AN EQUATION FOR ESTIMATION OF MAXIMUM COALBED-METHANE RESOURCE POTENTIAL

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KEYWORDS: Coalbed methane, resource estimation, equations, computer calculations, relationships, coalification gradient.

INTRODUCTION

This is a technical note on coalbed methane resource estimation. There is extensive literature on the subject of coalbed methane in coal. Many useful references can be found in the special publication by the American Association of Petroleum Geologists (1989).

There has been considerable interest in estimating methane gas content of deeply buried coal. In some coal basins the recovery of coalbed methane from wells penetrating coal seams is a reality and is economic. The potential maximum coalbed methane resource of many other coal basins is being calculated using available seam thickness, rank and depth data.

Often the method used to estimate the maximum methane resource per tonne of *in situ* coal relies on the empirical curves introduced by Eddy *et al.* (1982; Figure 4-1-1). These curves provide estimates of the lost and desorbed gas from coals of different ranks and at different depths. Lost and desorbed methane is an approximation of the maximum methane resource. The lost and desorbed gas content can be read from the appropriate rank curve based on the depth of the sample. The process is convenient for a few determinations but becomes increasingly awkward when rank is defined by a wide range of mean maximum reflectance ($\bar{R}_{max}$) measurements and data are required for a large number of depths.

DISCUSSION

A single equation that relates $\bar{R}_{max}$ and depth to maximum recoverable methane would make the process much

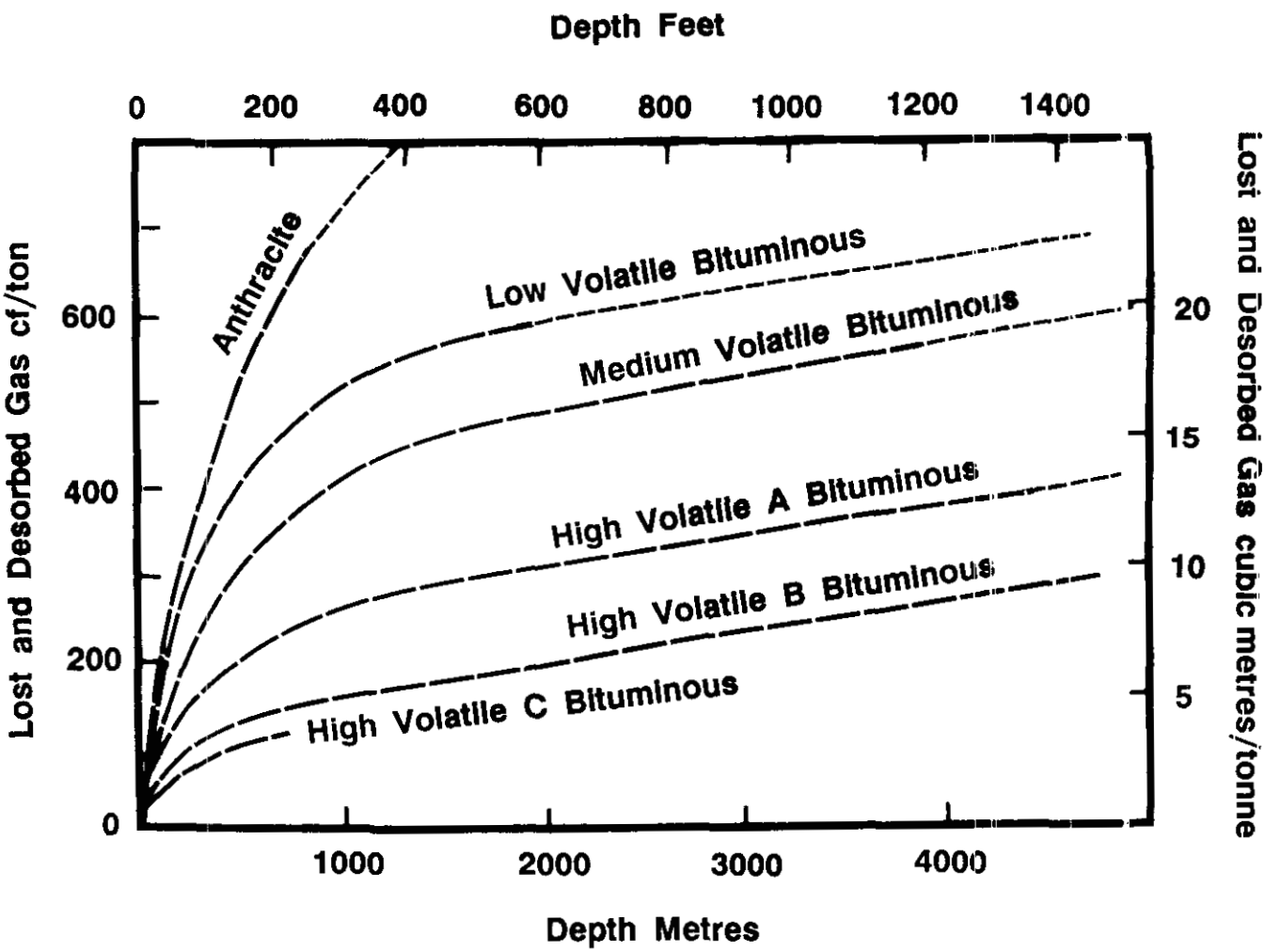

Figure 4-1-1. Empirical curves (Eddy *et. al.*, 1982).

TABLE 4-1-1
EQUATIONS FOR RELATING COALBED METHANE TO DEPTH AND MEAN MAXIMUM REFLECTANCE OF VITRINITE

EQUATION A

$R = \bar{R}_{max}\% \times K$

$C = \text{depth} \times R^{\wedge} 2.5 - 0.2$

$B = \text{Ln}(C) / 2.30259 - 1.095) / 0.003913$

$GAS = B \times (100 - M - A) / 100 / 32.037$

$\bar{R}_{max}\%$ = Mean maximum reflectance of vitrinite in oil.
K = 0.98 for mid-rank, 0.89 for lower limit and 1.25 for upper limit.
Ln = natural logarithm
Depth in metres
GAS in cubic centimetres per gram

EQUATIONS FOR THE FIVE RANK CURVES IN FIGURE 1

1/ HVB-C GAS = (104.85 = 0.0514 × D - 770.4 / D)/32.037
2/ HVB-B GAS = (122.74 = 0.155 × D - 1203.6 / D)/32.037
3/ HVB-A GAS = (267.62 + 0.09613 × D - 11499.3 / D)/32.037
4/ MVB GAS = (466.57 + 0.09974 × D - 25923.2 / D)/32.037
5/ ANTH GAS = (786.2 + 0.089 × D - 40290.1 / D)/32.037

KARWEIL CUMULATIVE GAS EQUATION

CGAS = - 325.6 Ln(VM / 37.8)

CGAS = Cumulative gas in cubic centimetres per gram
VM = Volatile matter; dry ash-free basis

TABLE 4-1-2
VALUES OF LOST PLUS DESORBED GAS VERSUS DEPTH FROM THE RANK CURVES IN FIGURE 1

RANK Average $\bar{R}_{max}$ Depth (Metres)	HVB C 0.52% g/cc	HVB B 0.64% g/cc	HVB A 0.82% g/cc	MVB 1.30% g/cc	LVB 1.80% g/cc	ANTH 3.50% g/cc
200	3.47	4.37	7.09	11.02	14.08	18.73
300	3.68	4.78	8.18	12.89	16.04	21.29
400	3.87	5.18	8.68	14.02	17.14	22.60
500	4.03	5.59	9.11	14.64	17.19	23.50
600	4.18	5.93	9.61	14.98	18.39	24.07
700	4.37	6.24	9.93	15.45	18.73	24.41
800	4.53	6.68	10.27	15.95	19.13	25.13
900	4.68	6.99	10.61	16.39	19.51	25.66
1000	4.84	7.43	11.02	16.73	19.82	26.22
1100	5.03	7.77	11.27	17.26	20.26	
1200	5.18	8.12	11.58	17.70	20.54	
1300	5.34	8.62	11.92	18.04	21.01	
1400	5.49	8.87	12.33	18.39	21.32	
1500	5.68	9.11	12.74	18.73	21.63	

Abbreviations:
$\bar{R}_{max}$ Mean maximum reflectance of vitrinite in oil.
HVB High-volatile bituminous.
MVB Medium-volatile bituminous.
ANTH Anthracite.

TABLE 4-1-3
RANGES OF $\bar{R}_{max}$ FOR DIFFERENT RANKS (FROM WARD, 1984) AND DIVERGENCE OF EQUATION A FROM RANK CURVES IN TABLE 4-1-1

Rank	$\bar{R}_{max}$ Low	Mid	High	Equation A Errors Absolute	Normative
HVB-C	0.47	0.52	0.57	ND	ND
HVB-B	0.57	0.64	0.71	-4	+6
HVB-A	0.71	0.90	1.10	+13	+13
MBV	1.10	1.30	1.50	-0.2	+1.0
LVB	1.5	1.8	2.05	-0.5	+0.6
SEMI-A	2.05	2.5	3.0	ND	ND
ANTH	3.0	3.5	ND	+0.04	+1.5

Errors represent the average divergence from the appropriate rank equation in Table 4-1-1 when the mid-range $\bar{R}_{max}$ value is used in Equation A.

less tedious and amenable to computerization. Such an equation is introduced here (Equation A, Table 4-1-1). It reproduces the original five rank curves in Figure 4-1-1 quite well, except for R_{max} values of less than 0.6 per cent.

Approximate readings of depth in metres and gas content in grams per cubic centimetre can be read from the five rank curves in Figure 4-1-1 (Table 4-1-2). Data were input into a curve-fitting computer program and for each rank the best-fit curve with the resultant constants defined (Table 4-1-1, Equations 1 to 5). In all cases an equation of the type Y = (A + B) × (X + C) / × fitted the data very well. In fact the R^2 correlation factors for the five curve fits varied from 0.996 to 1.0. These five equations therefore provide an accurate way of representing the five rank curves in Figure 4-1-1. These equations can be used to model the gas content versus depth relationship for coal with a rank represented by one of the five curves. Unfortunately it is difficult to relate the constants in each equation to changes of $\bar{R}_{max}$ from curve to curve so that the equations are not useful when coal rank is not represented by one of the five curves.

Equation A was developed to provide a single equation capable of predicting the gas content for coal from any depth and of any rank. In fact the equation works quite well for reflectances greater than 0.6 per cent and depths greater than 100 metres. It was first used in resource calculations for the Tuya River coal basin (Ryan, 1990). Obviously if Equation A is valid, then it should reproduce the five rank curves in Figure 4-1-1. The range and average ($\bar{R}_{max}$) values that define each rank of coal (Ward, 1984) are in Table 4-1-3. The mid- ($\bar{R}_{max}$) values were entered in Equation A. With the help of a computer program, predictions of gas content versus depth derived from Equation A were checked against those provided by the appropriate rank equation (Equations 1 to 5, Table 4-1-1).

The program incorporates Equation A and Equations 1 to 5. It calculates the average divergence of Equation A from the appropriate rank equation when the correct mid-range ($\bar{R}_{max}$) value (Table 4-1-3) is entered in Equation A. The divergence is calculated as an average, taking into account sign (absolute divergence), in which case random fluctuations about the rank curve will result in a zero divergence. The normative average divergence is also calculated. In this case fluctuations about the rank curve are summed and averaged irrespective of sign. The absolute average divergences range from −4.0 to +13.0 per cent and the normative average divergences from 0.6 to 13.0 per cent.

If the mid-point $\bar{R}_{max}$ values are used in Equation A then the five rank curves in Figure 4-1-1 are reproduced fairly accurately except for the high-volatile A bituminous rank curve. The mid-point $\bar{R}_{max}$ value for high-volatile A bituminous coal is 0.90 per cent; Equation A produces a good fit to the curve if a value of 0.82 per cent is used. Because Equation A fits the five rank curves quite well it reasonable to suppose that it can also model the depth versus gas content relationship for all intervening ranks of coal.

It is easy to adjust constant K in Equation A to enable the equation to model the five rank curves assuming that they represent the minimum $\bar{R}_{max}$ values for that rank, for example to model the lower limit of each rank, K = 0.89, or to

model the upper limit of each rank, K = 1.25. It is also possible to add a constant to Equation A that takes account of the effect of ash and moisture; the simplest assumption is that the five curves are at the same ash basis as the samples being modelled. If the five curves are for ash-free coal, then an adjustment of (100-M-A)/100 must be made where A = ash per cent and M = moisture per cent of the coal being modelled.

Equation A makes it easier to use the relationships explicit in the five rank curves. These curves are only approximations of actual coalbed methane resource potential. Using Equation A does not make the resource evaluation more accurate. It simply makes the process of initial order-of-magnitude resource calculations easier to perform when a lot of coal rank, depth and seam thickness data are available.

Generally coal rank increases with depth; it is therefore unrealistic to model a constant rank coal from 0 to 1500 metres. In fact the rank should increase with depth. Equation A can be modified with a term that allows for the consideration of a coalification gradient. Coalification gradients are expressed as the change in $\bar{R}_{max}$ per 100 metres. If a start-depth, mean maximum reflectance value and coalification gradient are specified, then a gas content versus depth profile can be calculated that cuts across the equi-rank curves.

Another way of estimating *in situ* lost and adsorbed methane was introduced by Kim (1977). This method uses proximate coal-quality data and information about the level of saturation of the coal. It is possible to computerize the Kim equations and compare results with those obtained from Equation A and the five rank equations. Generally results compare quite well. Exact comparisons between the Kim equations and Equation A are difficult because of the "degree of saturation" constant required by the Kim equation but not present in equation A. Karweil (1969) introduced an equation (reproduced in Meissner, 1984) for estimating cumulative methane generation for coals with volatile contents less than 37.8 per cent. Meissner (1984) also developed a series of equations that describe the relationship between volatile matter and mean maximum reflectance. It is possible to predict the cumulative methane generated by a coal for which the lost and adsorbed gas content is also calculated by using the equations of Karweil and Meissner. Obviously the difference between cumulative methane generated and methane retained is the gas available to charge adjacent reservoirs.

A computer program has been written that incorporates the equations in Table 4-1-1 and is available on request. An example of the output is included as Figure 4-1-2. It permits simple modelling of maximum potential methane resource under different conditions of depth, rank, ash content, moisture content and coalification gradient.

CONCLUSIONS

A simple equation is introduced that facilitates the initial estimation of maximum potential methane resource for coal from a wide range of depths and for a wide range of ranks. Recoverable reserves are often 50 to 10 per cent of initial resource estimates. In many cases a useful estimate of recoverable coalbed methane requires drilling and desorption tests.

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METHANE RETENTION USING EQUATION A AND GENERATION USING KARWEIL

DEPTH METRES	DEPTH FEET	METHANE RETAINED SCF	METHANE RETAINED c/g	METHANE GENERATED c/g	REFLECTANCE R MAX	VOLATILES VM DAF %
100.00	328.08	232.00	7.24	27.52	1.10	31.11
200.00	656.16	323.56	10.10	31.74	1.15	30.20
300.00	984.24	382.31	11.93	36.08	1.20	29.29
400.00	1312.32	427.21	13.33	40.56	1.25	28.38
500.00	1640.40	464.27	14.49	45.18	1.30	27.46
600.00	1968.48	496.19	15.49	49.96	1.35	26.55
700.00	2296.56	524.45	16.37	54.91	1.40	25.64
800.00	2624.64	549.93	17.17	60.04	1.45	24.72
900.00	2952.72	573.23	17.89	65.36	1.50	23.81
1000.00	3280.80	594.74	18.56	70.89	1.55	22.90
1100.00	3608.88	614.77	19.19	76.64	1.60	21.98
1200.00	3936.96	633.53	19.77	82.64	1.65	21.07
1300.00	4265.04	651.21	20.33	88.90	1.70	20.16
1400.00	4593.12	667.93	20.85	95.46	1.75	19.25
1500.00	4921.20	683.82	21.34	102.33	1.80	18.33

Figure 4-1-2. Example of output from program incorporating equations found in Table 4-1-1.

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