# ANALYTICAL REPORT

## METHANE AND CARBON DIOXIDE ADSORPTION ISOTHERMS

## LAST CHANCE #3

## PREPARED FOR GASSY COAL COMPANY NL

**APRIL 2050**

Energy Resources Consulting Pty Ltd
PO Box 54
Coorparoo, Qld 4151
Australia

# ADSORPTION ISOTHERM ANALYSIS

## INTRODUCTION

Twelve samples were received from the Gassy Coal Company NL Last Chance #3 well (see table below) to be evaluated for adsorption isotherm properties (composites only), vitrinite reflectance (composites only) and maceral content (all samples). Adsorption isotherm data are reported herein.

Last Chance #3 Work Programme

| Sample No. | From (m) | To (m) | Mass (g) | Isotherm No. | Temp. (°C) | Gases | | | | | Petrographics | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | $CH_4$ | $C_2H_4$ | $C_3H_6$ | $N_2$ | $CO_2$ | Maceral | Reflectance |
| A | 526.04 | 526.78 | 2616 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | Y | N |
| B | 557.43 | 557.81 | 4040 | Iso. 1 | 54.5 | Y | N | N | N | Y | Y | Y |
| C | 558.91 | 559.77 | 3324 | | | | | | | | | |
| D | 563.64 | 564.02 | 2456 | | | | | | | | | |
| E | 565.96 | 566.91 | 3442 | | | | | | | | | |
| F | 569.41 | 570.36 | 3134 | | | | | | | | | |
| G | 619.48 | 619.83 | 1930 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | Y | N |
| H | 620.12 | 621.03 | 1342 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | Y | N |
| I | 621.36 | 622.29 | 3702 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | Y | N |
| J | 652.08 | 653.05 | 3602 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | Y | N |
| K | 663.83 | 664.33 | 2518 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | Y | N |
| L | 667.93 | 668.43 | 2054 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | Y | N |

## ADSORPTION ISOTHERMS

### Sample Preparation

Individual samples were received as -6 mm coal which had been crushed elsewhere. Approximately 200 g of each sample was received. Composites were made by weighting each sample by mass of coal before combining the individual samples to produce a composite of total weight of 150 g. This 150 g sample was sub-sampled to obtain around 25 g for petrographic analysis. The remaining sample was then crushed to less than 0.212 mm and brought to an equilibrium moist state (AS 1038.17-1989) for methane adsorption isotherm analysis.

### Moisture Content and Ash Yield

Equilibrium moisture content, ash yield and helium density (for evaluation of dead volume of the system) were determined prior to methane adsorption isotherm analysis.

Moisture content was determined by weighing approximately 0.5 to 1 g of coal in a 4 digit balance (i.e to 0.1 mg), heating it to 110 °C in a nitrogen atmosphere, and then re-weighing the dry sample. The method is similar to AS1038.3-1989 "Methods for the analysis and testing of coal and coke. Part 3: Proximate analysis of higher rank coal."

Ash yield was determined on dry coal by weighing approximately 0.5 to 1 g of dry coal in a 4 digit balance (i.e. to 0.1 mg), heating it to 500 °C and holding it there for one hour and then raising the heat to 815 °C and maintaining this for a further one hour. The ash yield is then determined following re-weighing at room temperature. The method is similar to AS1038.3-1989 "Methods for the analysis and testing of coal and coke. Part 3: Proximate analysis of higher rank coal."

**Adsorption Isotherm**

Adsorption isotherm determination used at least nine pressure steps up to a maximum pressure of around 8 MPa (1160 psia) where the coals are at 800 m or shallower and additional pressure steps may be used for deeper coals. Analysis was performed as close as possible to formation temperature as advised. The procedure is detailed as follows:

1. adsorption isotherm cells are weighed
2. the equilibrium moist coal is placed in the cells and the cells weighed
3. the cells are evacuated and weighed
4. helium is introduced into the cells at pressures of approximately 2, 4, 6 and 8 MPa; this data is used to calculate the free volume of the cells and consequently the helium density of the coal
5. the cells are evacuated
6. a fixed volume of methane is introduced into the cell and the pressure monitored to the nearest 1 kPa until there is no change in pressure for a period of at least one hour
7. the adsorption is determined
8. steps 6 and 7 are repeated for each pressure step

Pressure steps for test gases are nominally at 250, 500, 1000, 2000, 3000, 4000, 6000 and 8000 kPa but may vary according to gas and sample depth. A test pressure of 8000 kPa is equivalent to approximately 800m hydrostatic depth.

**Note** Samples are retained by Energy Resources Consulting Pty Ltd for a period of 12 months following the reporting date. They may be discarded after this time.

## RESULTS

Adsorption isotherm results are tabulated and presented graphically as follows. Results are also provided as Excel spread sheet data.

Absolute adsorption isotherms are calculated. Results are presented at standardised conditions of 20°C and 1 atmosphere (101.3 kPa) pressure per gram of coal (which is equivalent to $m^3/t$) as well as in standard cubic feet (scf) at 60 °F and 1 atmosphere (14.7psia) per short ton (2000 lb) of coal.

Gibbs (excess) adsorption and other reporting bases (pressure / temperature) or as mmol/g can also be reported on reported on request.

### Single Gas Adsorption Isotherm Modelling

Single gas adsorption isotherms are modelled according to Langmuir for both as analysed and daf (dry, ash free) bases:

$$V = \frac{V_L P}{(P + P_L)}$$

where V = volume adsorbed
P = pressure
$V_L$ = Langmuir volume constant
$P_L$ = Langmuir pressure constant

Data is presented graphically as both the Langmuir plot and as a plot of P versus P/V which shows the goodness of fit of the data to the model.

### Extended Langmuir Modelling for Gas Mixtures

Both methane and carbon dioxide adsorption isotherms were determined. The adsorption isotherm of gas mixtures can be assessed using the extended Langmuir model:

$$V_i = \frac{V_{Li} P y_i}{P_{Li}\left(1 + \sum_{j=1}^{n} \frac{1}{P_{Lj}} y_j P\right)}$$

where :
$V_i$ = storage capacity of component i (cc/g or $m^3/t$ or scft/t)
$P_{Li}$ = Langmuir pressure of the ith phase obtained from the single component data
$V_{Li}$ = Langmuir volume of the ith phase obtained from the single component data
P = pressure ( kPa or psi)
$y_i$ = the mole fraction of species i in the free gas phase
n = number of components

This modelling has been carried out for a mixture of $CH_4$:$CO_2$ = 50:50 for the free gas phase.

**Other Adsorption Isotherm Models**

BET, Dubinin-Radushkevich (DR) and Dubinin-Astakhov (DA) modelling may also be undertaken:

BET:
$$\frac{1}{V\left\{\left(\frac{p^0}{p}\right)-1\right\}} = \frac{1}{V_m C} + \frac{(C-1)P}{V_m C p^0}$$

Dubinin-Radushkevich (DR):
$$\log V = \log V_0 - D\left[\log\left(\frac{p^0}{p}\right)\right]^2$$

Dubinin-Astakhov (DA):
$$\log V = \log V_0 - D\left[\log\left(\frac{p^0}{p}\right)\right]^n$$

Constants calculated for these models are tabulated.

**Methane ($CH_4$) Adsorption**

| | |
|---|---|
| **Client** | Gassy Coal Company NL |
| **Sample Details** | Last Chance #3 - Iso 1 (557.43 - 570.36 m) |

**Sample Properties**

| | | | |
|---|---|---|---|
| Inherent Moisture (%, ad) | 0.7 | Isotherm Sample Mass (g) [lb] | 122.47 [0.27000] |
| Ash (%, ad) | 42.4 | Particle Size (mm) [US mesh] | -0.212 [70] |
| Volatile Matter (%, ad) | 14.4 | Helium density (g/cc) | 1.681 |
| Fixed Carbon (%, ad) | 42.5 | Test Temperature (°C) [°F] | 54.5 [130.1] |
| Ash (%, Equilibrium Moisture ba | 42.1 | Analysis date | 25-Feb-50 |
| Moist. (%, Equilibrium Moisture | 1.6 | Test Gas | Methane |

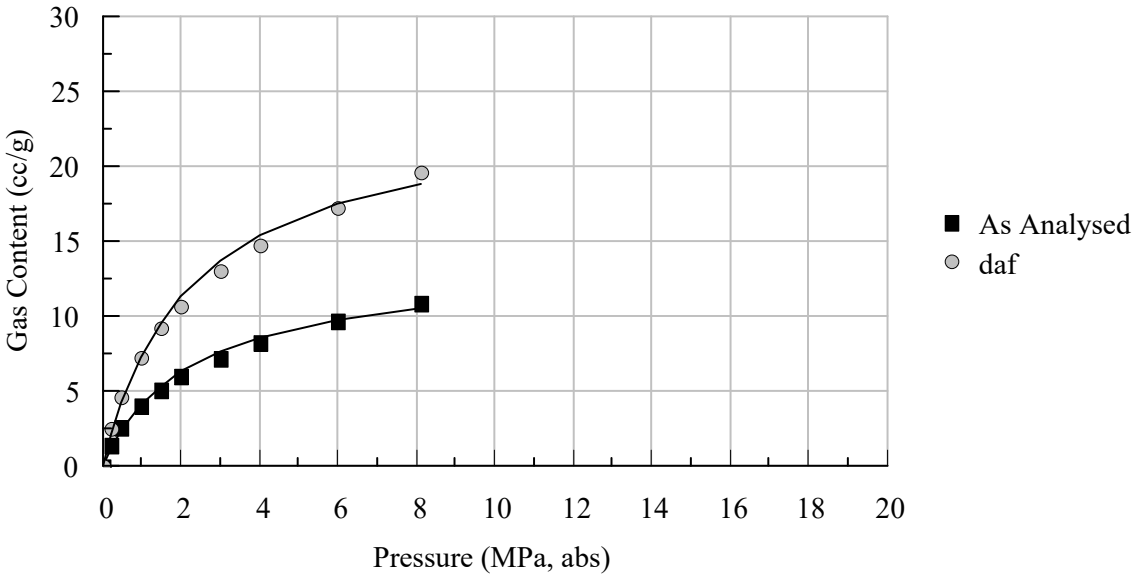
**Methane Absolute Adsorption at Equilibrium Moisture Basis**

| at 20°C; 101.1kPa (1 atm) | | | at 60°F, 14.7 psia | | |
|---|---|---|---|---|---|
| Pressure (MPa) (absolute) | Gas Content (cc/g) (as analysed) | Gas Content (cc/g) (daf) | Pressure (psia) | Gas Content (scf/t) (as analysed) | Gas Content (scf/t) (daf) |
| 0.234 | 1.47 | 2.61 | 34 | 46 | 83 |
| 0.501 | 2.64 | 4.69 | 73 | 83 | 148 |
| 1.005 | 4.14 | 7.36 | 146 | 131 | 232 |
| 1.494 | 5.20 | 9.23 | 217 | 164 | 291 |
| 2.018 | 6.07 | 10.78 | 293 | 192 | 340 |
| 3.015 | 7.35 | 13.05 | 437 | 232 | 412 |
| 4.015 | 8.35 | 14.83 | 582 | 263 | 468 |
| 5.993 | 9.78 | 17.37 | 869 | 309 | 548 |
| 8.130 | 11.04 | 19.61 | 1179 | 348 | 619 |

**Langmuir Isotherm Coefficients**

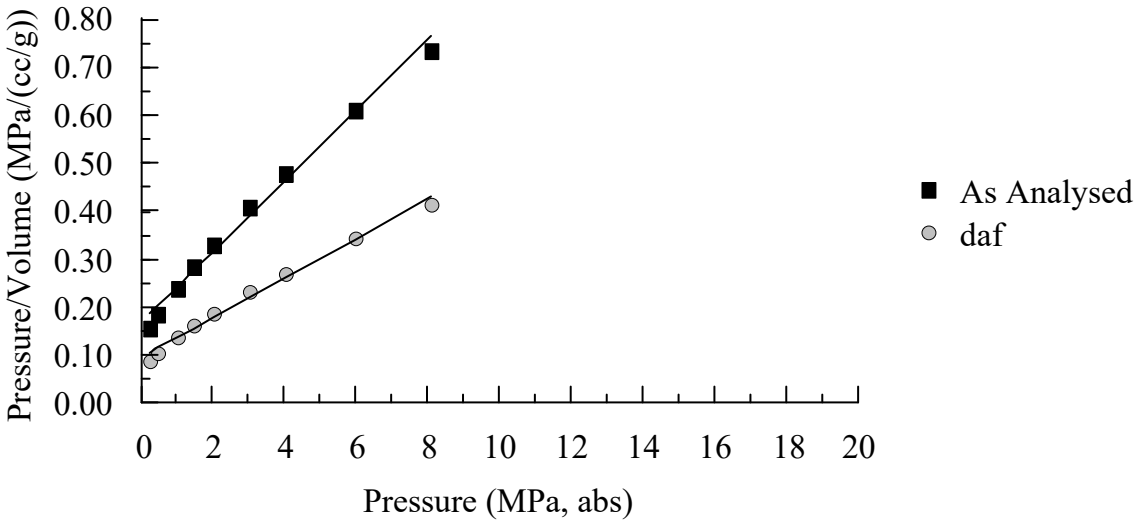
| | $P_L$ (MPa, abs) | $V_L$ (cc/g) | $P_L$ (psia) | $V_L$ (scf/t) |
|---|---|---|---|---|
| As analysed | 2.31 | 13.67 | 335 | 431 |
| daf | 2.31 | 24.28 | 335 | 766 |

Methane Absolute Adsorption Isotherm (20 °C, 101.3 kPa)
Last Chance #3 - Iso 1 (557.43 - 570.36 m)
Analysis Temperature 54.5 °C



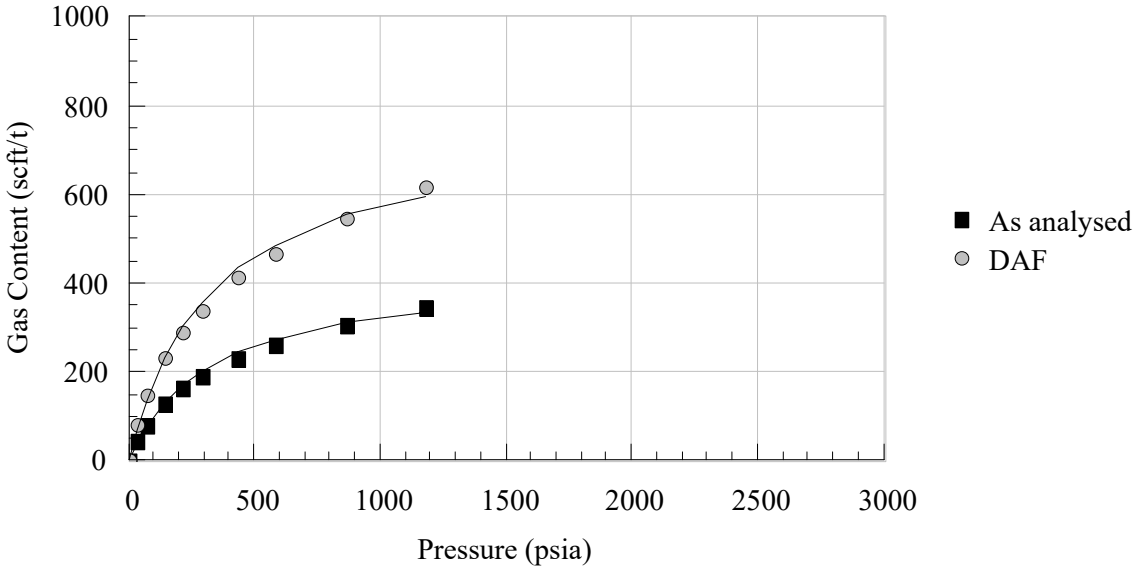

V = 13.67 P / (P + 2.31 ) (As analysed) V = 24.28 P / (P + 2.31 ) (daf)

Methane Absolute Adsorption Isotherm (20 °C, 101.3 kPa)
Last Chance #3 - Iso 1 (557.43 - 570.36 m)
Analysis Temperature 54.5 °C



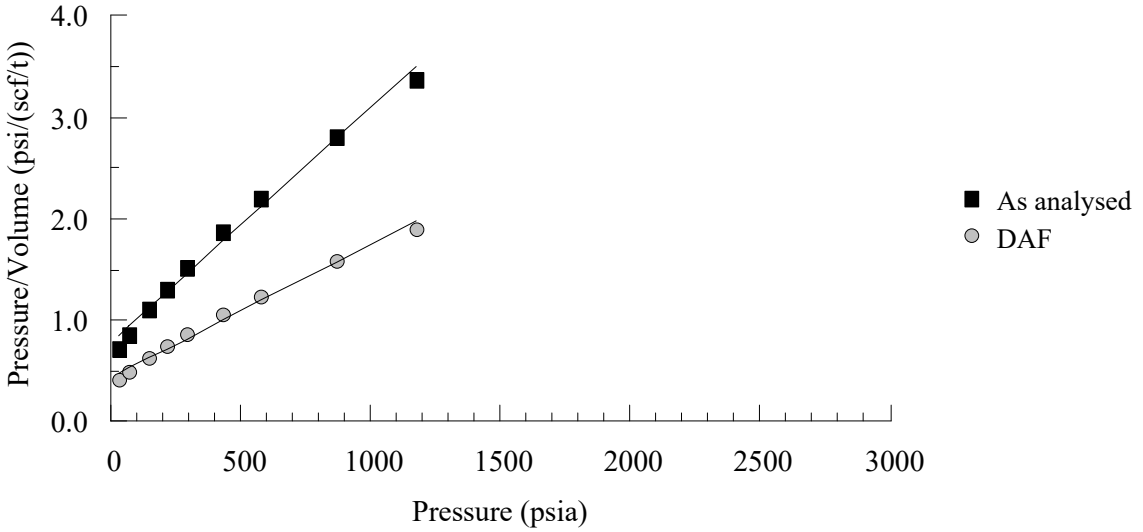

P/V = 0.073 P + 0.169; r^2 = 0.991 (As analysed)
P/V = 0.041 P + 0.095; r^2 = 0.991 (daf)

Methane Absolute Adsorption Isotherm (60 °F, 14.7 psia)
Last Chance #3 - Iso 1 (557.43 - 570.36 m)
Analysis Temperature 130.1 °F




V = 431 P / (P + 335 ) (As analysed) V = 766 P / (P + 335 ) (daf)

Methane Absolute Adsorption Isotherm (60 °F, 14.7 psia)
Last Chance #3 - Iso 1 (557.43 - 570.36 m)
Analysis Temperature 130.1 °F




P/V = 0.00232 P + 0.776; r^2 = 0.991 (As analysed)
P/V = 0.00130 P + 0.437; r^2 = 0.991 (daf)

| | |
|---|---|
| **Client** | Gassy Coal Company NL |
| **Sample Details** | Last Chance #3 - Iso 1 (557.43 - 570.36 m) |

**Sample Properties**

| | | | |
|---|---|---|---|
| Inherent Moisture (%, ad) | 0.7 | Isotherm Sample Mass (g) [lb] | 122.47 [0.27000] |
| Ash (%, ad) | 42.4 | Particle Size (mm) [US mesh] | -0.212 [70] |
| Volatile Matter (%, ad) | 14.4 | Helium density (g/cc) | 1.681 |
| Fixed Carbon (%, ad) | 42.5 | Test Temperature (°C) [°F] | 54.5 [130.1] |
| Ash (%, Equilibrium Moisture ba | 42.1 | Analysis date | 25-Feb-50 |
| Moist. (%, Equilibrium Moisture | 1.6 | Test Gas | Methane |

**Methane Absolute Adsorption at Equilibrium Moisture Basis**

**Model Co-efficients**

| | P in MPa, abs<br>V in cc/g | | P in psia<br>V in scf/t | |
|---|---|---|---|---|
| | aa | daf | aa | daf |
| **Langmuir Coefficients** | | | | |
| PL | 2.31 | 2.31 | 335 | 335 |
| VL | 13.67 | 24.28 | 766 | 766 |
| model fit : no. of points = 9 | | r^2 = 0.9907 | | |
| **BET Coefficients** | | | | |
| Vm | 10.23 | 18.17 | n/a | n/a |
| C | 27.44 | 27.44 | n/a | n/a |
| model fit : no. of points = 9 | | r^2 = 0.9992 | | |
| **D-R Coefficients** | | | | |
| Vo | 13.25 | 23.53 | n/a | n/a |
| D | 0.19 | 0.19 | n/a | n/a |
| model fit : no. of points = 9 | | r^2 = 0.9990 | | |
| **D-A Coefficients** | | | | |
| n | 1.81 | 1.81 | n/a | n/a |
| Vo | 14.50 | 25.76 | n/a | n/a |
| D | 0.23 | 0.23 | n/a | n/a |
| model fit : no. of points = 9 | | r^2 = 0.9998 | | |
| po = 42.356 | | | | |

**Carbon Dioxide ($CO_2$) Adsorption**

| | |
|---|---|
| **Client** | Gassy Coal Company NL |
| **Sample Details** | Last Chance #3 - Iso 1 (557.43 - 570.36 m) |

**Sample Properties**

| | | | |
|---|---|---|---|
| Inherent Moisture (%, ad) | 0.7 | Isotherm Sample Mass (g) [lb] | 130.54 [0.28779] |
| Ash (%, ad) | 42.4 | Particle Size (mm) [US mesh] | -0.212 [70] |
| Volatile Matter (%, ad) | 14.4 | Helium density (g/cc) | 1.720 |
| Fixed Carbon (%, ad) | 42.5 | Test Temperature (°C) [°F] | 54.5 [130.1] |
| Ash (%, Equilibrium Moisture ba | 42.1 | Analysis date | 25-Feb-50 |
| Moist. (%, Equilibrium Moisture | 1.4 | Test Gas | Carbon Dioxide |

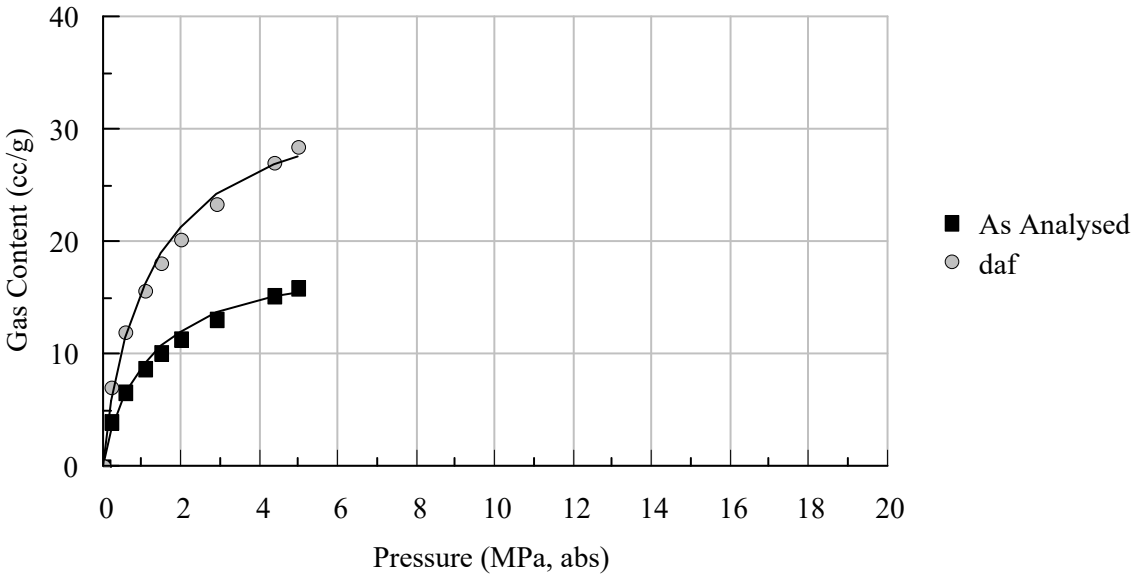
**Carbon Dioxide Absolute Adsorption at Equilibrium Moisture Basis**

| at 20°C; 101.1kPa (1 atm) | | | at 60°F, 14.7 psia | | |
|---|---|---|---|---|---|
| Pressure (MPa) (absolute) | Gas Content (cc/g) (as analysed) | Gas Content (cc/g) (daf) | Pressure (psia) | Gas Content (scf/t) (as analysed) | Gas Content (scf/t) (daf) |
| 0.244 | 4.04 | 7.15 | 35 | 128 | 226 |
| 0.605 | 6.79 | 12.01 | 88 | 214 | 379 |
| 1.078 | 8.92 | 15.79 | 156 | 282 | 498 |
| 1.494 | 10.23 | 18.10 | 217 | 323 | 571 |
| 1.976 | 11.41 | 20.19 | 287 | 360 | 637 |
| 2.924 | 13.19 | 23.35 | 424 | 416 | 737 |
| 4.390 | 15.36 | 27.18 | 637 | 485 | 858 |
| 4.998 | 16.06 | 28.43 | 725 | 507 | 897 |

**Langmuir Isotherm Coefficients**

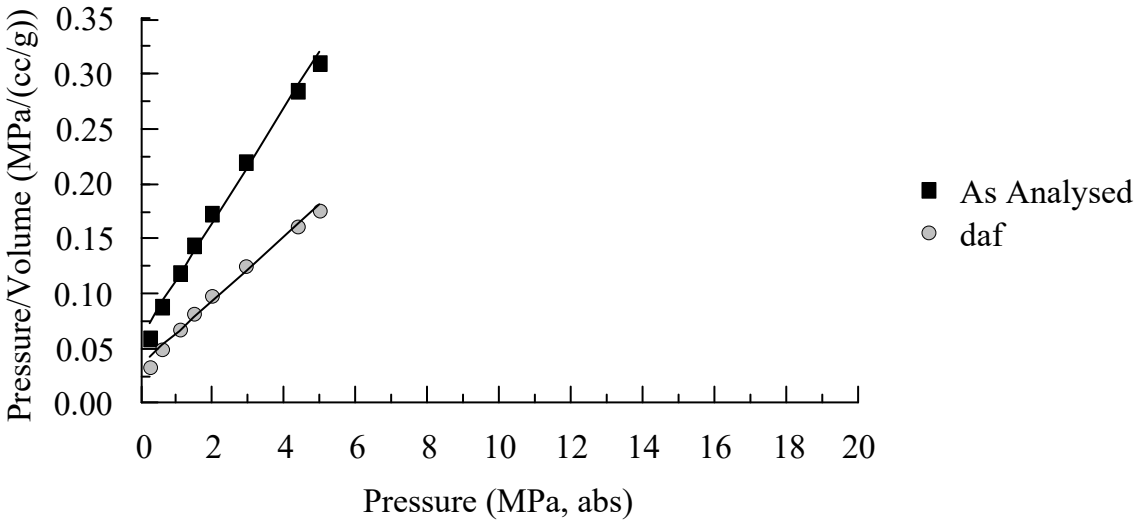
| | $P_L$ (MPa, abs) | $V_L$ (cc/g) | $P_L$ (psia) | $V_L$ (scf/t) |
|---|---|---|---|---|
| As analysed | 1.18 | 19.30 | 172 | 609 |
| daf | 1.18 | 34.15 | 172 | 1078 |

Carbon Dioxide Absolute Adsorption Isotherm (20 °C, 101.3 kPa)
Last Chance #3 - Iso 1 (557.43 - 570.36 m)
Analysis Temperature 54.5 °C



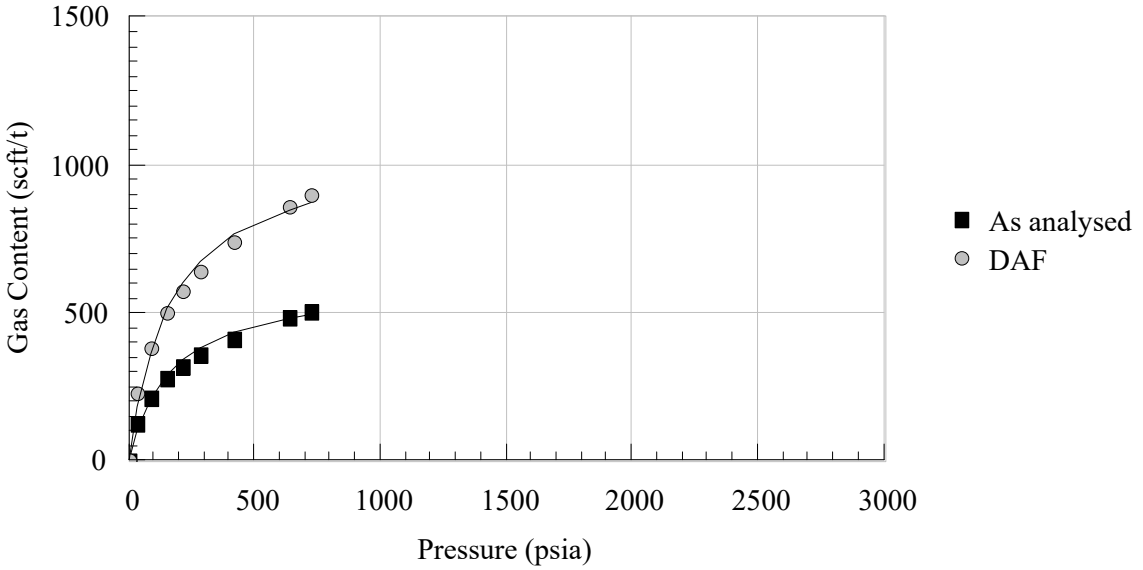

V = 19.30 P / (P + 1.18 ) (As analysed) V = 34.15 P / (P + 1.18 ) (daf)

Carbon Dioxide Absolute Adsorption Isotherm (20 °C, 101.3 kPa)
Last Chance #3 - Iso 1 (557.43 - 570.36 m)
Analysis Temperature 54.5 °C



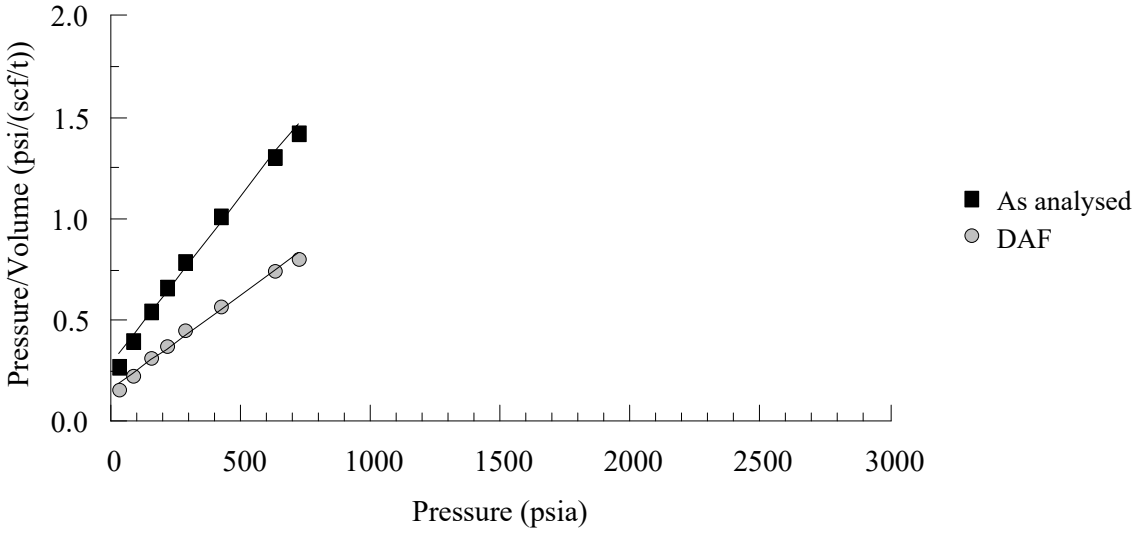

P/V = 0.052 P + 0.061; r^2 = 0.991 (As analysed)
P/V = 0.029 P + 0.035; r^2 = 0.991 (daf)

Carbon Dioxide Absolute Adsorption Isotherm (60 °F, 14.7 psia)
Last Chance #3 - Iso 1 (557.43 - 570.36 m)
Analysis Temperature 130.1 °F




V = 609 P / (P + 172 ) (As analysed) V = 1078 P / (P + 172 ) (daf)

Carbon Dioxide Absolute Adsorption Isotherm (60 °F, 14.7 psia)
Last Chance #3 - Iso 1 (557.43 - 570.36 m)
Analysis Temperature 130.1 °F




P/V = 0.00164 P + 0.282; r^2 = 0.991 (As analysed)
P/V = 0.00093 P + 0.159; r^2 = 0.991 (daf)

**Extended Langmuir Modelling**

| | |
|---|---|
| **Client** | Gassy Coal Company NL |
| **Sample Details** | Last Chance #3 - Iso 1 (557.43 - 570.36 m) |

**Pure CH4 Langmuir Adsorption Isotherm Coefficients**

| | $P_L$ (MPa, abs) | $V_L$ (cc/g) | $P_L$ (psia) | $V_L$ (scf/t) |
|---|---|---|---|---|
| As analysed | 2.31 | 13.67 | 335 | 431 |
| daf | 2.31 | 24.28 | 335 | 766 |

**Pure CO2 Langmuir Adsorption Isotherm Coefficients**

| | $P_L$ (MPa, abs) | $V_L$ (cc/g) | $P_L$ (psia) | $V_L$ (scf/t) |
|---|---|---|---|---|
| As analysed | 1.18 | 19.30 | 172 | 609 |
| daf | 1.18 | 34.15 | 172 | 1078 |

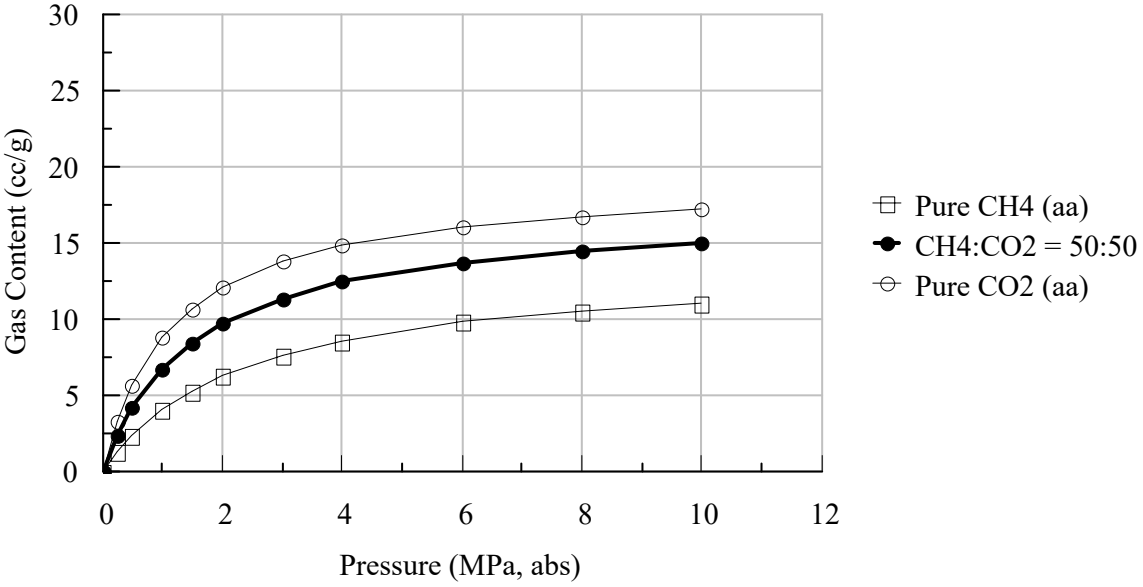
**Modelled Extended Langmuir Adsorption Isotherm for CH4:CO2 = 50:50**

| at 20°C; 101.1kPa (1 atm) | | | at 60°F, 14.7 psia | | |
|---|---|---|---|---|---|
| Pressure (MPa) (absolute) | Gas Content (cc/g) as analysed | Gas Content (cc/g) (daf) | Pressure (psia) | Gas Content (scf/t) (as analysed) | Gas Content (scf/t) (daf) |
| 0.250 | 2.40 | 4.24 | 36 | 76 | 134 |
| 0.500 | 4.21 | 7.46 | 73 | 133 | 235 |
| 1.000 | 6.78 | 12.01 | 145 | 214 | 379 |
| 1.500 | 8.51 | 15.08 | 218 | 269 | 476 |
| 2.000 | 9.76 | 17.29 | 290 | 308 | 546 |
| 3.000 | 11.43 | 20.25 | 435 | 361 | 639 |
| 4.000 | 12.50 | 22.15 | 580 | 395 | 699 |
| 6.000 | 13.79 | 24.44 | 870 | 435 | 771 |
| 8.000 | 14.54 | 25.77 | 1160 | 459 | 813 |

**Extended Langmuir Adsorption Isotherm Coefficients**

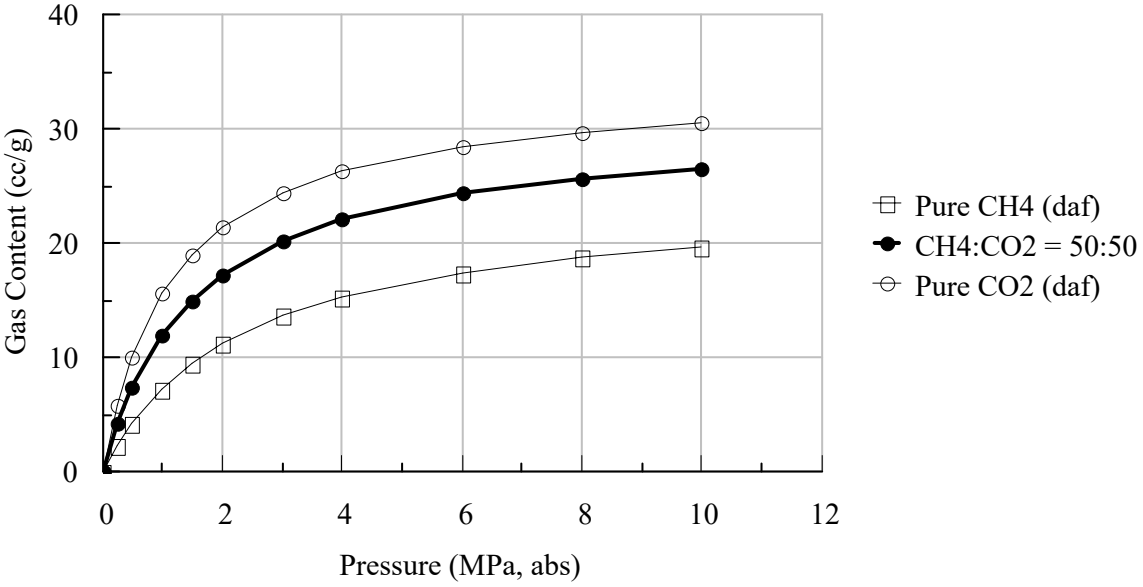
| | $P_L$ (MPa, abs) | $V_L$ (cc/g) | $P_L$ (psia) | $V_L$ (scf/t) |
|---|---|---|---|---|
| As analysed | 1.56 | 17.39 | 227 | 549 |
| daf | 1.56 | 30.81 | 227 | 972 |

Extended Langmuir Adsorption Isotherm - CH4:CO2 = 50:50 (20 °C, 10[illegible]
Last Chance #3 - Iso 1 (557.43 - 570.36 m)
Analysis Temperature 54.5 °C



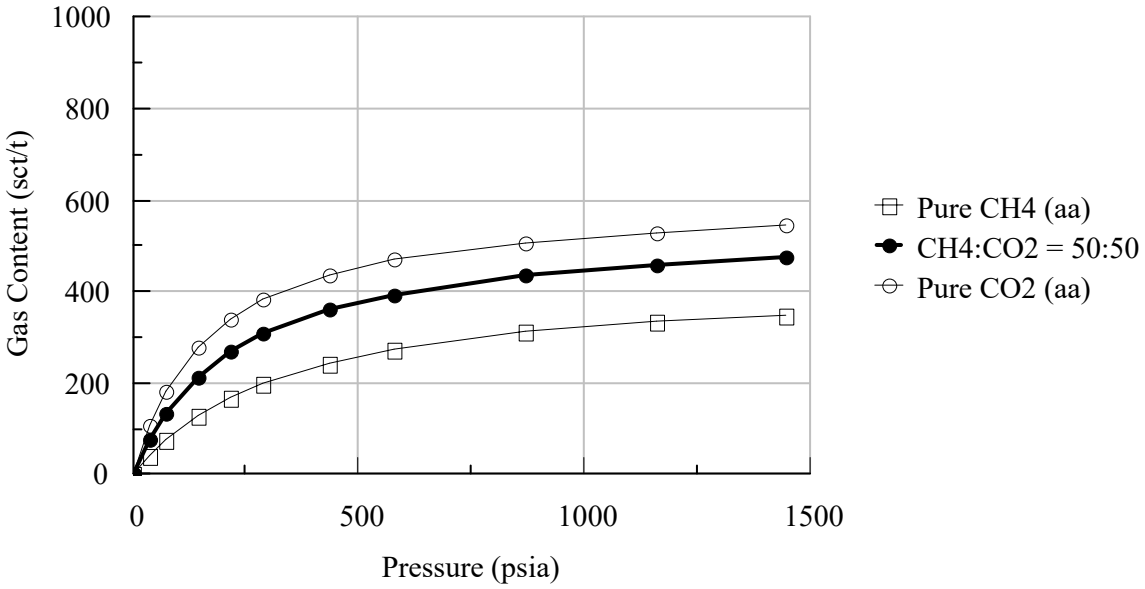

V = 17.39 P / (P + 1.56 )  (As analysed)

Extended Langmuir Adsorption Isotherm - CH4:CO2 = 50:50 (20 °C, 10[illegible]
Last Chance #3 - Iso 1 (557.43 - 570.36 m)
Analysis Temperature 54.5 °C



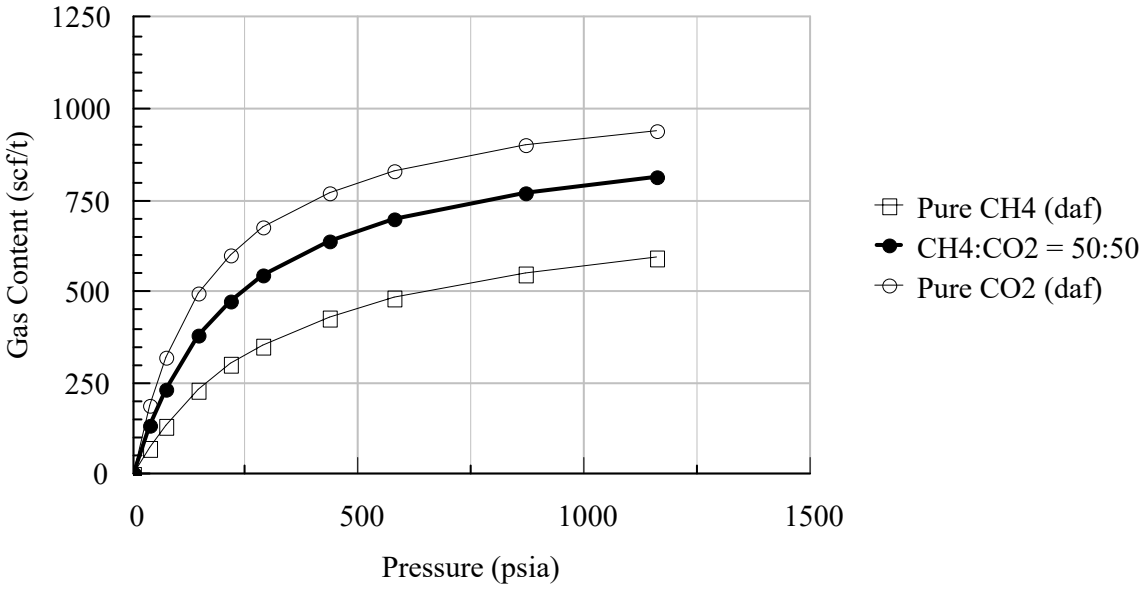

V = 30.81 P / (P + 1.56 )  (daf)

Extended Langmuir Adsorption Isotherm - CH4:CO2 = 50:50 (60 °F, 14.7 psia)
Last Chance #3 - Iso 1 (557.43 - 570.36 m)
Analysis Temperature 130.1 °F




V = 549 P / (P + 227 )  (As analysed)

Extended Langmuir Adsorption Isotherm - CH4:CO2 = 50:50 (60 °F, 14.7 psia)
Last Chance #3 - Iso 1 (557.43 - 570.36 m)
Analysis Temperature 130.1 °F




V = 972 P / (P + 227 )  (daf)



*Our ref : EXAMPLE*

Dr Peter Crosdale (MAIG)
Director, ERC
1st April, 2050