SG16

The Application of Adsorption Isotherm Data to Define Gas-in-Place Volumes for Shales-Gas Reservoirs

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SUMMARY

In the development and exploitation of Unconventional reservoirs, having an understanding of Gas-in-Place is fundamental in assessing the viability of a particular field or basin and is ultimately necessary for commercial development. In attempting to assess the GIP volumes approximations may be qualified by log data but to truly understand the correct gas volumes, direct measurements must be made. One such direct measurement that empirically quantifies GIP is the Adsorption Isotherm. Adsorption isotherm data are important because isotherm behavior indicates the maximum gas volume that can be stored at a specific temperature and pressure. An adsorption isotherm specifies the adsorbed gas storage capacity of organic material (macerals/kerogen) as a function of pressure.

This presentation will discuss the theory, methods and equations that are used in generating the data. It will explore how the functions of Langmuir pressure and Langmuir volume equations are used in defining the GIP results. It will also extend the basic data delivery of standard cubic feet per ton (SFC/t) of gas to acreage gas volumes (Mscf/acre-ft) and ultimately the GIP volumes of a section area (Bscf) of a reservoir.

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LABORATORIES

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Adsorbed Gas Storage Capacity

- What is adsorption?
 - A physical phenomena common to microporous materials, such as kerogen, where gas and solids share a weak attraction (van Der Waal's force) in response to high surface area to pore volume ratio ($10^8 \text{ ft}^2 \text{ per ft}^3$).
 - Sorbed gas density increases to near liquid density.
- Significance
 - A primary storage mechanism in many unconventional reservoirs.
 - Necessary for indirect gas content estimates, GIP estimates and core-geophysical log calibration.
 - Provides information needed to delineate between the adsorbed and free gas content.
 - In coals, wherein gas is stored 99.9% by adsorption, provides an indication of initial gas saturation, critical desorption pressure, and EUR.

Gas Sorption Locations

- Organic Material
 - Total Organic Carbon (solid)
 - Organic Liquids
- Clays and ?
 - Chlorite , Illite, Kaolinite, Montmorillonite, Vermiculite

Total & Regression Uncertainty

Effects of Reservoir and Rock Properties on Adsorption Potential

Parameter	As the Parameter:	Gas Storage Capacity:
Pressure	Increases	Increases
Temperature	Increases	Decreases
Moisture Content	Increases	Decreases
Organic Richness	Increases	Increases
Thermal Maturity	Increases	Increases

Shale Total Gas Storage Capacity and Empirically Measured Gas Content

$$G_{st} = G_{sa} + G_{sf}^* + G_{sd}$$

- G_{st} Total Gas Storage Capacity, scf/ton
- G_{sa} Adsorbed Gas Storage Capacity, scf/ton
- G_{sf}^* Corrected Free Gas Storage Capacity, scf/ton
- G_{sd} Dissolved Gas Storage Capacity, scf/ton

Adsorbed Gas Storage Capacity

$$G_{sa} = G_{sL} \frac{p}{p + p_L}$$

G_{sa}	Adsorbed gas storage capacity, scf/ton
G_{sL}	Langmuir storage capacity, scf/ton
p	Reservoir pressure, psia
p_L	Langmuir pressure, psia

Free Gas Storage Capacity

$$G_{sf} = 32.0368 \frac{\phi S_g}{\rho B_g}$$

G_{sf}	Free gas volume, scf/ton
ϕ	Total porosity, fraction of bulk volume
S_g	Gas Saturation, fraction of porosity
ρ	Bulk density, g/cm ³
B_g	Formation volume factor, res. vol./ surf. Vol.

New Petrophysical Model

- Recognizes that the available porosity for free-gas and adsorbed gas storage are interconnected.
- Evidence has historically existed in the methods used to measure adsorption isotherms.
 - Sorbed volume must be accounted for during isotherm analysis as some fraction of the initially determined void volume is consumed with adsorbed gas

$$\phi S_g = \phi (1 - S_w - S_a)$$

Adsorption Isotherm Evidence – Gibbs Correction

Free Pore-Space Correction

$$G_f = 32.0368 \frac{\phi(1 - S_w) - \phi_a}{\rho_b B_g}$$

$$\phi_a = 1.318 \times 10^{-6} \hat{M} \frac{\rho_b}{\rho_s} \left(G_{sL} \frac{p}{p + p_L} \right)$$

$$G_f = \frac{32.0368}{B_g} \left[\frac{\phi(1 - S_w)}{\rho_b} - \frac{1.318 \times 10^{-6} \hat{M}}{\rho_s} \left(G_{sL} \frac{p}{p + p_L} \right) \right]$$

Example of Pore Scale Considerations on Barnett GIP Calculations

• Porosity	= 0.06
• Water Saturation	= 0.35
• Oil Saturation	= 0.0
• Gas Formation Factor	= 0.0046 rcf/scf
• Molecular Weight	= 20 lb/lb-mol
• Langmuir Storage Capacity	= 50 scf/ton
• Langmuir Pressure	= 1150
• Reservoir Pressure	= 4000 psia
• Reservoir Temperature	= 180 °F
• Bulk Density	= 2.5 g/cm ³
• Adsorbed Density	= 0.37 g/cm ³

Historic Petrophysical Model

$$G_f = 32.0368 \frac{\phi(1-S_w)}{\rho_b B_g} = 32.0368 \frac{0.06(1-0.35)}{2.5 \cdot 0.0046} = 108.6 \text{ scf/ton}$$

$$G_a = G_{sL} \frac{p}{p + p_L} = 50 \frac{4000}{4000 + 1150} = 38.8 \text{ scf/ton}$$

$$G_{st} = 108.6 \text{ scf/ton} + 38.8 \text{ scf/ton} = 147.4 \text{ scf/ton}$$

New Petrophysical Model

$$G_f = \frac{32036}{B_g} \left[\frac{8\phi(1-S_w)}{\rho_b} - \frac{1.3181 \cdot 10^{-6} \hat{M}}{\rho_s} \left(G_{sL} \frac{p}{p + p_L} \right) \right]$$

$$= \frac{32036}{0.0046} \left[\frac{80.06(1-0.35)}{2.5} - \frac{1.3181 \cdot 10^{-6} \cdot 20}{0.37} \left(50 \frac{4000}{4000 + 1150} \right) \right] = 894 \text{ scf/ton}$$

$$G_a = G_{sL} \frac{p}{p + p_L} = 50 \frac{4000}{4000 + 1150} = 38.8 \text{ scf/ton}$$

$$G_{st} = 894 \text{ scf/ton} + 38.8 \text{ scf/ton} = 932.8 \text{ scf/ton}$$

Consideration of in-situ pore space occupied by adsorbed gas results in a decrease of 17.7% of free gas and 13% of total gas

Correlations Between Gas Storage Capacity and Content

Gas-in-Place Relationship

$$GIP = 1359.7 A h \rho G_{st}$$

- Drainage Area (A)
- Reservoir Thickness (h)
- Bulk Density (ρ)
- Total Gas Content (G_{st})
 - Indirect Method Assumes Total Gas Storage Capacity = G_{st}

Adsorption Potential – TOC Relationship

Given that kerogen in a given source rock are of similar type and maturity there is a significant correlation between TOC and adsorbed gas storage capacity if computed at similar pressures.

Comparison Pressure = 5500 psia

$R^2 = 0.9$

$Y = 1092 x - 9.23$

Adsorption Prospect Appraisal Application – Core-to-log Calibraion

1: Load, quality assure, and edit log and core data.

2: Core to log depth shifting.

3: Apply environmental corrections to logs, if necessary.

4: Determine if there are sufficient core samples.

5: Set parameter values, based on available log and core data.

6: Compute Total Organic Carbon (TOC) from log and core data.

7: Compute fluid density.

8: Compute average inorganic matrix density and TOC density.

9: Compute total porosity corrected for the volume of kerogen.

10: Convert TOC (weight percent) to bulk volume of kerogen.

11: Recalculate apparent matrix values, for the presence of kerogen.

12: Compute water saturation and bulk volume gas (gas-filled porosity).

13: Compute gas storage capacity: free, adsorbed, total.

14: Compute gas-in-place.

15: Compute lithologic volumes.

Once a TOC track is developed you can then generate an adsorbed gas storage capacity track

Discrete computation of matrix density and volume kerogen are necessary to accurately determine porosity in unconventional reservoirs

Once an adsorption track is computed one can calculate corrected free gas pore volume and total gas-in-place

Adsorption Prospect Appraisal Application

$$GIP = 1359.7 A h \rho G_{st}$$

- Drainage Area (A) –can be arbitrarily set to 640 acres
- Reservoir thickness (h), bulk density (ρ), and total gas content (G_{st}) are all calculated from the log traces that were developed and at same resolution of the .LAS logs digits (~0.5 ft).
- Resulting GIP estimates per depth “layer” are summed to provide accurate and high resolution estimates of GIP throughout the target formation

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