

ESTABLISHMENT OF MORE RELIABLE EQUATIONS FOR ESTIMATION OF COALBED METHANE PROXIMATE ANALYSIS DATA

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ABSTRACT

Coal bed methane (CBM) data such as ash contents, moisture contents, volatile matters, and fixed carbon – commonly obtained from log analysis - are direct input to calculation of gas accumulation in CBM reservoirs. However, recent studies on some coal samples taken from Rambutan field CBM pilot project have shown that the commonly used log analysis equations are simply inapplicable for the field's coal samples. Calculation results tend to give far different magnitudes when compared to laboratory results. After a series of re-evaluations and re-measurements on the laboratory results it was convinced that the problem does not lie with the laboratory results but with these 'conventional' equations. Therefore modification efforts are spent to find better equations.

Comparisons between measured data (coal samples taken from two coal seams in the field) and calculated data show that only equation for ash contents gives accurate results. The other proximate analysis output data - i.e. moisture contents, volatile matter, and fixed carbon – is at considerable odd with their corresponding calculated data. Modification upon the original empirical models is then carried out. The following modifications on the equations have produced analogous but different empirical equations to the original equations. These equations certainly work more reliably for the field's coals, and these better results underline that future log analyses in the field have to use the modified equations.

Key words: coal bed methane, proximate analysis, log analysis, modification, better-suited equations.

I. INTRODUCTION

In the last two decades coalbed methane (CBM) has received plentiful attention in almost every part of the world. In coal mining industry the contained methane gas in the coal seams were mostly regarded as hazard to the mining activities themselves. Various methane related accidents have occurred throughout the history of coal mining, often resulted in serious fatalities, especially in deep mining activities.

In petroleum industry CBM has actually been long considered as a potential alternative to gas production from conventional gas reservoirs. This is true since coal beds are often encountered in petroleum wells, but too deep to be economically exploited

through conventional deep mining operations. However, low gas price in the past and the relative small CBM accumulation in most coal beds compared to conventional gas reservoirs prevented its exploitation.

Situation in today's petroleum industry - with awareness that world's gas reserve has its certain limit - has led to an emphasis that CBM has to be given a more appropriate attention. Based on technology available to petroleum and mining industries technology for drilling and production of CBM have been developed. The various techniques that have been developed, including ones in formation evaluation, have exhibited their usefulness but improvements are indeed required. Recent execution on the first

pilot project in Indonesia in Rambutan field – South Sumatra, has shown the need.

During the trial of this first CBM field in Indonesia, coal samples were retrieved from the five wells drilled so far. Log survey using standard log suites were also run, but it was doubted whether the common equations/models used in log interpretation are valid for the required reserve assessment. This was proved based on significant difference between results of proximate analysis – ash contents, moisture, volatile matter, and fixed carbon – from laboratory and the corresponding estimates using conventional equations. As fully acknowledged, error in such data will result in erroneous estimates in a field's CBM accumulation. It is the theme of this paper to show the bias and to offer alternative equations/models that at least are valid for Rambutan field.

II. 'STANDARD' MODELS

In a manner similar to conventional oil and gas reservoirs in their early era of exploitation, evaluation over CBM reservoirs were also carried out much using core samples and testing in the laboratory. Considering the costs needed for coring and testing of all existing wells (especially for CBM reservoirs, which success of exploitation is much influenced by well density), it was thought that means had to be established to utilize the most common and widely used method for reservoir evaluation, the wireline logs.

Mullen (1989) proposed a set of interpretation models for proximate analysis data derived from basin-wide database reported by Fassets and Hinds in their 1971 US Geological Survey Professional Paper 676. The original set of equations presented in Mullen (1988) is

$$V_{ash} = 64.94 * \rho_b - 66.27 \quad (1)$$

$$V_{FC} = -0.517 * V_{ash} + 51.2 \quad (2)$$

$$V_M = -0.1 * V_{ash} + 4.61 \quad (3)$$

$$V_{VM} = 100 - V_{ash} - V_{FC} - V_M \quad (4)$$

with V_{ash} , V_{FC} , V_M , V_{VM} , r_b represent the data of ash contents, fixed carbon, moisture, volatile matter, and bulk density, respectively. The proximate analysis data is in weight fraction and bulk density in gr/cc. Although these equations were derived from a certain

database they are subject to modification in order to accommodate 'local effect', as has been shown in Mullen (1989).

The proximate analysis data estimated using Equations (1) through (4) enables the estimation of gas contents. There are some methods available, amongst others is Modified Kim method (Kim, 1977) of

$$V = (1 - V_M - V_{ash}) * \frac{V_w}{V_d} * \left\{ k_o * 0.96h^{n_o} - 0.14 \left(\frac{1.8h}{100} \right) + 11 \right\} \quad (5)$$

where

V = gas contents, ft³/ton,

V_w = gas volume in wet condition,

V_d = gas volume in dry condition,

h = depth, meters,

$V_w / V_d = 0.75$,

$$k_o = 0.800 * \left(\frac{V_{FC}}{V_M} \right) + 5.60 \quad (6)$$

and

$$n_o = 0.390 - 0.100 * \left(\frac{V_{FC}}{V_M} \right) \quad (7)$$

Other fully empirical methods are average gas contents, V_{av} , from Mullen (1989)

$$V_{av} = -542\rho_b + 1053 \quad (8)$$

and the equation from Mavor et al (1990) of

$$V = 604.1 - 751.8a_d \quad (9)$$

with

$$a_d = \frac{V_{ash}}{(1 - V_M)} \quad (10)$$

The equations presented above are at present still being used in the interpretation of well log data from CBM wells. Comparison and calibration using tested cores are suggested but various practices have shown that this recommended practice is not always carried out. Instead, direct use without any corrective measure is often practiced.

III. CASE STUDY: RAMBUTAN FIELD

Regionally, the Rambutan field pilot project is situated in the southern part of the South Sumatra sedimentary basin in Sumatra (Figure 1). The basin, which development was much influenced by the subduction of the Indo-Australian Plate underneath the South-east Asian Plate during the Late Cretaceous – Early Tertiary, contains sediments from Tertiary terrestrial to marine clastics with minor limestone (Suwarna et al, 2003). The coal seams that serve as the focus, from which the methane gas is expected, are contained within the tertiary (Oligocene to Pleistocene) Muara Enim formation (Suwarna et al, 2003).

The Muara Enim formation comprises approximately 900 m of paralic sandstones with interbedded coal seams, which typically form between 10% and 20% of total formation thickness. Referring to well log data the coal seams are dispersedly distributed throughout the formation. With regard to age the Muara Enim formation is sub-divided, from the oldest to the youngest, into M1, M2, M3, and M4 Sub-divisions (Figure 2). From the four Sub-divisions, M2 Sub-division with its A1, A2, B, and C (Figure 3) coal seams is the focus of the pilot project (Suwarna et al, 2003).

The A1 and A2 seams range between 6 and 15 meters in thickness. From studies from outcrops, the A1 seam tends to thin out in the southern part of the field whereas the A2 seam tends to be uniform with its 9 – 15 meters thickness throughout the field. The B seam appears to be the thickest with maximum thickness of 19 meter with an average value of 16.7 meters. Laterally, most of the seam is present in a single body except some vertical separation in some parts in the field's northern area. The C seam is apparently the thinnest seam in the M2 Sub-division with thickness from 7 to 11 meters. The seam tends to reach its maximum thickness in the western part of the field.

Maceral analysis previously conducted for the coals (from A seams) show that the maceral group is predominantly vitrinite that varies within 71% - 94%, with exinite and inertinite components of 1 – 7% and 3 – 10%, respectively. Based on the vitrinite reflectance results for samples from the A seams and the Enim seam (M4 Sub-division) of 0.50 – 0.52% and 0.38 – 0.47%, respectively, it is interpreted that the CBM present is a combination of biogenic and ther-

mogenic types, dominated by the thermogenic one. If the tested coal samples are taken as the representative for the coals in Rambutan project, the vitrinite reflectance results suggest that the coals vary from lignite to sub-bituminous C – B ranks.

The coals have fairly developed cleat system with averaged cleat spacing of 27.5 cm and 8.2 cm for A and Enim seams, respectively, and cleat aperture of 0.1 – 0.2 cm. Despite fairly cleated (i.e. moderate permeability), the coals tend to exhibit very low porosity. The high volatile matter contents (39.3 – 43.4%) shown by the samples indicate characteristics of very low *in situ* methane contents. However, other characteristics of dull to dull-banded lithotype, vitrinite dominated maceral composition, low to medium vitrinite reflectance, moderate moisture contents, and low ash contents indicate moderate level of CBM contents within the seams.

IV. LABORATORY WORKS

A total of 53 core samples were taken from the pilot project's wells nos. 3 and 4. The sizes of full diameter cores are 3.5 inch and 2.5 inch for A seams and C seam, respectively. All samples were retrieved under hydrostatic pressure from mud column in the

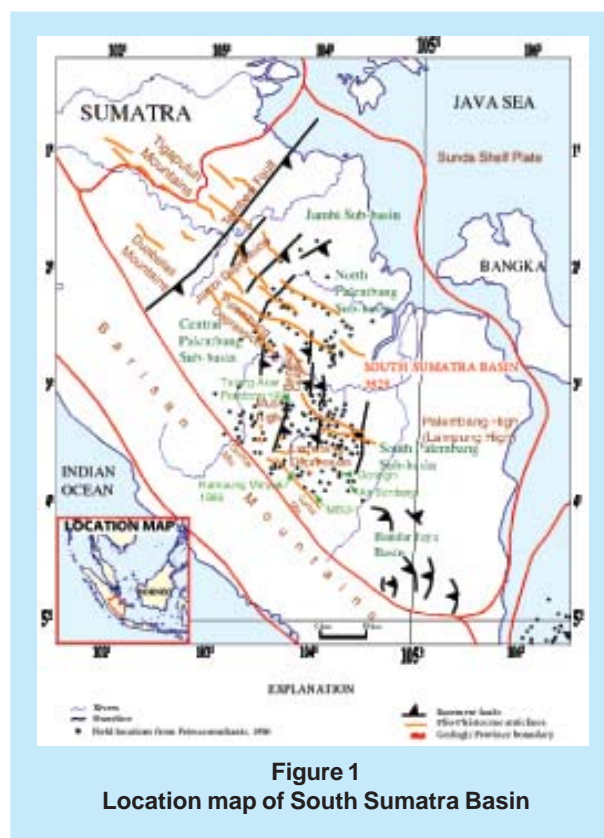


Figure 1
Location map of South Sumatra Basin

wells. The samples were to undergo gas contents, proximate analysis, ultimate analysis, and bulk density measurements.

As the core samples were retrieved from the wells, they were stored in canisters and isolated completely. Following the standard procedure, total volumes of released gas within the canisters during transportation (Q_2) were measured upon arrival at the laboratory through the use of *fast desorption method*. Simultaneously, gas composition was measured using gas chromatograph. Core samples were then removed from the canister and tested for their bulk density using mercury displacement method. Next step was to put the samples into crusher. As the samples were being pulverized the released gas (Q_3) was measured thoroughly. Using the recorded Q_2 and Q_3 , the volumes of released gas during the time-measured core retrieval (Q_1) were estimated using fast desorption method. Figure 4 presents an example of Q_1 estimation. Summation of Q_1 , Q_2 , and Q_3 serves as the estimates of total gas contents (V) in the core samples.

After the samples were sufficiently crushed (grain size < 150 μ m) some of the powder was taken for proximate analysis. For proximate analysis, a sufficient quantity of powder samples was put into furnace, and following the procedures described in ASTM D 3173 – 00, ASTM D 3174 – 00, and ASTM D 3175 – 01, moisture content (V_M), ash content (V_{ash}), and volatile matter (V_{VM}) were measured. Proximate analysis mea-

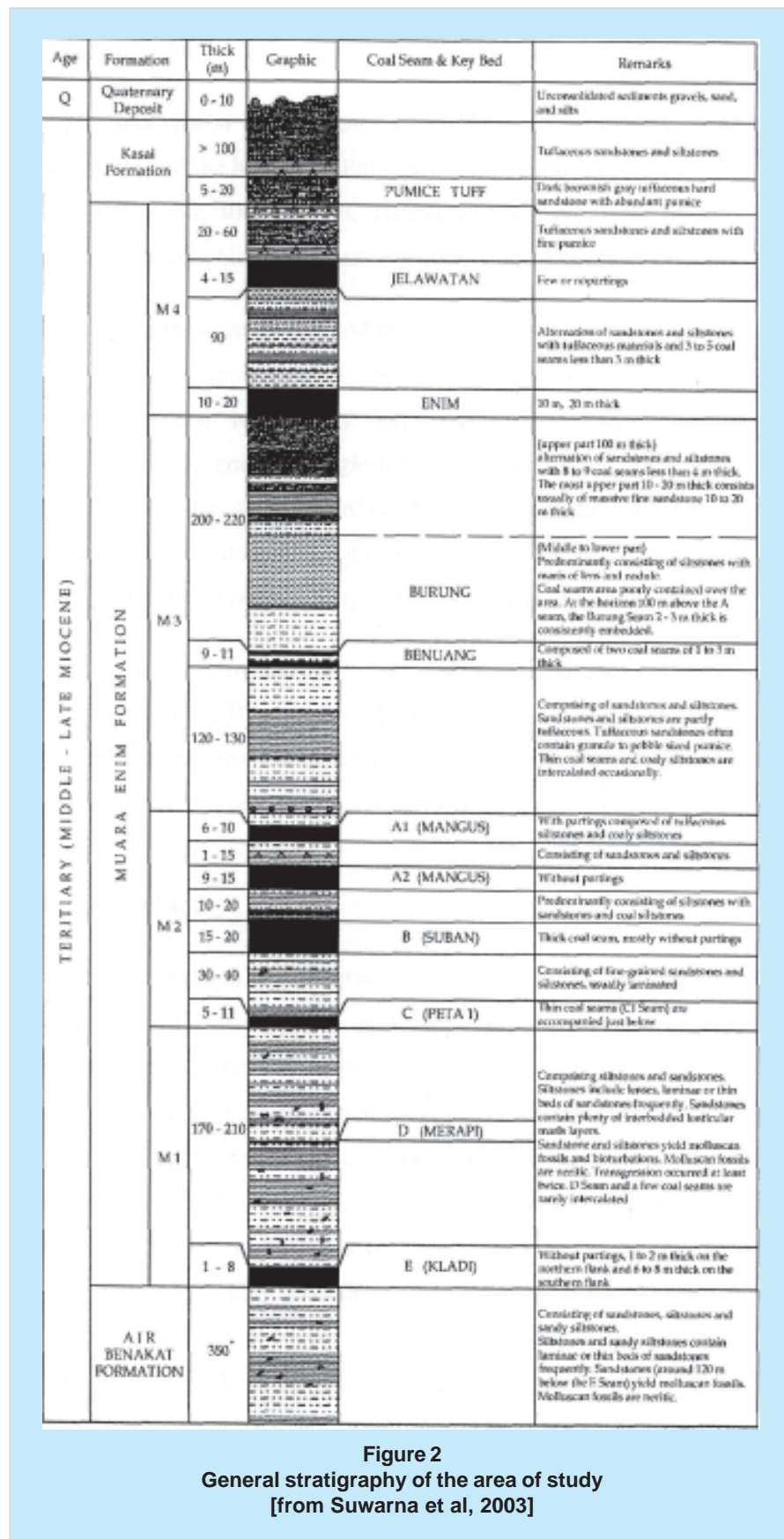


Figure 2
General stratigraphy of the area of study
[from Suwarna et al, 2003]

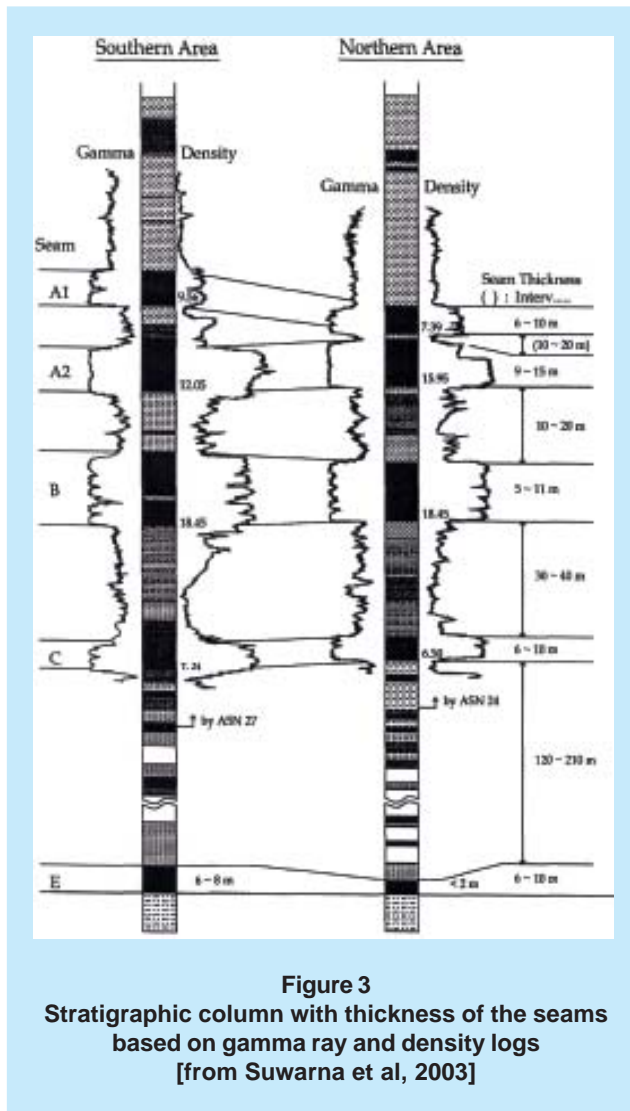


Figure 3

Stratigraphic column with thickness of the seams based on gamma ray and density logs [from Suwarna et al, 2003]

measurements are made in *air dry basis* (adb), which results are then converted into *as received* (ar) condition imitating *in situ* condition in wells.

All proximate analysis results are presented in weight fraction. Fixed carbon (V_{FC}) is simply a subtraction of the combined three parameters from 100%. Notice the difference shown by Mullen's Equations (1) through (4), in which fixed carbon is calculated and volatile matter is merely a product of the other three proximate analysis parameters. For log analysis purposes, it could arguably be considered irrelevant whether volatile matter or fixed carbon as the product of the other three parameters, but it is indeed volatile matter that actually 'matters' – and is measured in the laboratory – since it determines the tested coal's rank.

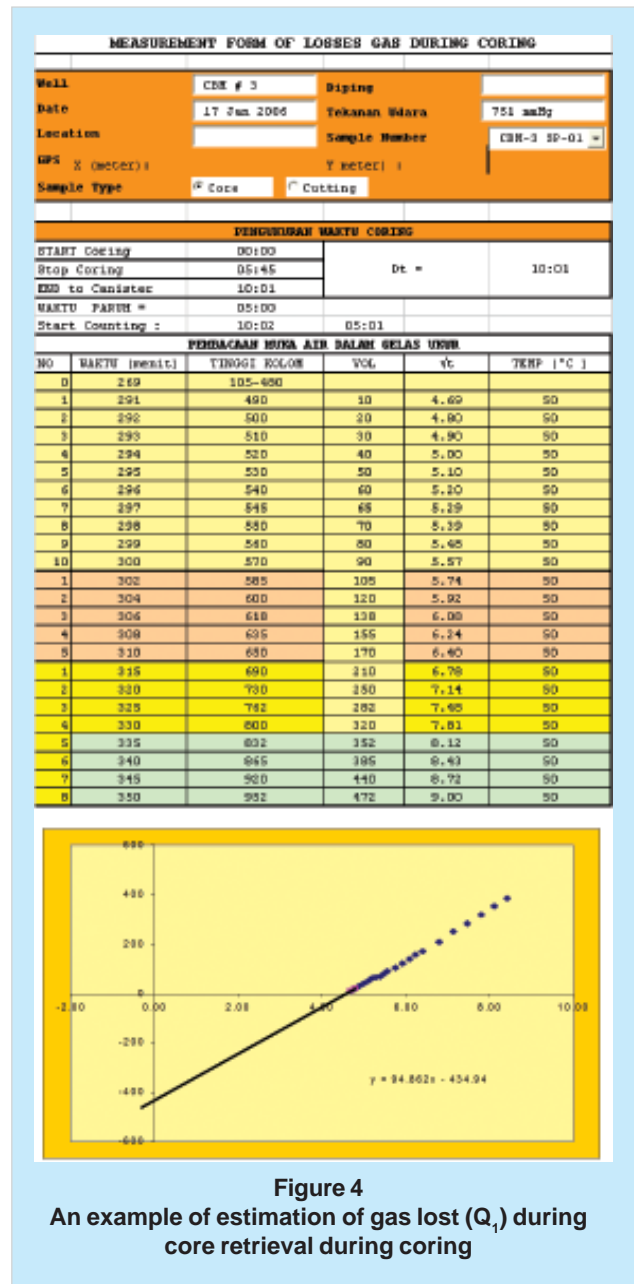


Figure 4

An example of estimation of gas lost (Q_g) during core retrieval during coring

Apart from the above tests, ultimate analysis tests were also carried out to determine the coal's elemental contents and callory values. The resulting data is treated as supplemental information to this study. Main results of the overall laboratory measurements are presented in Table 1.

V. ANALYSIS OF DATA

As in standard activities related to the estimation of CBM accumulation, all laboratory tests on samples in this study were performed under the most representative conditions. As this condition was satisfied

Sampling depth Feet		Air dry basis (A _{db})				As received (A _r)				Bulk density g/cc	Gas Content	
		Moisture (%)	Ash content (%)	Volatile (%)	Fixed carbon (%)	Moisture (%)	Ash content (%)	Volatile (%)	Fixed carbon (%)		cc/gr	SCF/ton
1700.00	- 1700.30	4.370	7.476	54.434	33.721	4.570	7.217	56.921	30.692	1.141	0.174	6.160
1702.50	- 1702.80	4.298	7.402	55.012	33.288	4.491	7.734	57.483	30.292	1.139	0.174	6.160
1704.20	- 1704.50	6.080	6.045	49.577	38.298	6.474	6.437	52.786	34.303	1.119	0.461	16.284
1705.70	- 1705.80	6.120	6.125	48.934	38.821	6.519	6.524	52.124	34.833	1.121	0.461	16.284
1706.10	- 1706.30	1.002	5.490	40.227	53.281	1.012	5.546	40.634	52.808	1.106	0.363	12.827
1707.70	- 1707.90	1.024	5.302	41.021	52.663	1.036	5.367	41.445	52.163	1.112	0.363	12.827
1710.10	- 1710.50	1.556	7.344	40.650	50.449	1.581	7.460	41.293	49.666	1.135	0.170	5.999
1711.50	- 1711.60	1.476	7.428	39.735	51.361	1.498	7.539	40.330	50.632	1.129	0.170	5.999
1713.65	- 1713.10	1.033	6.387	42.613	49.967	1.044	6.453	43.068	49.445	1.120	0.131	4.619
1714.20	- 1714.40	1.124	6.213	43.028	49.635	1.137	6.284	43.517	49.062	1.119	0.131	4.619
1716.50	- 1716.60	1.004	6.075	43.864	49.057	1.014	6.137	44.309	48.540	1.115	0.131	4.638
1717.50	- 1717.10	1.119	6.185	42.997	49.699	1.132	6.255	43.484	49.130	1.128	0.131	4.638
1718.70	- 1719.20	1.204	7.515	40.249	51.033	1.218	7.606	40.739	50.436	1.138	0.277	9.768
1720.10	- 1720.30	1.137	7.678	40.987	50.198	1.150	7.766	41.458	49.625	1.142	0.277	9.768
1721.30	- 1721.40	1.307	8.127	43.772	46.793	1.325	8.235	44.352	46.088	1.148	0.182	6.443
1722.90	- 1723.30	1.298	8.298	42.998	47.406	1.315	8.407	43.563	46.714	1.139	0.182	6.443
1724.10	- 1724.20	1.380	9.545	39.641	49.433	1.400	9.678	40.196	48.726	1.168	0.283	9.992
1725.10	- 1725.50	1.456	9.908	38.807	49.829	1.478	10.054	39.380	49.088	1.173	0.283	9.992
1805.00	- 1805.10	3.620	9.905	40.397	46.079	3.755	10.277	41.914	44.054	1.195	0.706	24.923
1806.60	- 1806.80	6.090	9.288	52.265	32.357	6.485	9.890	55.654	27.970	1.190	0.590	20.852
1808.25	- 1808.30	4.378	5.296	57.838	32.488	4.579	5.538	60.486	29.397	1.118	0.084	2.953
1809.90	- 1809.10	0.938	8.707	56.032	34.323	0.947	8.790	56.562	33.701	1.184	0.284	8.961
1811.50	- 1811.65	15.341	9.052	43.618	31.989	18.121	10.692	51.522	19.665	1.187	0.031	1.082
1814.10	- 1815.15	14.775	6.793	37.248	41.184	17.336	7.970	43.706	30.988	1.142	0.330	11.648
1816.70	- 1816.90	10.148	7.497	45.622	36.734	11.294	8.343	50.774	29.589	1.161	0.084	2.957
1818.70	- 1818.90	8.936	7.502	49.998	33.564	9.813	8.238	54.904	27.045	1.160	0.148	5.211
1820.95	- 1821.10	5.236	6.404	55.361	32.998	5.526	6.758	58.420	29.296	1.139	0.154	5.447
1823.35	- 1823.50	3.608	5.336	54.783	36.273	3.743	5.535	56.834	33.887	1.118	0.576	20.328
1826.50	- 1826.70	2.178	3.514	56.715	37.594	2.227	3.592	57.978	36.204	1.085	0.326	11.502
1829.70	- 1830.00	5.259	7.202	52.306	35.233	5.551	7.602	55.210	31.638	1.154	0.550	19.417
1831.90	- 1832.10	4.839	6.922	53.392	34.847	5.085	7.274	56.107	31.534	1.150	0.010	0.364
1834.20	- 1834.35	15.734	7.472	40.294	36.500	18.671	8.867	47.818	24.644	1.162	0.066	2.328
1836.20	- 1836.40	21.911	5.923	33.999	38.166	28.059	7.586	43.539	20.816	1.132	0.216	7.619
2951.00	- 2951.40	2.110	10.619	46.802	40.468	2.155	10.848	47.811	39.185	1.184	0.702	24.790
2952.30	- 2952.60	2.098	10.702	47.078	40.122	2.143	10.931	48.087	38.839	1.179	0.702	24.790
2953.00	- 2953.20	7.967	5.058	43.456	43.518	8.656	5.496	47.218	38.629	1.096	0.691	24.475
2955.60	- 2955.70	7.896	5.201	41.905	44.998	8.573	5.647	45.497	40.283	1.089	0.691	24.475
2956.00	- 2956.20	2.861	3.577	48.791	44.770	2.945	3.683	50.228	43.144	1.075	0.640	22.606
2957.00	- 2957.30	2.509	3.987	46.988	46.516	2.574	4.090	48.197	45.140	1.081	0.640	22.606
2958.00	- 2958.30	7.169	2.005	47.912	42.915	7.722	2.160	51.612	38.506	1.051	1.239	43.754
2959.70	- 2959.90	7.204	2.109	46.988	43.699	7.763	2.273	50.636	39.328	1.049	1.239	43.754
2960.00	- 2960.30	4.647	2.945	47.528	44.880	4.874	3.089	49.844	42.194	1.066	0.885	30.387
2961.50	- 2961.10	4.599	3.002	46.905	45.494	4.821	3.147	49.166	42.866	1.059	0.885	30.387
2963.00	- 2963.50	4.189	3.376	45.936	46.499	4.372	3.524	47.944	44.160	1.072	0.749	26.471
2964.70	- 2964.10	4.202	3.401	44.687	47.710	4.386	3.550	46.647	45.416	1.097	0.749	26.471
2966.00	- 2966.40	6.562	2.520	48.622	42.296	7.023	2.697	52.037	38.243	1.059	0.583	20.670
2967.20	- 2967.50	6.389	2.704	47.097	43.810	6.825	2.889	50.311	39.975	1.109	0.583	20.670
3038.00	- 3038.30	2.467	14.696	50.502	32.335	2.529	15.067	51.780	30.623	1.253	2.070	73.093
3041.00	- 3041.20	10.592	5.430	41.436	42.542	11.847	6.074	46.345	35.735	1.114	1.188	41.950
3044.00	- 3044.20	2.206	13.007	54.062	30.725	2.256	13.301	55.281	29.162	1.227	0.465	16.413
3048.00	- 3048.50	3.359	7.110	51.171	38.360	3.476	7.367	52.960	36.217	1.134	1.341	47.346
3051.00	- 2051.50	5.012	10.098	45.830	39.060	5.276	10.631	48.248	35.844	1.184	0.410	14.483
3060.00	- 3060.30	5.147	6.407	48.922	39.524	5.426	6.754	51.577	36.243	1.125	1.514	53.468

Table 1
Laboratory measurement data for A and C seams' samples

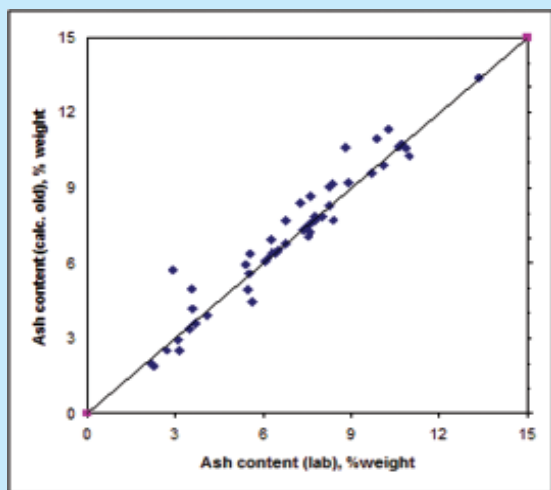


Figure 5
Comparison between measured and calculated ash content (original equation)

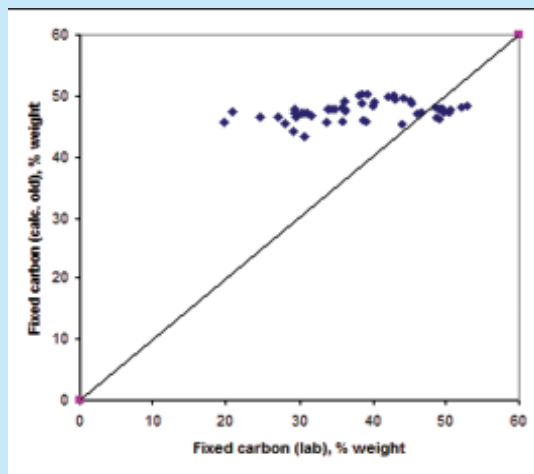


Figure 7
Comparison between measured and calculated fixed carbon (original equation)

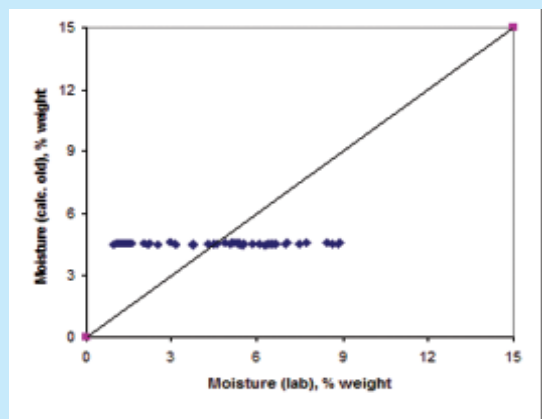


Figure 6
Comparison between measured and calculated moisture content (original equation)

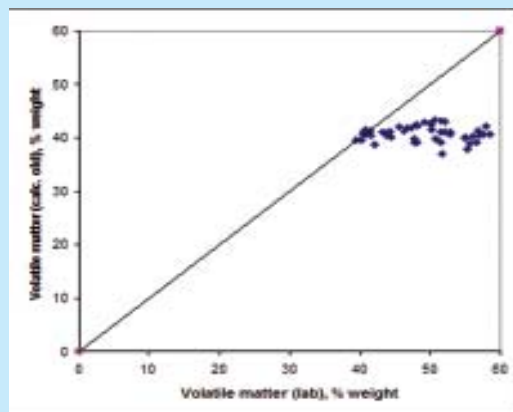


Figure 8
Comparison between measured and calculated volatile matter (original equation)

then the resulting data was valid for comparison to its corresponding log analysis results. Discrepancies between the two data sources were expected but it was hoped that they would still be within an acceptable degree not to lead into a need to modify the existing equations.

Figures 5 through 8 exhibit comparisons between observed (measured) and calculated ash contents, fixed carbon, moisture contents, and volatile matters data for all samples tested. The comparisons have shown that only equation for ash contents (Equation 1) seems to work properly by yielding accurate V_{ash} estimates. Comparisons for the other three show very

significant disagreements, of which calculated data tends to differ much compared to observed data. The use of alternate bulk density from density log did not provide any improvements.

Comparisons between measured (i.e. $Q_1+Q_2+Q_3$) and calculated gas contents were also carried out. Figures 9 through 11 present the comparisons for Modified Kim (1977), Mullen (1989), and Mavor et al. (1990) equations, respectively. From the three comparisons, it is obvious that there is no acceptable degree of accuracy given by the three equations. At this point it is worth emphasizing that the validity of the observed gas contents is very much determined

by the validity of the method for determining Q_1 , the *fast desorption method*.

All comparisons for proximate analysis and gas contents data have proved that the ‘standard’ equations and methods are not applicable for the Rambutan coals. Modifications, even establishments of new equations, upon the ‘standard’ equations are apparently needed if the well log data in the Rambutan field is to remain in use for the assessments of CBM accumulation in the project.

VI. SUGGESTED MODELS

For the proximate analysis tests data, Mullen equations for moisture contents (Equation 2) and fixed carbon (Equation 3) estimation are the ones that need modification. For volatile matter, Equation 4 is certainly in no need for modification but the resulting estimates were later to be compared with observed V_{VM} from laboratory. This additional source of comparison was later to prove useful in providing control during modifications of Equations 2 and 3.

Modifications on Equations 2 and 3 were essentially carried out through a series of trials of alterna-

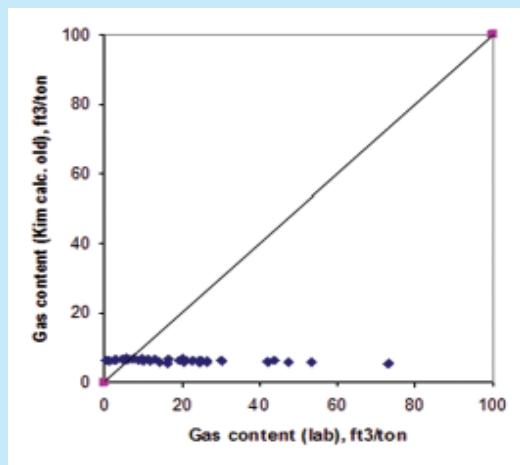


Figure 9
 Comparison between measured and calculated gas content (Mod Kim, original equation)

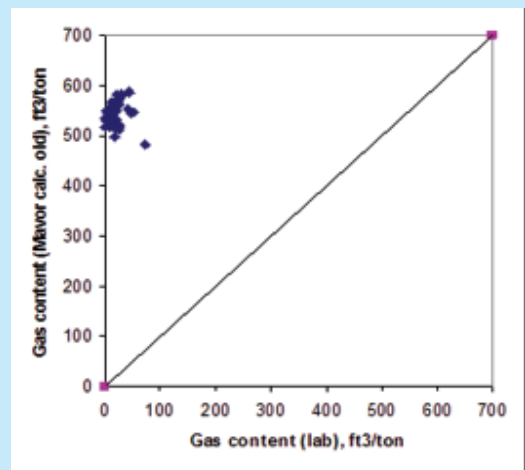


Figure 11
 Comparison between measured and calculated gas content (Mavor et al, original equation)

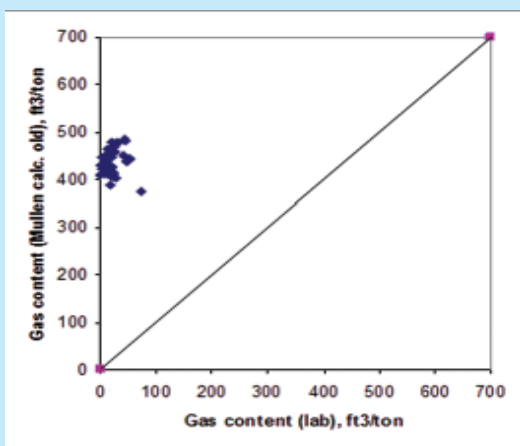


Figure 10
 Comparison between measured and calculated gas content (Mullen, original equation)

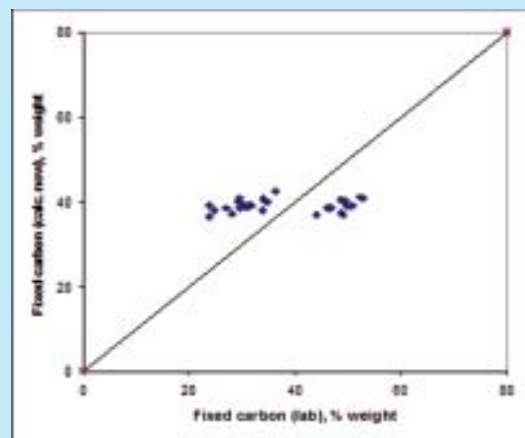


Figure 12
 Comparison between measured and calculated fixed carbon for A seam (modified equation)

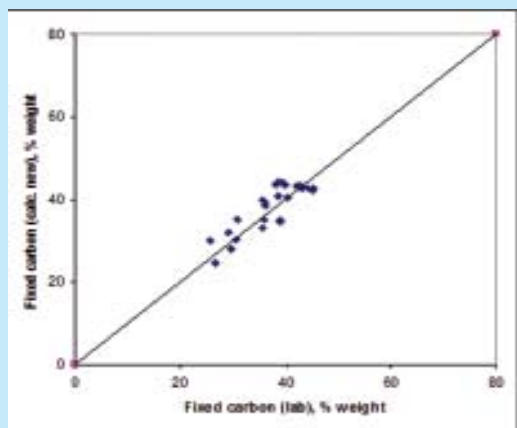


Figure 13
Comparison between measured and calculated fixed carbon for C seam (modified equation)

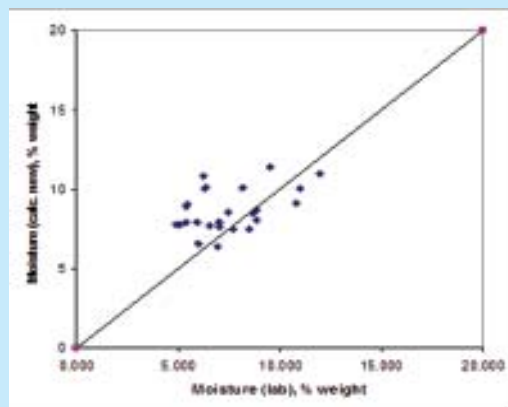


Figure 15
Comparison between measured and calculated moisture content for C seam (modified equation)

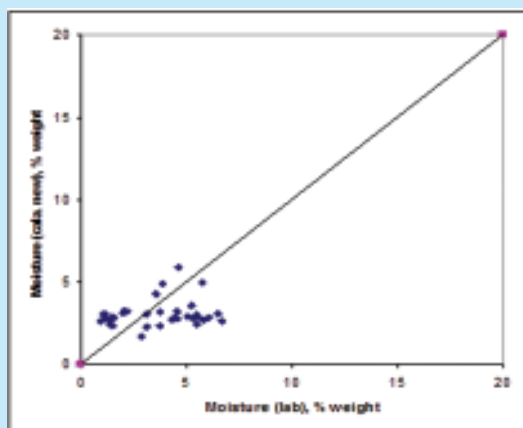


Figure 14
Comparison between measured and calculated moisture content for A seam (modified equation)

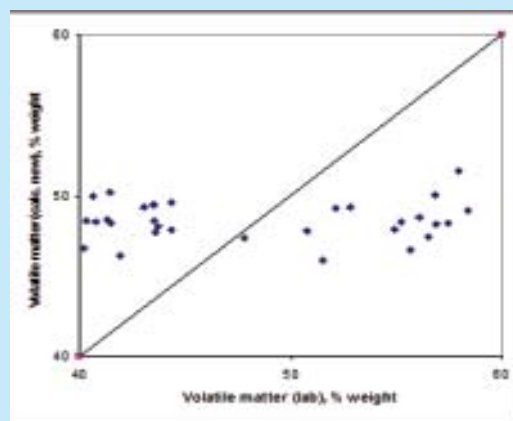


Figure 16
Comparison between measured and calculated volatile matter for A seam (modified equation)

tive pairs of slopes and intercepts. Improvement in agreement between calculated data with observed ones is the prime objective with an acceptable degree of agreement between calculated and observed V_{VM} as the constraint. The most optimum results of the modifications are the adjustments of Equations 2 and 3 into

$$V_{FC} = -0.874 * V_{ash} + 45.8 \text{ (A seam)} \quad (11)$$

$$V_{FC} = -0.094 * V_{ash} + 46.6 \text{ (C seam)} \quad (12)$$

for the fixed carbon equations, and

$$V_M = -0.185 * V_{ash} + 4.26 \text{ (A seam)} \quad (13)$$

$$V_M = -0.302 * V_{ash} + 6.84 \text{ (C seam)} \quad (14)$$

for the moisture contents equations.

Figures 12 through 15 present the comparisons between observed and calculated data produced through the use of Equations 11 through 14. Obvious improvements are apparent when compared to comparisons presented in Figures 6 and 7. Figures 16 and 17 show similar comparison for the resulting volatile matter data obtained using Equation 4. Significant improvement is particularly shown by the comparison in Figure 17 when compared to the old comparison in Figure 8. This underlines the validity of Equations 12 and 14 for Rambutan's C seam.

The comparison in Figure 16 for A seam is indeed less encouraging for the data points are scat-

tered far off the 45 degree line indicating a complete disagreement between calculated and observed V_{VM} . This could be taken as an indication that validity of Equations 11 and 13 are less convincing than Equations 12 and 14. However, when it is considered that the V_{FC} and V_M equations for A seam have gone through calibration using laboratory data, it can arguably be taken that the inconsistency is somewhat caused by non-linearity relationship between the four proximate analysis parameters in A seam coals. Regardless the V_{VM} results, Equations 11 through 14 can safely be considered more valid than Equations 2 and 3 for the Rambutan coals.

For gas contents, similar approaches were also used for the modifications of existing models/equations. This is especially true for Mullen and Mavor et al equations. For Mullen average gas contents equation, Equation 8 becomes

$$V_{av} = 32\rho_b + 10 \quad (15)$$

and the Mavor et al equation becomes

$$V = 81 - 110a_d \quad (16)$$

With V_M data in the a_d resulted from the new Equations 13 and 14. Figures 18 and 19 present comparisons between the new calculated and measured

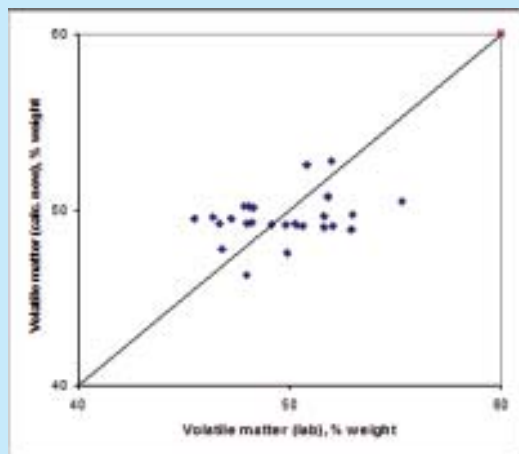


Figure 17

Comparison between measured and calculated volatile matter for C seam (modified equation)

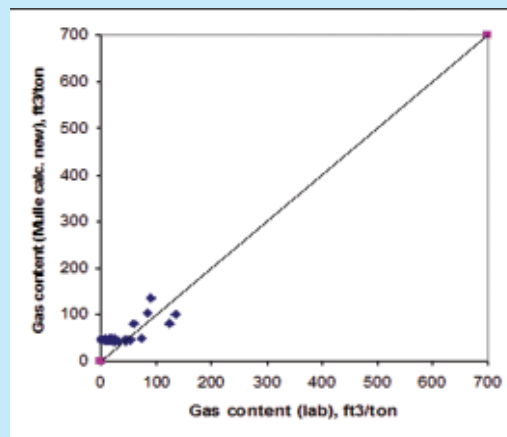


Figure 19

Comparison between measured and calculated gas content (Mavor et al, modified equation)

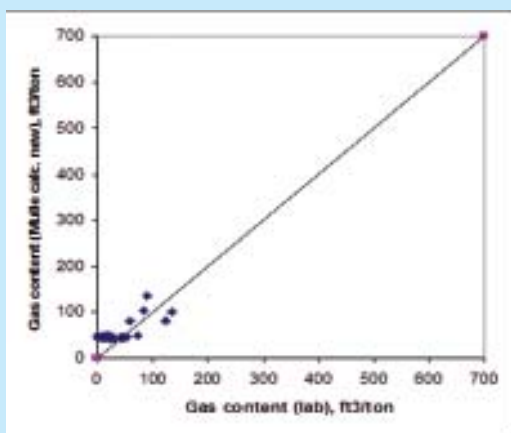


Figure 18

Comparison between measured and calculated gas content (Mullen, modified equation)

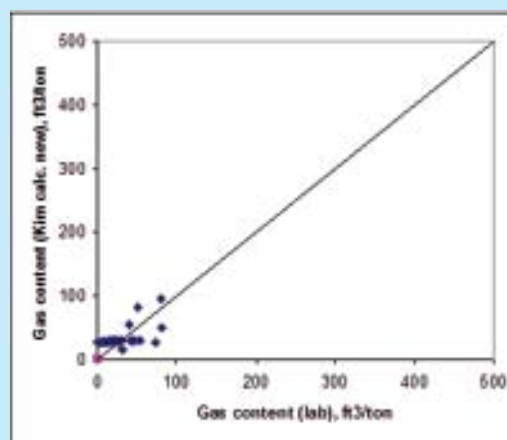


Figure 20

Comparison between measured and calculated gas content (Mod Kim, modified equation)

(i.e. $Q_1+Q_2+Q_3$) gas contents. Better agreement has been achieved when the two equations are used.

For Modified Kim equation, the modification is less simple. Equations 5 through 7 obviously show presence of first and second order variables and constants. From a quick look it is certainly unclear about how the sensitivity trials and adjustments should start from and are focused on. However, provided that the proximate analysis parameters are accepted while expressions of $0.96h$ and $0.14(1.8h/100)$ obviously represent pressure and temperature at depths, respectively, it is variables of k_o and n_o that have to be given attention. Through a series of sensitivity trials the k_o and n_o become

$$k_o = 0.8009 * \left(\frac{V_{FC}}{V_M} \right) + 5.59 \quad (17)$$

$$n_o = 0.390 - 0.015 * \left(\frac{V_{FC}}{V_M} \right) \quad (18)$$

Figure 20 presents a comparison between the new calculated gas contents data and the measured data. The reasonably good agreement show the practical validity of the Modified Kim (1977) equation, but with k_o and n_o represented by Equations 17 and 18, for Rambutan coals, at least for the tested samples. It is well understood that adjustments on the k_o and n_o equations are somewhat subjective and non-unique in nature. Other investigators may have attention and focus given to other aspects within and that are related to Equation 5. A more theoretical approach should be adopted even though the semi-empirical nature of the equation may make the effort very challenging.

VII. CONCLUSIONS

Modified equations from existing proximate analysis and gas contents equations have been established. Despite their varried level of validity, the equations can nevertheless be regarded as more valid for the Rambutan coals. Any future analysis on well log data in Rambutan should use these equations. The use of 'standard' equations that are often still in use for CBM log analysis will yield inaccurate results.

Modifications over the 'standard' equations have reinforced the conviction that different coals should be treated differently in CBM log analysis, even though some sort of groupings in the application may be justified (i.e. different equations for different

groups of coal ranks). The coals in the Rambutan field are of lignite to sub-bituminous(C – B) by rank. Whether the modified equations are valid for all coals belonging to those ranks, it is future and further applications that will prove.

REFERENCES

1. ASTM D 3173 – 00 (2002) "Standard Test Method for Moisture in the Analysis Sample of Coal and Coke". ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428 – 2959 – USA.
2. ASTM D 3174 – 00 (2002) "Standard Test Method for Ash in the Analysis Sample of Coal and Coke from Coal". ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428 – 2959 – USA.
3. ASTM D 3175 – 01 (2002) "Standard Test Method for Volatile Matter in the Analysis Sample of Coal and Coke". ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428 – 2959 – USA.
4. Kim, A.G. (1977). "Estimating Methane Content of Bituminous Coalbeds from Adsorption Data". US Bureau of Mines, Report of Investigations 8245, 22p.
5. Mavor, M.J., Close, J.C. & McBane, R.A. (1990). "Formation Evaluation of Exploration Coalbed Methane Wells". SPE Paper #90-101, presented at the International Technical Meeting, Calgary June 10 – 13.
6. Mullen, M.J. (1989). "Coalbed Methane Resource Evaluation From Wireline Logs in the Northeastern San Juan Basin: A Case Study". SPE Paper #18946, presented at the SPE Joint Rocky Mountain Regional/Low Permeability Reservoirs Symposium and Exhibition, Denver – Colorado, March 6 – 8.
7. Mullen, M.J. (1988). "Log Evaluation in Wells Drilled for Coalbed Methane". Rocky Mountain Association of Geologists, pp 113 – 124.
8. Smith, D.M. & Williams, F.L. (1981). "A New Method for Determining of the Gas Content of Coal: Procedures and Results". U.S. Bureau of Mines Report of Investigations 8515.
9. Suwarna, N & 9 others (2003). "Evaluation of CBM Exploration in South Sumatera, Vol. 1A". (in Bahasa Indonesia), unpublished report, Ministry of Energy and Mineral Resources – The Republic of Indonesia.