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# A CRITICAL ANALYSIS OF GAS DATA IN RELATION TO GAS DRAINABILITY IN THE BULLI SEAM

Lei Zhang<sup>1</sup>, Ting Ren<sup>1</sup>, Naj Aziz<sup>1</sup>, Jan Nemcik<sup>1</sup> and Andrew Hyslop<sup>2</sup>

**ABSTRACT:** To prevent the outburst fatality, outburst threshold limits was established. It is the stipulation of limits on seam gas content prior to mining. The outburst threshold limits varied linearly based on gas composition, increasing from a minimum in CO<sub>2</sub> rich conditions to a maximum in CH<sub>4</sub> rich conditions. It is believed that the gas data of the drainage boreholes are closely related to the gas drainability in Bulli Seam. A total of 519 sample results from Metropolitan mine has been examined. It was found that Q<sub>1</sub>, Q<sub>2</sub> and Q<sub>3</sub> components increased in response to increasing measured total gas content Q<sub>M</sub>. Statistical analysis also shows an increasing trend in the Q<sub>1</sub>:Q<sub>M</sub> and Q<sub>2</sub>:Q<sub>M</sub> ratio corresponding to increased Q<sub>M</sub>, but there was a decrease in trend in the Q<sub>3</sub>:Q<sub>M</sub> ratio corresponding to increased Q<sub>M</sub>. A power relationship was considered to more accurately represent the average of each gas content component relative to Q<sub>M</sub>, especially for "Fail" samples. The average value of CO<sub>2</sub> composition of "Pass" samples is 73.5 % and it was 82.6 % for "Fail" samples. The zone with CH<sub>4</sub>/ (CH<sub>4</sub>+CO<sub>2</sub>) ratio of less than 0.2 includes 171 "Fail" samples, accounting for 88.1 % of total "Fail" samples.

## INTRODUCTION

The generation of coal bed methane during coalification occurs in two ways (Singh and Singh, 1999): (a) metabolic activity of biological agencies (biological process) and (b) thermal cracking of hydrogen-rich substances (thermogenic process). In comparison, gas in Sydney Basin coals has been derived from multiple sources, including (Faiz, *et al.*, 2007): (a) thermogenic CH<sub>4</sub> and higher hydrocarbons formed at deep burial during the Jurassic and Early Cretaceous periods, (b) secondary biogenic CH<sub>4</sub> formed since Late Cretaceous uplift, and (c) CO<sub>2</sub> derived mostly from intermittent igneous activity between the Permian and Tertiary periods. Coal seam gas generally comprises CH<sub>4</sub> with subordinate amounts of CO<sub>2</sub>, C<sub>2</sub>H<sub>6</sub>, higher hydrocarbons (C<sub>2+</sub>) and N<sub>2</sub>. However, in some parts of the Sydney Basin, coals contain over 90% CO<sub>2</sub> and up to 12% C<sub>2</sub>H<sub>6</sub> (Faiz, *et al.*, 2007). Clayton (1998) reviewed the geochemistry of seam gas and listed four sources for CO<sub>2</sub> gas in coal seams: (a) decarboxylation reactions of kerogen and soluble organic matter during burial heating of the coal, (b) mineral reactions such as thermal decomposition or dissolution of carbonates or other metamorphic reactions, (c) bacterial oxidation of organic matter and (d) magmatic intrusion.

Faiz and Hutton (1995) reported variable amounts of CO<sub>2</sub> and CH<sub>4</sub> occurring within the Illawarra Coal Measures. It is believed that the CH<sub>4</sub> and other hydrocarbons present within the Southern Coalfield were formed as by-product of the coalification process and most of the CO<sub>2</sub> was introduced during periodic igneous activity. The variations of CO<sub>2</sub> and CH<sub>4</sub> are mainly related to the geological structure and depth. The variations in the gas composition have no clear relationship with the coal composition or rank but show well-defined relationships with stratigraphy and geological structure. High proportions of CH<sub>4</sub> occur in the synclinal structures whereas the CO<sub>2</sub> content increases towards structural highs. Extensive areas of pure CO<sub>2</sub> gas occur on anticlines and domes. In structural lows, local pockets of high CO<sub>2</sub> concentrations are found near some dykes and related faults. Increasing concentrations of CO<sub>2</sub> also occur in the stratigraphically higher levels. Migration of gases mainly occurred upwards in aqueous solution, down the pressure gradient. During the upward migration of gas-saturated solutions, gas was continually released from the solution due to decreasing pressure. Due to the lower solubility of CH<sub>4</sub> relative to CO<sub>2</sub>, CH<sub>4</sub> was exsolved within the deeper strata whereas increasing amounts of CO<sub>2</sub> being exsolved within the shallower strata. Therefore, in most parts of the Southern Coalfield, increasing amounts of CO<sub>2</sub> gas occur at shallower depths.

High gas content and hence the concentration of methane and carbon dioxide gas typically in close proximity to geological structures, have been identified as a major contributing factor in the coal and gas outburst phenomenon (Lama, 1995). The Bulli seam in Australia, which is located in the southern Sydney Basin, is extremely prone to the occurrence of coal and gas outbursts. Totally 12 lives have been lost as a result of outbursts in the history of mining in the Bulli seam (Harvey and Singh, 1998). As pointed by

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Black (2012), in addition to the explosion and outburst risk, accumulations of methane and carbon dioxide in underground mines may exceed the diluting capacity of the mine ventilation system and hence exceeding prescribed maximum concentration limits. To prevent excessive build up of gas, coal production is required to cease until the gas concentration in the mine ventilation air is reduced below the statutory limit. Operation of the ventilation system alone to manage high gas emission in the gassy mines with highly permeable coal seams may result in frequent and prolonged production delays. In such mines the use of gas drainage is required to assist the mine ventilation system in reducing the coal seam gas content, minimize the risk of a dangerous gas accumulation, reduce the risk of an outburst, improve ventilation air quality, reduce ventilation costs, and ultimately make mining safer and more efficient (Lama, 1980; Kahil and Masszi, 1982; Clark, *et al.*, 1983).

Several mines operating the Bulli seam have coal seam zones which are difficult to drain. Metropolitan Colliery is one of such mines. The mine has experienced difficulties in reducing gas content within the available drainage lead time in an area of MG22, as the coal seam would not drain even with additional drainage boreholes. The Bulli coal seam appears to be CO<sub>2</sub> rich in the concerned area. A research program has been undertaken at the University of Wollongong aimed at: (a) identifying the main reasons for “hard-to-drain” zones in areas between 8-11 c/t of MG 22; (b) establishing the fingerprints of coals that give early warning signs for future drainage process; (c) Coal seam flushing using N<sub>2</sub> gas to drain the coal in the hard-to-drain areas. In order to identify the main reasons for “hard-to-drain” and give early warning signs, the study is currently engaged in examining the field drainage data. This paper provides the latest on the research results of critical analysis of the whole gas data base in this research program.

### BULLI SEAM OUTBURST THRESHOLD LIMITS (TLV) ANALYSIS

As a result of the investigation into the last fatal Bulli seam outburst at West Cliff Colliery on 25 January 1994, a directive was issued to all Bulli seam coal mine operators, under the authority of the Coal Mines Regulation Act 1982, prescribing Threshold Limit Values (TLV), among with other actions, to be implemented to prevent future coal and gas outbursts (Clarke, 1994; NSWDMR, 1995; Black, 2012). The TLV represent the maximum allowable gas content, relative to seam gas composition, considered safe for mine operations. Mine operators are required to ensure seam gas content has been reduced below the applicable TLV prior to mining. The outburst threshold limits varied linearly based on gas composition, increasing from a minimum in CO<sub>2</sub> rich conditions to a maximum in CH<sub>4</sub> rich conditions. According to the test results from BHP Gas Lab, the whole database of Metropolitan Colliery containing totally 519 sample results was studied. From the mining level values in the database, the threshold limits was generated. As shown in Figure 1, the gas content was 6.0 m<sup>3</sup>/t for pure CO<sub>2</sub> and 9.5 m<sup>3</sup>/t for pure CH<sub>4</sub>. Thus the test gas content for coal sample is under this TLV limit, accordingly the tested samples will be marked as “Pass”, if they are under the TLV limit, otherwise it will be marked as “Fail”.

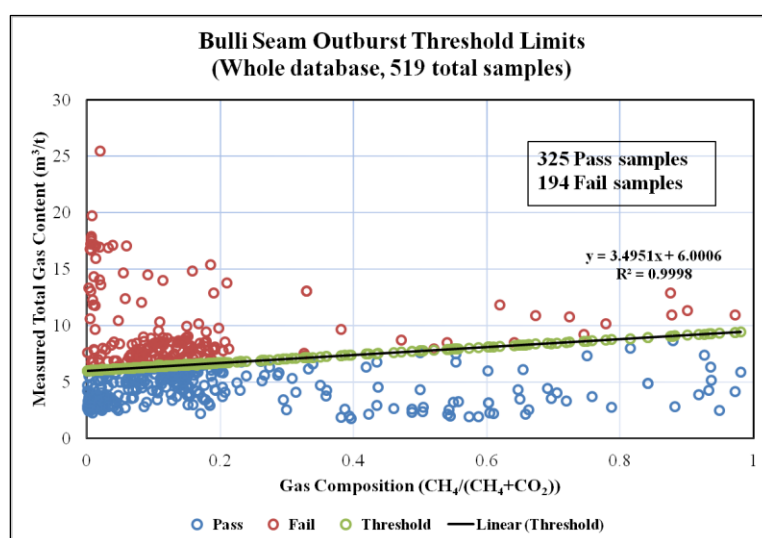


Figure 1 - Bulli Seam outburst threshold limits (whole data base)

Figure 1 shows the whole gas composition data scatter, ranging from CO<sub>2</sub> rich to CH<sub>4</sub> rich area. From 519 samples tested, 325 samples are “Pass” samples, accounting for 62.6 %, while 194 samples are “Fail” samples, accounting for 37.4 %. The value of total gas content of “Fail” samples ranges from 6.14 m<sup>3</sup>/t to

25.44 m<sup>3</sup>/t. The average value of measured total gas content  $Q_M$  of "Pass" samples is 4.4 m<sup>3</sup>/t and 9.2 m<sup>3</sup>/t for "Fail" samples. The average value of CH<sub>4</sub> concentration of "Pass" samples is 17.1 % and 14.0 % for "Fail" samples, while the average value of CO<sub>2</sub> concentration of "Pass" samples is 73.5 % and 82.6 % for "Fail" samples, which indicates the seam of this area is CO<sub>2</sub> rich condition. The zone of gas composition CH<sub>4</sub>/(CH<sub>4</sub>+CO<sub>2</sub>) less than 0.2 includes 171 "Fail" samples, accounting for 88.1 % of total "Fail" samples. Including the "Pass" samples, 41.0 % of samples in the zone of gas composition CH<sub>4</sub>/(CH<sub>4</sub>+CO<sub>2</sub>) less than 0.2 are failed, compared with 22.5 % in the gas composition zone CH<sub>4</sub>/(CH<sub>4</sub>+CO<sub>2</sub>) more than 0.2.

### Q<sub>1</sub> GAS CONTENT COMPONENT ANALYSIS

The Q<sub>1</sub> component of measured total gas content ( $Q_M$ ) represents the gas lost from a coal sample, during core recovery stage and prior to being sealed in a gas desorption canister. Figure 2a shows the distribution of Q<sub>1</sub> gas content data relative to  $Q_M$ . The average Q<sub>1</sub> gas content is 0.5 m<sup>3</sup>/t for the whole database, 0.2 m<sup>3</sup>/t for "Pass" samples and 1.0 m<sup>3</sup>/t for "Fail" samples. Q<sub>1</sub> increased in response to increasing  $Q_M$ . Figure 2b shows the distribution of Q<sub>1</sub>: $Q_M$  ratio data relative to  $Q_M$ . Although a high degree of scatter was evident, the statistical analysis confirmed an increase in the Q<sub>1</sub>: $Q_M$  ratio corresponding to increased  $Q_M$ . The average Q<sub>1</sub>: $Q_M$  ratio is 6.0 % for the whole database, 4.0 % for "Pass" samples and 9.5 % for "Fail" samples.

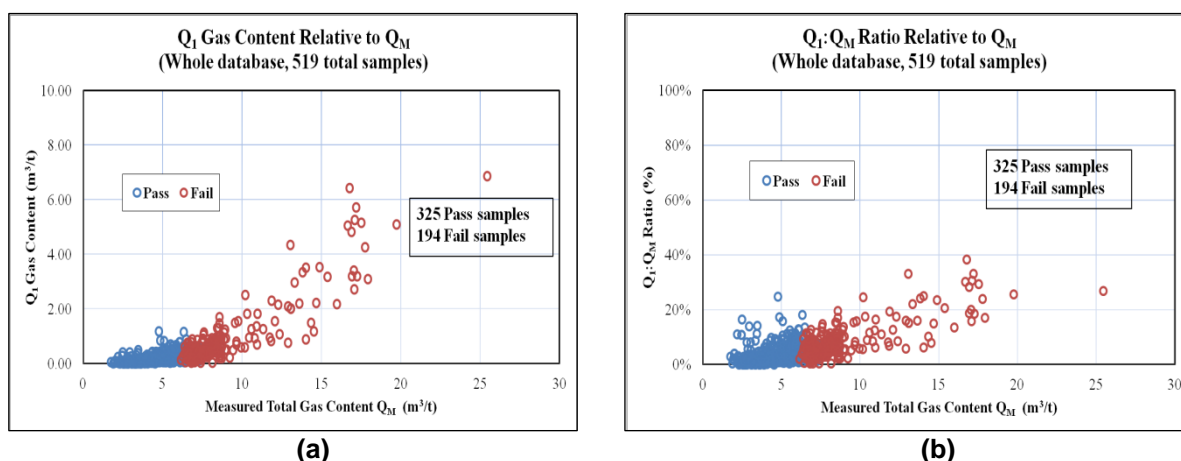


Figure 2 - Distribution of Q<sub>1</sub> gas content and Q<sub>1</sub>: $Q_M$  ratio relative to  $Q_M$  (whole data base)

Figure 3a shows the distribution of Q<sub>1</sub> data relative to the gas composition (CH<sub>4</sub> %) of each sample. In the 0-20 % CH<sub>4</sub> gas composition zone, the average Q<sub>1</sub> gas content is 0.6 m<sup>3</sup>/t for all the samples, 0.2 m<sup>3</sup>/t for "Pass" samples and 1.1 m<sup>3</sup>/t for "Fail" samples, while in the 20-80 % CH<sub>4</sub> gas composition zone the average Q<sub>1</sub> gas content is 0.3 m<sup>3</sup>/t for all the samples, 0.2 m<sup>3</sup>/t for "Pass" samples and 0.9 m<sup>3</sup>/t for "Fail" samples. Figure 3b shows the distribution of the Q<sub>1</sub>: $Q_M$  ratio data relative to gas composition. In the 0-20 % CH<sub>4</sub> gas composition zone the average Q<sub>1</sub>: $Q_M$  ratio is 6.3 % for all the samples, 4.1 % for "Pass" samples and 9.5 % for "Fail" samples, while in the 20-80 % CH<sub>4</sub> gas composition zone the average ratio is 4.7 % for all the samples, 3.5 % for "Pass" samples and 8.7 % for "Fail" samples.

### Q<sub>2</sub> GAS CONTENT COMPONENT ANALYSIS

The Q<sub>2</sub> component of measured total gas content ( $Q_M$ ) represents the measurable gas desorbed from as-received coal sample during the laboratory gas emission testing at atmospheric pressure. Figure 4a shows the distribution of Q<sub>2</sub> gas content data relative to  $Q_M$ . The average Q<sub>2</sub> gas content is 1.2 m<sup>3</sup>/t for the whole database, 0.6 m<sup>3</sup>/t for "Pass" samples and 2.2 m<sup>3</sup>/t for "Fail" samples. Q<sub>2</sub> increased in response to increasing  $Q_M$ . Figure 4b shows the distribution of Q<sub>2</sub>: $Q_M$  ratio data relative to  $Q_M$ . Although a high degree of scatter was evident, statistical analysis confirmed an increase in the Q<sub>2</sub>: $Q_M$  ratio corresponding to increased  $Q_M$ . The average Q<sub>2</sub>: $Q_M$  ratio is 17.1 % for the whole database, 14.1 % for "Pass" samples and 22.0 % for "Fail" samples.

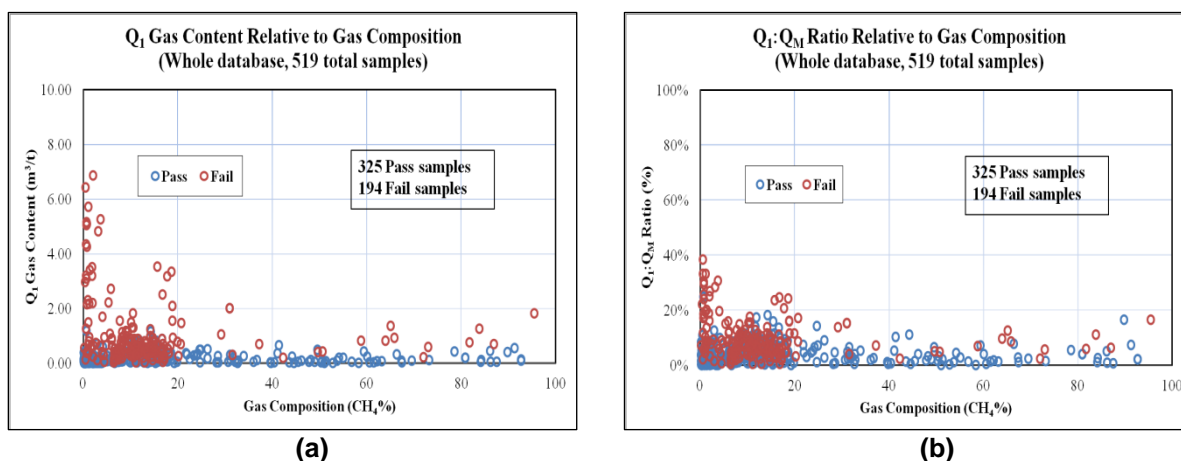


Figure 3 - Distribution of  $Q_1$  gas content and  $Q_1:Q_M$  ratio relative to gas composition (whole data base)

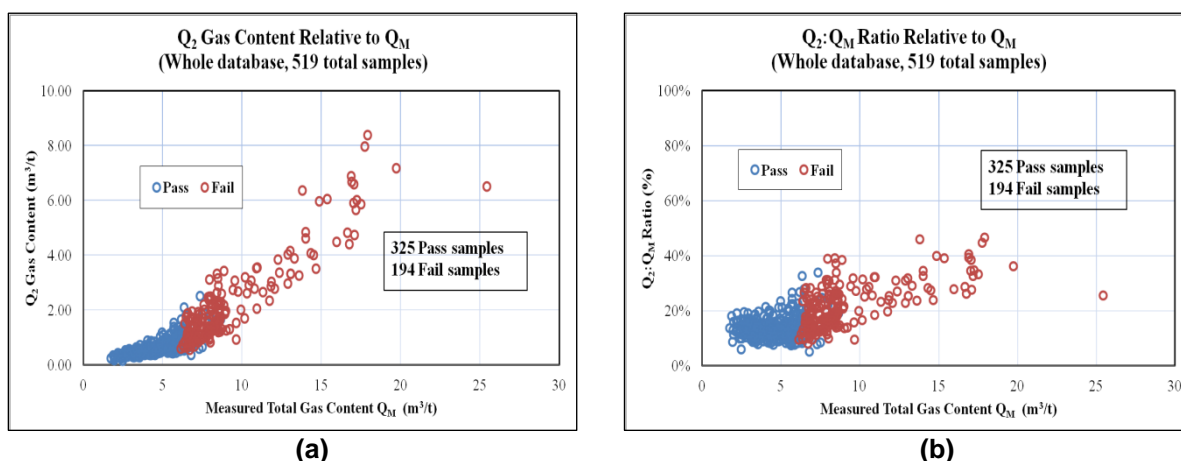


Figure 4 - Distribution of  $Q_2$  gas content and  $Q_2:Q_M$  ratio relative to  $Q_M$  (whole data base)

Figure 5a shows the distribution of  $Q_2$  data relative to the gas composition (CH<sub>4</sub> %) of each sample. In the 0-20 % CH<sub>4</sub> gas composition zone the average  $Q_2$  gas content is 1.3 m<sup>3</sup>/t for all the samples, 0.6 m<sup>3</sup>/t for "Pass" samples and 2.2 m<sup>3</sup>/t for "Fail" samples, while in the 20-80 % CH<sub>4</sub> gas composition zone the average  $Q_2$  gas content is 0.9 m<sup>3</sup>/t for all the samples, 0.6 m<sup>3</sup>/t for "Pass" samples and 2.1 m<sup>3</sup>/t for "Fail" samples. Figure 5b shows the distribution of the  $Q_2:Q_M$  ratio data relative to gas composition. In the 0-20 % CH<sub>4</sub> gas composition zone the average  $Q_2:Q_M$  ratio is 17.5 % for all the samples, 14.3 % for "Pass" samples and 22.2 % for "Fail" samples, while in the 20-80 % CH<sub>4</sub> gas composition zone the average  $Q_2:Q_M$  ratio is 15.1 % for all the samples, 13.5 % for "Pass" samples and 20.7 % for "Fail" samples.

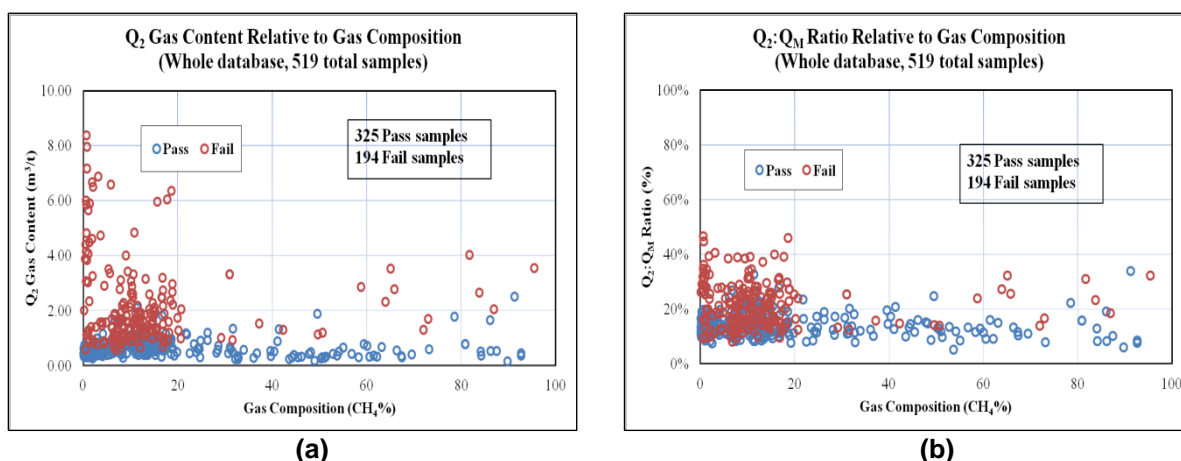


Figure 5 - Distribution of  $Q_2$  gas content and  $Q_2:Q_M$  ratio relative to gas composition (whole data base)

### Q<sub>3</sub> GAS CONTENT COMPONENT ANALYSIS

The Q<sub>3</sub> component of measured total gas content (Q<sub>M</sub>) represents the gas released from a coal sample following crushing to less than 212  $\mu\text{m}$ . Figure 6a shows the distribution of Q<sub>3</sub> gas content data relative to Q<sub>M</sub>. The average of Q<sub>3</sub> gas content is 4.5 m<sup>3</sup>/t for the whole database, 3.6 m<sup>3</sup>/t for "Pass" samples and 6.0 m<sup>3</sup>/t for "Fail" samples. Q<sub>3</sub> increased in response to increasing Q<sub>M</sub>. Figure 4b shows the distribution of Q<sub>3</sub>:Q<sub>M</sub> ratio data relative to Q<sub>M</sub>. Although a high degree of scatter was evident, statistical analysis confirmed a decrease in the Q<sub>3</sub>:Q<sub>M</sub> ratio, corresponding to increased Q<sub>M</sub>. The average Q<sub>3</sub>:Q<sub>M</sub> ratio is 76.9 % for the whole database, 81.9 % for "Pass" samples and 68.5 % for "Fail" samples.

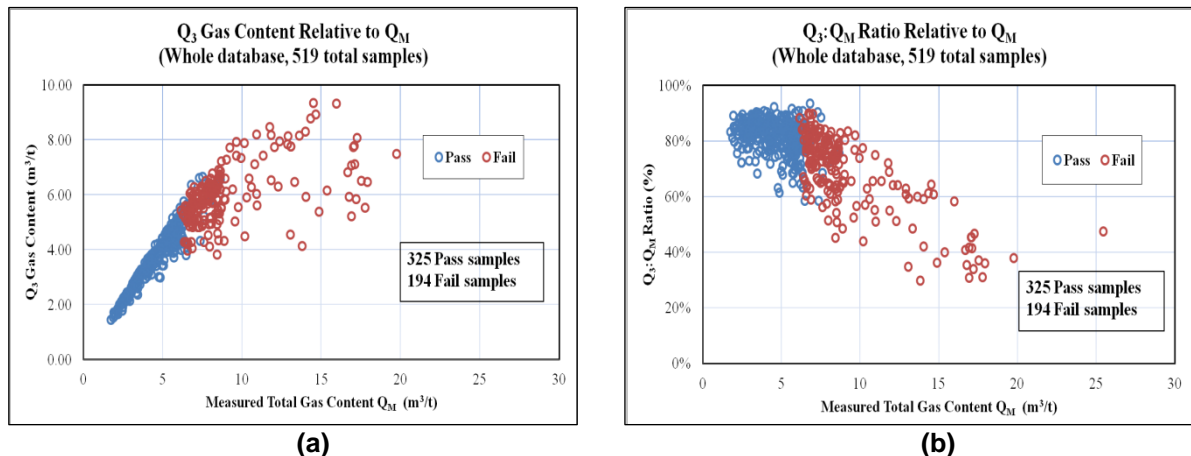


Figure 6 - Distribution of Q<sub>3</sub> gas content and Q<sub>3</sub>:Q<sub>M</sub> ratio relative to Q<sub>M</sub> (whole data base)

Figure 7a shows the distribution of Q<sub>3</sub> data relative to the gas composition (CH<sub>4</sub> %) of each sample. In the 0-20 % CH<sub>4</sub> gas composition zone the average Q<sub>3</sub> gas content is 4.5 m<sup>3</sup>/t for all the samples, 3.6 m<sup>3</sup>/t for "Pass" samples and 5.9 m<sup>3</sup>/t for "Fail" samples, while in the 20-80 % CH<sub>4</sub> gas composition zone the average Q<sub>3</sub> gas content is 4.3 m<sup>3</sup>/t for all the samples, 3.5 m<sup>3</sup>/t for "Pass" samples and 6.9 m<sup>3</sup>/t for "Fail" samples. Figure 7b shows the distribution of the Q<sub>3</sub>:Q<sub>M</sub> ratio data relative to gas composition. In the 0-20 % CH<sub>4</sub> gas composition zone the average Q<sub>3</sub>:Q<sub>M</sub> ratio is 76.2 % for all the samples, 81.6 % for "Pass" samples and 68.3 % for "Fail" samples, while in the 20-80 % CH<sub>4</sub> gas composition zone the average Q<sub>3</sub>:Q<sub>M</sub> ratio is 80.2 % for all the samples, 83.0 % for "Pass" samples and 70.6 % for "Fail" samples.

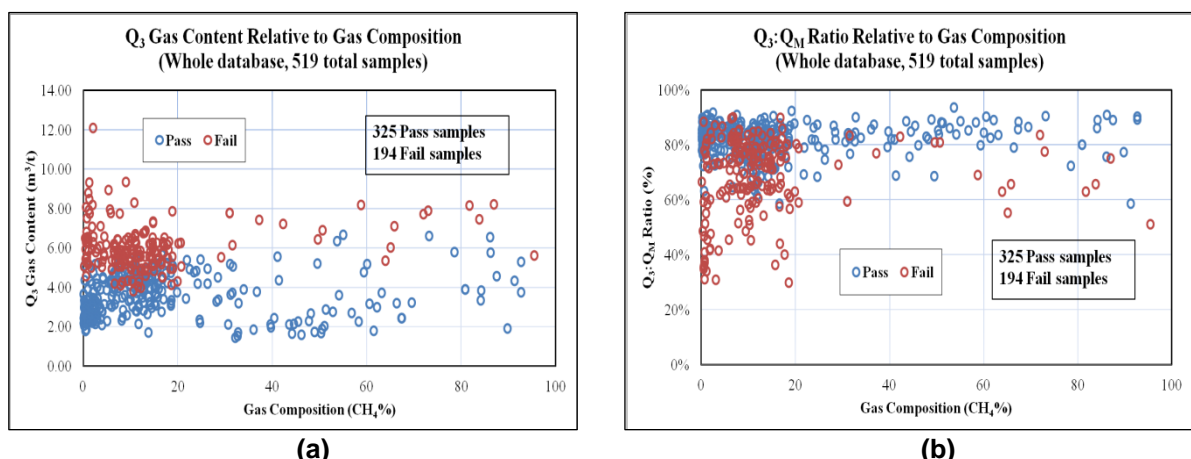


Figure 7 - Distribution of Q<sub>3</sub> gas content and Q<sub>3</sub>:Q<sub>M</sub> ratio relative to gas composition (whole data base)

### COMBINED GAS CONTENT COMPONENTS ANALYSIS

Figure 8 shows the results of the gas content component values Q<sub>1</sub>, Q<sub>2</sub> and Q<sub>3</sub>, plotted relative to Q<sub>M</sub> for each sample of whole database. A linear trend line was plotted to represent the average relationship of each gas content component relative to Q<sub>M</sub>. As shown in Figure 8a, for "Pass" samples, Q<sub>1</sub> = 0.047Q<sub>M</sub>, Q<sub>2</sub> = 0.1469Q<sub>M</sub> and Q<sub>3</sub> = 0.8062Q<sub>M</sub>. The statistical correlation is greater for Q<sub>3</sub> gas component, which indicates a better linear relationship between Q<sub>3</sub> and Q<sub>M</sub> for "Pass" samples. As shown in Figure 8b, for



"Fail" samples,  $Q_1 = 0.1384Q_M$ ,  $Q_2 = 0.2599Q_M$  and  $Q_3 = 0.6017Q_M$ . The statistical correlation is small for  $Q_3$  gas component, which indicates a non linear relationship between  $Q_3$  and  $Q_M$  for "Fail" samples.

Figure 9 shows the results of the gas content component values,  $Q_1$ ,  $Q_2$  and  $Q_3$ , plotted relative to  $Q_M$  for each sample with the power trend line. As shown in Figure 9a, for "Pass" samples,  $Q_1 = 0.0029Q_M^{2.4819}$ ,  $Q_2 = 0.1172Q_M^{1.1046}$  and  $Q_3 = 0.9102Q_M^{0.9241}$ . For "Fail" samples, shown in Figure 9b,  $Q_1 = 0.0017Q_M^{2.7218}$ ,  $Q_2 = 0.0365Q_M^{1.7947}$  and  $Q_3 = 2.642Q_M^{0.3686}$ . The statistical correlation is greater for power trend line than linear trend line, which indicates a power relationship was considered to more accurately represent the average of each gas content component relative to  $Q_M$ . Figure 9b shows gas content of  $Q_1$  and  $Q_2$  gas component increase sharply with the increasing total gas content  $Q_M$ .

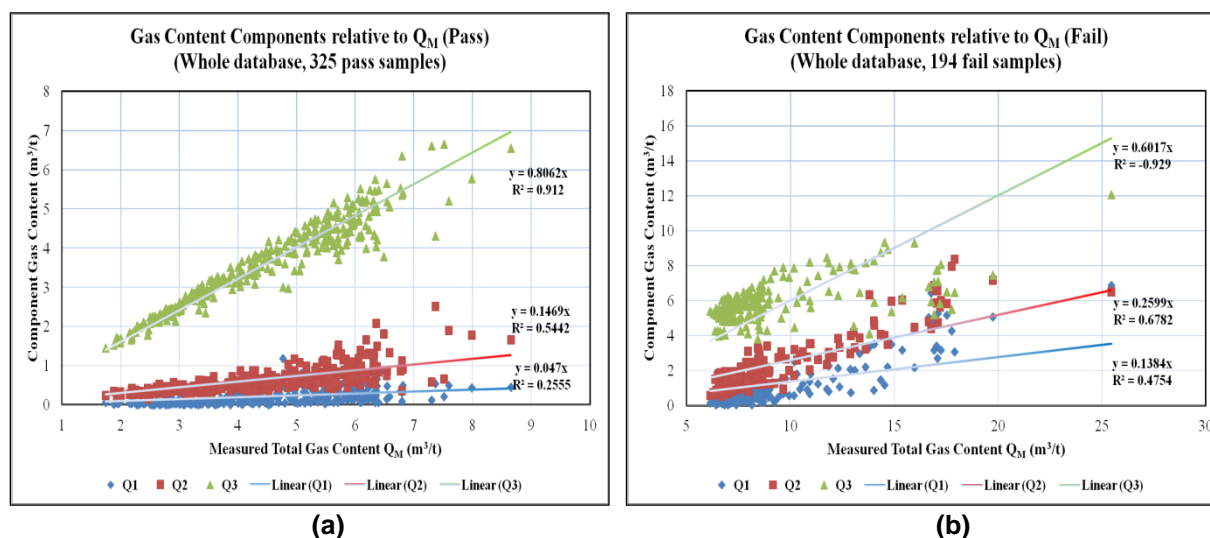


Figure 8 - Gas content component relative to  $Q_M$  (whole data base, linear relationship)

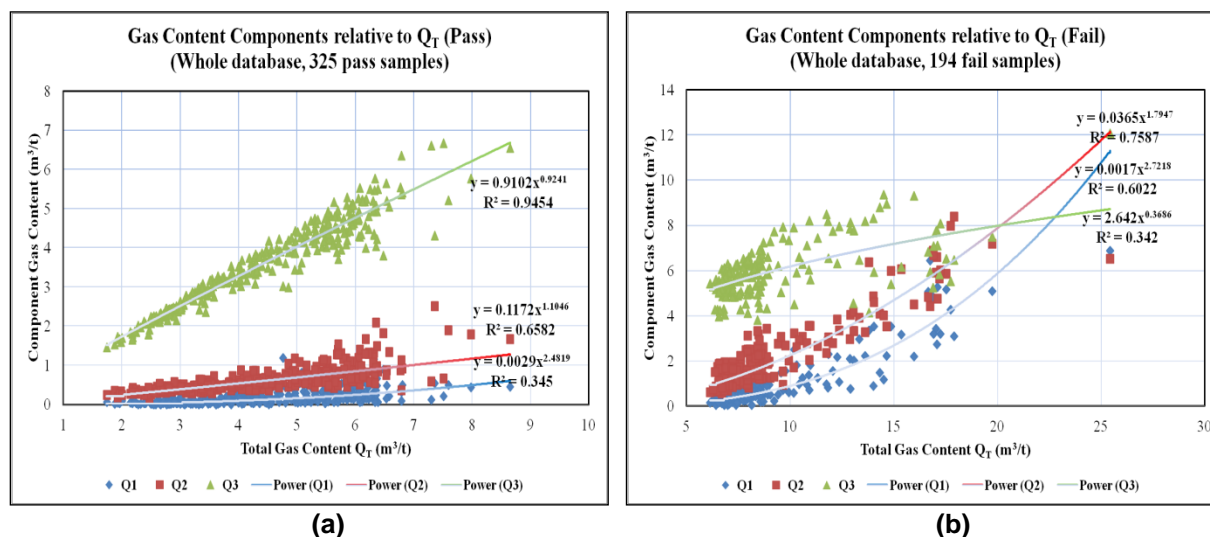


Figure 9 - Gas content component relative to  $Q_M$  (whole data base, power relationship)

## CONCLUSIONS

An analysis of the whole gas database found that the  $Q_1$ ,  $Q_2$  and  $Q_3$  components increased in response to increasing measured total gas content  $Q_M$ . Statistical analysis also shows an increase trend in the  $Q_1:Q_M$  and  $Q_2:Q_M$  ratio corresponding to increased  $Q_M$ , but an decrease trend in the  $Q_3:Q_M$  ratio corresponding to increased  $Q_M$ . No clear correlation was found between the gas components and their ratio corresponding to the gas composition. Because of the seam is  $CO_2$  rich, the samples are mainly located in areas with less than 20 %  $CH_4$ .

It can be concluded that, a linear trend line can be fitted to represent the average relationship of each gas content component relative to  $Q_M$  of the whole gas database as well as typical hard-to-drain area. The statistical correlation shows a better linear trend line fitting for "Pass" samples than "Fail" samples

especially  $Q_3$  gas component. A power relationship was considered to more accurately represent the average of each gas content component relative to  $Q_M$ , especially for "Fail" samples. Analysis also shows that  $Q_1$  and  $Q_2$  gas component increased more sharply than  $Q_3$  with the increase of  $Q_M$ , especially for "Fail" samples.

The whole database contains 519 samples, from  $CO_2$  rich to  $CH_4$  rich area. The average value of  $CO_2$  composition of "Pass" samples is 73.5 % and 82.6 % for "Fail" samples. The zone with  $CH_4/(CH_4+CO_2)$  ratio less than 0.2 includes 171 "Fail" samples, accounting for 88.1 % of total "Fail" samples. Including the "Pass" samples, 41.0 % of samples in the zone with  $CH_4/(CH_4+CO_2)$  ratio less than 0.2 are failed, compared with 22.5 % when in the zone with  $CH_4/(CH_4+CO_2)$  ratio greater than 0.2.

## ACKNOWLEDGMENT

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