion coefficient for the homogeneous coal material and confirmatory microscopic examination of polished

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sections, sorption times (governing experiment times) can be predicted for typical cores.

Diffusion coefficients for Australian coals had already been measured by Bolt and Innes (1959). There had been several overseas studies of coal core permeability to either gas or water (Pomeroy, et al., 1967; Dabbous, et al., 1974; Patching, 1965; Somerton, et al., 1974; Krivitskii, et al., 1972; Kuznetsov, et al., 1973) but apart from poorly documented reports (e.g. Stewart, 1970), there appeared to be no readily available data on Australian coal permeability. The present study was therefore undertaken to provide preliminary input to a data base for the larger project, as well as to find out if any more immediate information might be forthcoming from an examination of the permeability distribution.

It was realised that permeability cannot be studied without reference to the in-situ stress condition, and as only a low stress permeameter was available in the authors' laboratory, simultaneous measurements were also made of the dynamic elastic constants of the cores. This provided a tentative basis for evaluating the in-situ significance of permeability variation between coals.

MATERIALS AND METHODS

SAMPLING AND PREPARATION OF MATERIALS

Lump coal samples, properly oriented with respect to bedding plane, were obtained from three of the most gas-troubled collieries in Australia (The Bulli Seam, South Sydney Basin - from the Westcliff and Appin Collieries in N.S.W.; and the Gemini Seam, Bowen Basin - from the Leichhardt Colliery in Queensland). The lumps were cut to convenient size, then set in casting plaster or polyurethane foam, preserving orientation. Using various methods, depending on difficulties experienced, coring was then carried out using a 38 mm I.D. Diamant and Boart surface-set concrete-dia bit, 460 mm long. Controlled water flow was used for lubrication with the Westcliff and Appin Coal. Air at 200 kPa was found to be the most satisfactory cutting dispersant for the Queensland, Leichhardt Colliery coal. Water tended to hydrofracture this intrinsically highly fissured material. Some experimentation was necessary to achieve satisfactory core recovery with the softer coals. Cores of length from 76 to 150 mm long were obtained this way. Cores were then washed, bagged and cut into 40 mm sections using a fine diamond saw, and dried in a vacuum oven for 64 hours at 40°C prior to permeability measurement. The cores were visually examined for fissures and appropriate sketches made.

PERMEABILITY MEASUREMENT

Coal core permeability was measured using the Hassler sheath-type of instrument which is depicted schematically in Fig. 1. 38 mm cores cut to lengths of approximately 40 mm were gently inserted into a 38 mm (Nom. 1.5 inch) I.D. section of thick-walled rubber tube ("Clark's" elevated sink drain overflow moulding or "Apex-Rubberflex" Drench-Drain tube proved satisfactory). One end cap of the test cell (e.g., "EC_1", Fig. 1) was unscrewed and the sheath plus core inserted until the tube slid over the projecting boss of the other end cap ("EC_2", Fig. 1). A little glycerol smeared on the inside tube end facilitated this insertion. The detached end cap was then replaced, making sure that its projecting boss also slid inside the sheath (containing core) at the proximal end. It was then screwed home. Air line connections to the cell were then made using Swagelok*R Quick-connects*R. Water from a pre-heated thermostat bath was then pumped into a jacket surrounding the cell and maintained at a constant level above the cell whilst continually circulating (water bath indicated by dashed line in Fig. 1). Air from a cylinder at 700 kPa was then applied to the regulators (R_1, R_2 - Fig. 1), R_1 being initially turned "off". R_2 was then adjusted to the

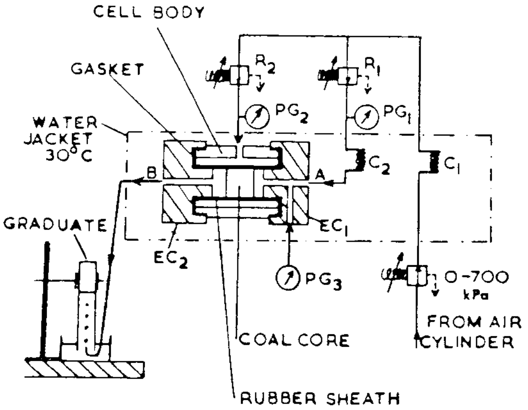

Fig. 1. Laboratory Permeameter - See text for detailed description

chosen sheath pressure (usually 500 kPa), and the cell observed for leaks. Air pressure in the chamber surrounding the sheath ensured adequate sealing of the sheath at either end, and no flow could ever be detected at the outflow end (B) unless the inlet regulator (R_1) was turned on. Air to regulators "R_1" and "R_2" passed first through a heat exchanger coil ("C_1", Fig. 1), and air from regulator "R_1" to the test air inlet "A" (Fig. 1), passed through a second heat exchanger ("C_2") immersed in the same water bath. Upstream air pressure was set against the pressure gauge ("PG_1", Fig. 1), and the air flow measured by timing the displacement of a water column in a graduated cylinder selected to ensure the desired accuracy of volume measurement at the selected flow. A quartz digital stop-watch was used to measure the efflux time. The resulting accuracy of flow rate measurement was of the order of $\pm$ 2%. The pressure gauges were periodically checked for calibration against an attached mercury manometer. The bath temperature was maintained at 30 $\pm$ 0.2°C; and, during a period of initial setting up, the gas temperature was measured at the outflow end of the test cell using a mercury thermometer and shown to be constant for the range of flow rates measured. The heat exchanger coils were provided to avoid variation of gas temperature at the test cell inlet caused by adiabatic heat loss across the regulators.

Typically, air flow was measured at each of four set upstream pressure levels (P_u). Downstream pressure (P_d) was in all cases sufficiently close to atmospheric for the difference to be ignored. Mean pressure of the air in the coal sample was assumed to be the mean of the upstream and downstream levels (i.e. $P_m = (P_u+P_d)/2$), this being the only assumption that can be made. The permeability is then calculated from the well-known formula:-

$$K = Q\mu L/A(P_u-P_d)P_m \quad \ldots. \quad 1$$

where Q is the actual measured flow rate in ml/s, μ is the gas viscosity in centipoise, L is the sample length in cm, A the sample cross-sectional area in cm^2. The viscosity of air at 30°C was found to be 183.31 cP by interpolation from the Tables in the Handbook of Chemistry and Physics (CRC). If P_u-P_d is expressed in atmospheres, then the calculated permeability (K) is in units of the Darcy.

If there is no leakage forward between the coal and the sheath, and no significant manifestation of the Klinkenberg Effect at the chosen pressures (Klinkenberg, 1941), a plot of $Q' = Q/P_m$ (the actual flow within the core), versus the pressure drop (P_u-P_d) should give a linear relation as shown in the typical example of Fig. 2.

DYNAMIC ELASTIC CONSTANTS

These were obtained by measurement of shear and longitudinal wave velocity of sound along the core using an established technique (see Obert and Duvall, 1967). A "Terrametrics" Sonic Velocity instrument was employed equipped with shear wave transducers. From the shear and longitudinal wave velocities (V_s and V_l), and the sample density (ρ), Poisson's ratio (ν)

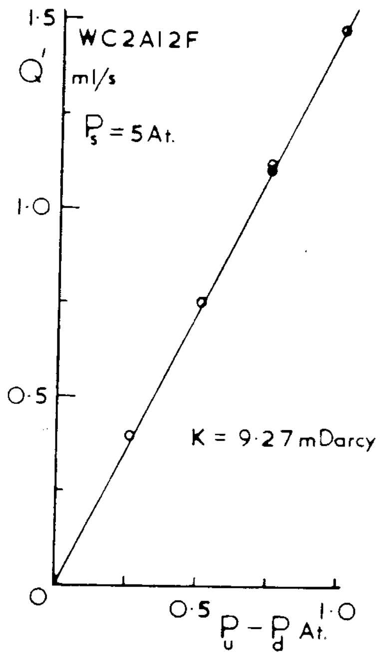

Fig. 2. Normalised air flow rate (Q') versus pressure drop for typical core. P_s = sheath pressure.

and the dynamic Young's modulus were calculated from the following formulae:-

$$\nu = (V_1^2 - 2V_s^2)/2(V_1^2 - V_s^2) \qquad \ldots 2$$

and

$$E = \rho V_1^2 (1 + \nu)(1 - 2\nu)/(1 - \nu) \qquad \ldots 3$$

RESULTS

FLOW RATE-PRESSURE DROP RELATIONS

Figs. 2-4 show typical normalised flow rate data obtained with the permeameter. The measured flow rate is normalised to the mean core pressure in each case to give the actual flow (i.e. $Q' = Q/P_m$). Fig. 2 shows the linear relation obtained when measurement is confined in the range of upstream pressure (P_u) from 0-100 kPa. Fig. 3 shows what happens if the upstream pressure is enough to produce some "lift-off" of the rubber sheath, increasing

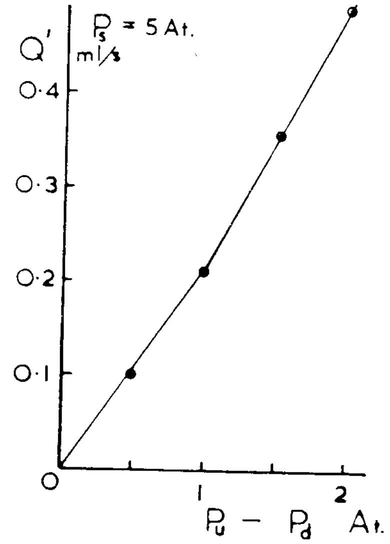

Fig. 3. Normalised air flow rate ($Q' = Q/P_m$) versus pressure drop for upstream pressure great enough to produce partial "lift-off" of rubber sheath.

the surface area of the core accessible to the upstream pressure. The resulting, apparently bi-linear relation is a typical finding when either elastic particles in a fluid environment are squeezed through rigid tubes or rigid particles pass through flexible tubes; and conversely, when fluid is forced past either a flexible obstruction in a rigid tube or past a rigid obstruction in a flexible tube (Lighthill, 1968).

Fig. 4 shows the effect of sheath pressure in the range considered, even though the flow rate-pressure relation is still linear. This suggests an effect of compression of the core by the applied air pressure. Indeed, significant circumferential compression of typical cores has been confirmed using strain gauges in the present study (Fig. 5). Clearly, some compression is necessary to ensure sealing between the core and sheath, hence the sheath pressure at which measurements are made must be standardised at a level sufficient for sealing with the maximum upstream pressure applied. It was found for most of the samples studied in the present series that linear, time-

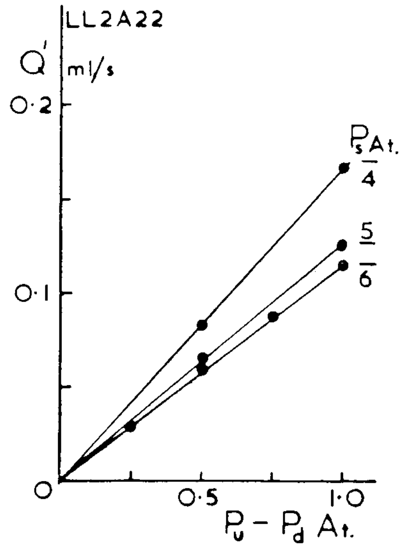

Fig.4. Effect of radial sheath pressure (P_s) on flow rate Q' at series of driving pressures.

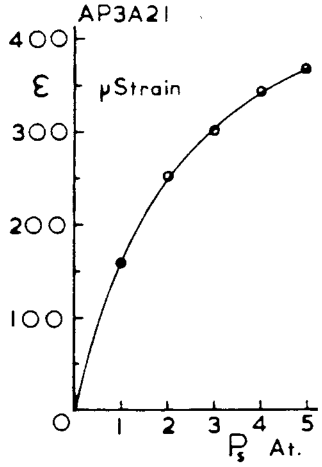

Fig. 5. Circumferential strain detected in typical core as sheath pressure (P_s) changes.

independent flow rate-pressure drop relations did apply. In some tests, however, a detectable fall in flow rate was observed with time. This appeared to be related to time dependence of core compression during the application of sheath pressure (P_s), but the effect remains to be investigated fully.

PERMEABILITY STATISTICS

A total of 71 permeability measurements was made on individual cores. The major findings are summarised with relevant statistics in Tables 1-4.

The Tables list the means, standard deviations (SD), standard errors of the means (SE), number of cores (N) and coefficients of variation (C.V.%) for each class. In Table 1 data for all cores from each colliery are compared, and then subdivided into results for cores cut perpendicular and parallel to the original bedding plane, respectively. Table 2 further subclassifies the data into results for cores with and without visual evidence of fissuration (i.e. fissures of width > ca. 0.05 mm). In Table 3, the variation between samplings from lump to lump is shown for different collieries, and finally Table 4 shows the observed variation from 40 mm section to section along several single cores.

For the Tables two common statistical parameters have been calculated and are also shown. These are 'Student's' "t" and the Probability (P) that the difference tested arises by pure chance. The samples or groups compared are indicated as to location by the direction of the small arrows, viz ← "t"(P)→ or ↑ "t"(P) ↓ . In this test, a P-value of less than the stated percentage indicates there is less than that percentage chance of the two groups belonging to the same population.

DYNAMIC ELASTIC MODULUS

Statistics for the dynamic elastic modulus (E) and Poisson's ratio (ν) derived from sonic velocity measurements for the cores through Eqs. 2 and 3 are listed in Tables 5 and 6. Table 5 gives comparable data to those in Table 1 for coal core permeability. It compares all the results for the different coals, both without distinction, and subclassified as cores

Table 1. Permeability of Australian Coals with complete statistics

Colliery Code		Permeability milliDarcys All Data	Perpendicular to B.P.	←"t"→ ←(P)→	Parallel To B.P.
	Mean:	3.193	4.864		0.965
	SD	5.831	7.202	2.1	1.225
"WC"	SE:	1.122	1.859	(~5%)	0.369
	N:	(28)	(16)		(12)
	C.V.%	183	148		127
	↑ "t"(P)↓	4.4(<0.1%)	2.1(~5%)		3.8(<1%)
	Mean:	15.159	9.544		19.122
	SD:	28.257	15.634	1.9	33.793
"AP"	SE:	5.321	4.714	(NS)	8.448
	N:	(29)	(12)		(17)
	C.V.%	186	239		177
	↑ "t"(P)↓	2.3(<5%)	3.2(<1%)		2.1(~5%)
	Mean:	35.582	64.354		6.811
	SD:	91.451	122.579	2.5	6.751
"LL"	SE:	25.364	50.043	(<5%)	2.756
	N:	(14)	(7)		(7)
	C.V.%	257	191		99

Key:- "WC" = West Cliff Colliery, N.S.W.; "AP" = Appin Colliery, N.S.W.; "LL" = Leichhardt Colliery, Queensland.

perpendicular and parallel to the bedding plane. The effect of fissures on the dynamic modulus is shown in Table 6.

The dynamic elastic modulus is related to the dynamic compressibility modulus as its reciprocal. Thus in comparing compressibilities for the coals from Tables 5 and 6 one uses the reciprocals of the values given.

Although in-situ, coal underground is subject to predominantly static stress, and the static compressibility is the parameter required for comparing the effect of stress on permeability, Evans and Pomeroy (1966) showed in a study of Yorkshire coals (Barnsley Hards) that although the dynamic modulus is slightly higher than the static modulus, it is uniformly so. Comparisons made using the one parameter should thus be applicable to the other and vice versa.

Table 2. Effect of fissures on permeability of some Australian Coals

Colliery Code		Permeability milliDarcys Visible Fissures All	←"t"→ ←(P)→	-Visible Fissures All
	Mean:	10.702		0.690
	SD:	7.626	13.6	0.946
"WC"	SE:	3.113	(<0.1%)	0.212
	N:	(7)		(21)
	C.V.%	71		137
	Mean:	26.554		1.135
	SD:	33.869	5.4	0.507
"AP"	SE:	8.745	(<0.1%)	0.146
	N:	(16)		(13)
	C.V.%	128		45
	Mean:	59.855		3.218
	SD:	115.110	2.4	3.794
"LL"	SE:	43.508	(<5%)	1.697
	N:	(8)		(6)
	C.V.%	192		118

DISCUSSION

Taken together, the data show different coals to possess significant differences in their elastic modulus (∝ 1/compressibility) and permeability to air flow under the defined conditions. The order of increasing permeability is West Cliff, Appin and Leichhardt coal. This is also the order in which compressibility increases among the collieries (Table 5). However, the ratios of increasing permeability between the Appin and Leichhardt collieries relative to West Cliff are much greater than those of compressibility.

Although there is a marginally significant difference between the permeabilities for two sets cut parallel and perpendicular to the bedding plane for two collieries (West Cliff and Leichhardt), this was not generally so, and there was no significant difference between the elastic modulus data for the two groups (Table 5).

However, when the data are split into those for cores with and without visible

Table 3. Permeability variation within collieries

Colliery Code		Sample No.1	←"t"→ ←(P)→	Sample No.2	←"t"→ ←(P)→	Sample No.3
	Mean:	7.591		0.476		0.828
	SD:	7.664	10.9	0.126	0.8	2.127
"WC"	SE:	2.555	(<0.1%)	0.973	(NS)	0.059
	N:	(10)		(4)		(14)
	C.V.%	101		27		257
	Mean:	31.66		1.277		6.971
	SD:	37.33	4.2	0.320	1.97	15.006
"AP"	SE:	11.81	(<1%)	0.143	(NS)	4.525
	N:	(11)		(6)		(12)
	C.V.%	118		25		215
	Mean:	0.286		41.465		
	SD:	0.179	1.7	97.545		
"LL"	SE:	0.179	(NS)	29.411		
	N:	(2)		(12)		
	C.V.%	63		235		

Key: "WC" = Westcliff Colliery, N.S.W.; "AP" = Appin Colliery, N.S.W.; "LL" = Leichhardt Colliery, Queensland.

Table 4. Permeability of single cores sectioned along their length, at successive intervals

Sample No.	K, mDarcy
WC4A21F	8.46
WC4A22	0.179
WC4A23	0.088
WC4A24	0.513
AP3B21	0.80
AP3B22	0.43
AP3B23	1.44
LL2B11F	9.31
LL2B12	3.99
LL2B13	2.36
LL2B14	11.20
LL2B15F	20.30

fissures (not fractures - viz. cores still intact), a highly significant difference of permeability (Table 2), but not of elastic modulus (Table 6) is then observed. Without fissures, typical permeability lies between 0.1 and 5 mDarcy, the range being wider for the more obviously fissured cores (3 - 180 mDarcy). The effect of fissures on permeability and Darcy flow of gases is well-known in relation to overseas coals, and it goes without question that coal with structured, hollow fissures will conduct more gas than coals without. This appears to be the first published data on Australian coals which shows the magnitude of the fissure effect on permeability. The term "Visible" fissures means those apparent to the naked eye. Microscopic inspection shows that apparent fissures, not visible to the eye (viz. 0.5-30 μm) are also present, and the relationship to permeability of this microscopic fissure structure is now being investigated. Removal of the permeability data for fissured cores (Table 2) reveals that both with and without visible fissures the difference in permeability between collieries is still significant in both groups.

The coefficient of variation (C.V.% = 100% x SD/Mean) is very large for both permeability and elastic modulus. This is a measure, expressed as percent of mean, of the spread of 65% of sampled values on either side of the mean. It describes the inhomogeneity of the sample tested. This inhomogeneity is greater for the permeability than for the elastic modulus, and presumably reflects the much greater effect of fissure structures on the former than the latter parameter.

A component of the above variation in permeability arises both from within an individual core, sectioned at approximately 4 cm intervals (Table 4), and between cores cut from lump coal taken from different locations within a colliery (Table 3).

Also coal from within the same seam (the Bulli, N.S.W.) but from different geographical regions is clearly of different permeability, as shown in Table 1. Coal permeability (and to a lesser extent the elastic modulus) therefore varies both on the macro- and the micro-scale.

The standard deviations and coefficients of

Table 5. Dynamic elastic modulus and Poisson's ratio for Australian coals - with complete statistics

Colliery Code		Dynamic Young' Modulus, E, MPa All Data	Perpen-dicular	←"t"→ (P)	Parallel to B.P.	Poisson's ratio ν
	Mean:	3636	3779		3399	0.260
	SD:	1604	1752	1.3	1286	0.135
"WC"	SE:	288	402	(NS)	389	0.024
	N:	(32)	(20)		(12)	(32)
	C.V.%	44	46		38	52
↑"t"(P)↓		2.55(<5%)	1.05(NS)		3.0(<1%)	4.25(<0.1%)
	Mean:	2920	3304		2605	0.334
	SD:	2555	3515	1.2	1238	0.109
"AP"	SE:	586	1243	(NS)	392	0.025
	N:	(20)	(9)		(11)	(20)
	C.V.%	88	106		48	33
↑"t"(P)↓		5.8(<0.1%)	3.8(<1%)		5.4(<0.1%)	0.05 (NS)
	Mean:	938	794		1065	0.335
	SD:	914	482	1.1	1153	0.136
"LL"	SE:	244	197	(NS)	436	0.035
	N:	(15)	(7)		(7)	(15)
	C.V.%	97	61		108	39

Key: "WC" = West Cliff colliery, N.S.W., "AP" = Appin Colliery, N.S.W., "LL" = Leichhardt Colliery, Queensland.

variation were calculated from the present data assuming a normal distribution of the permeability values. A frequency plot of the permeability in all cases reveals two peaks. There is a sharp one which is well-defined in the 0-10 milliDarcy range, and a low broad peak representing the data from the more highly fissured cores. Although a more detailed analysis has yet to be performed, the indication is that the naturally occurring distribution of coal permeabilities is skewed, the majority of values concentrating at the very low end. No permeabilities are found, however, below about 10^{-5} Darcy.

It may be hazardous, at present, to attempt to relate the above directly to underground conditions, although this exercise is clearly desirable. One can state conclusively both from Fig. 4 and findings overseas on Derbyshire sandstones and Pennsylvanian coals (Mordecai and Morris, 1974; Somerton, et al., 1974), that the in-situ permeability of coal subject to stress will be very much less. Assuming that resultant in-situ stress is of the order of 20 MPa (3000 psi) the data of Somerton et al. for Pittsburgh and Pocahontas coals suggest that a reduction of the order of 10-100 times would not be unreasonable. Measurements to be made shortly at the University of New South Wales on Australian coals using a high stress triaxial testing rig will elucidate this point.

An important factor, not made clear in the American study, was the interaction between stress and permeability through the differences of coal compressibility. Undoubtedly, one can expect that coals of high compressibility (small E-value in Table 5) will close up more under a given stress and achieve a more significant reduction of permeability.

Table 6. Effect of fissures on dynamic elastic modulus (E) of Australian coals

Colliery Code		Dynamic Young's Modulus MPa + Visible Fissures All	←"t"→ ←"p"→	-Visible Fissures All
	Mean:	3252		3744
	SD:	1587	1.75	1592
"WC"	SE:	648	(NS)	325
	N:	(7)		(25)
	C.V.%	49		43
	Mean:	2124		3260
	SD:	1559	2.03	2810
"AP"	SE:	697	(NS)	779
	N:	(6)		(14)
	C.V.%	73		86
	Mean:	680		1233
	SD:	496	2.46	1160
"LL"	SE:	187	(5%)	474
	N:	(8)		(7)
	C.V.%	73		94

Key: "WC" = West Cliff colliery, N.S.W.; "AP" = Appin colliery, N.S.W., "LL" = Leichhardt colliery, Queensland.

On this basis one might expect that the from 5-11 fold difference in permeability between the West Cliff and Appin coal will be reduced under in-situ stress conditions. Under the same compressive force, the deformation of the Leichhardt coal will be more than 3 times that of the West Cliff and Appin coals (Table 5), but without more extensive data and a suitable theoretical treatment, the magnitude of the resulting permeability reduction is impossible to predict.

CONCLUSIONS

It presumably stands without extensive justification that a knowledge of coal permeability distribution within a seam will permit improved understanding of in-seam gas movement; as well as the movement of gases between the seam and adjacent strata. The present data are obviously not extensive enough to permit the detailed prediction of in-seam gas movements in any single colliery. Many more data would be required from an exploration survey for the above aim to be approached.

The most important conclusion at present is that there are significant differences between collieries, from point to point within a seam, and on a micro-scale within the space of the few hundred millilitres of coal comprising a typical long core. In the prediction of gas movement therefore, it seems that the group average permeability for, say 0.5 m^3 of coal would signify the general level for a particular region. The present data show (Table 3) that there are significant differences between samplings on this scale.

However, one cannot avoid being plagued by uncertainty that the method of collection of the cores (fron run-of-the-mine lumps, subjected to recent stress cycling caused by excavation from a region subject to abutment stresses) might lead one to erroneous conclusions because some of the fissures present may not have been there in the virgin coal. Likewise, one is forced to be selective in sampling during coring. For example, nearly all the tests on the Leichhardt coal come from one of only two lumps kindly supplied by the colliery. Coring in the initial stages was highly unproductive of anything but slivers and fragments on the first sample cored. Such an experience naturally forces bias into an otherwise valid selection.

The only firm conclusion that can be made at present is that, as tested, the permeabilities of coal within the different colliery regions will probably vary, paralleling those of the measurements described. More detailed study of stress related effects on gas permeability relative to individual variation of coal elastic properties is thus desirable, and is being conducted by the authors at the University of New South Wales.

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DISCUSSION

K. NOACK (Westfalische Berggewerkschaftskasse, West Germany): Bergbau-Forschung are doing a lot of work with permeability. It has been found that it is impossible to transfer laboratory values to in-situ situations. As a result Bergbau-Forschung has begun to develop methods for measuring permeability in-situ. Is it planned to develop such methods also? Also it was stated that permeability parallel to the bedding planes is lower than perpendicular. Bergbau-Forschung has found quite the opposite of this result. Comment on this would be appreciated.

P.S. LINGARD (University of New South Wales): Three sets of basic data have been obtained from three different collieries. Only in two cases was the permeability of the samples cored parallel to the bedding plane less than that of the cores cored perpendicular. In the other case, the Appin Colliery case, it was the other way around. So there may be some variation in the distribution.

No, there is no present intention of getting into in-seam permeability studies. This may be something for the future. The present study was carried out in order to get basic data for another project in which it is proposed to stress coal in the laboratory triaxially, measure permeability and sorption capacities of solid coal core. For that it was necessary to estimate experiment times. The permeability data was needed in order to get a feeling for the fissure distribution in the coal. That is what has been done. Other people represented at this meeting are doing in-seam permeability work and it would be interesting to hear about this.

C. JEGER MADIOT (CERCHAR, France): According to the observations and measurements made in France and in European countries, the permeability of the seams is naturally very low (less than 0.5 md) while, in some other countries, can be quite big (more than 1 to 5 md). That is the reason why what is often called drainage here is in fact predrainage from the European point of view, i.e., drainage of gas before mining. Nevertheless, in some situations, European seams can become permeable: when destressed by overlying or underlying workings as will be presented later. Only in this instance can they be predrained.

Driving of headings in destressed permeable zones of seams is very difficult because the amount of gas coming from all the destressed zones is too large. Those zones could be partially degasified through boreholes perpendicularly crossing destressed seams. A computer program to simulate the desorption and the flow of gas in the plane of a seam was developed by CERCHAR, similar to the work described by Hemala above.

After the experimental and theoretical studies of Gunther, CERCHAR selected physical laws for the modelling: the Darcy's law expressed in term of Fick's law, the law of continuity, the relation content-pressure of gas; the content and the permeability in situ characterises the coal. Eventually the delay between the evolution of gas pressure and the decreasing of mean gas content can be taken into account. Four programs were developed:

- flow to a rib side in a thin seam
- flow to a roadway in a thick seam
- flow to a borehole crossing seams perpendicularly
- flow to an in-seam borehole.

As results, the flow of gas and the repartition of the contents in the seam were obtained. Principal parameters such as permeability are to be deduced from previous measurements (good accordance between measured and predicted flowrate, versus time). After this method, the flowrate of gas and its evolution in time and the residual content after a certain period of predrainage by boreholes or of degasification by flowing of gas to a roadway can be predicted. Residual contents calculated were in good accordance with the measured figures.

As an important result of measurements and of simulations with the above computer program, it can be concluded that in a permeable seam (everywhere or on a quite wide area), drainage by in-seam long boreholes can efficiently degasify this seam only if there are several boreholes close enough to each other (probably not more than 20 - 25 m), and long enough (surely more than 150 - 200 m). In this configuration, the gas flowing from the lateral and in front areas cannot any more maintain a quite high content in the zone to be degasified, because it is drained before reaching the most important internal part of this zone.