Enhancing the Material Balance Equation for Shale Gas Reservoirs

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Agenda

- ❑Personal Background
- ❑Introduction
- ❑Research
  1. Material Balance Equation
  2. Enhancing the MBE
  3. Results
- ❑Project Findings
- ❑Questions
- ❑Final Conclusion

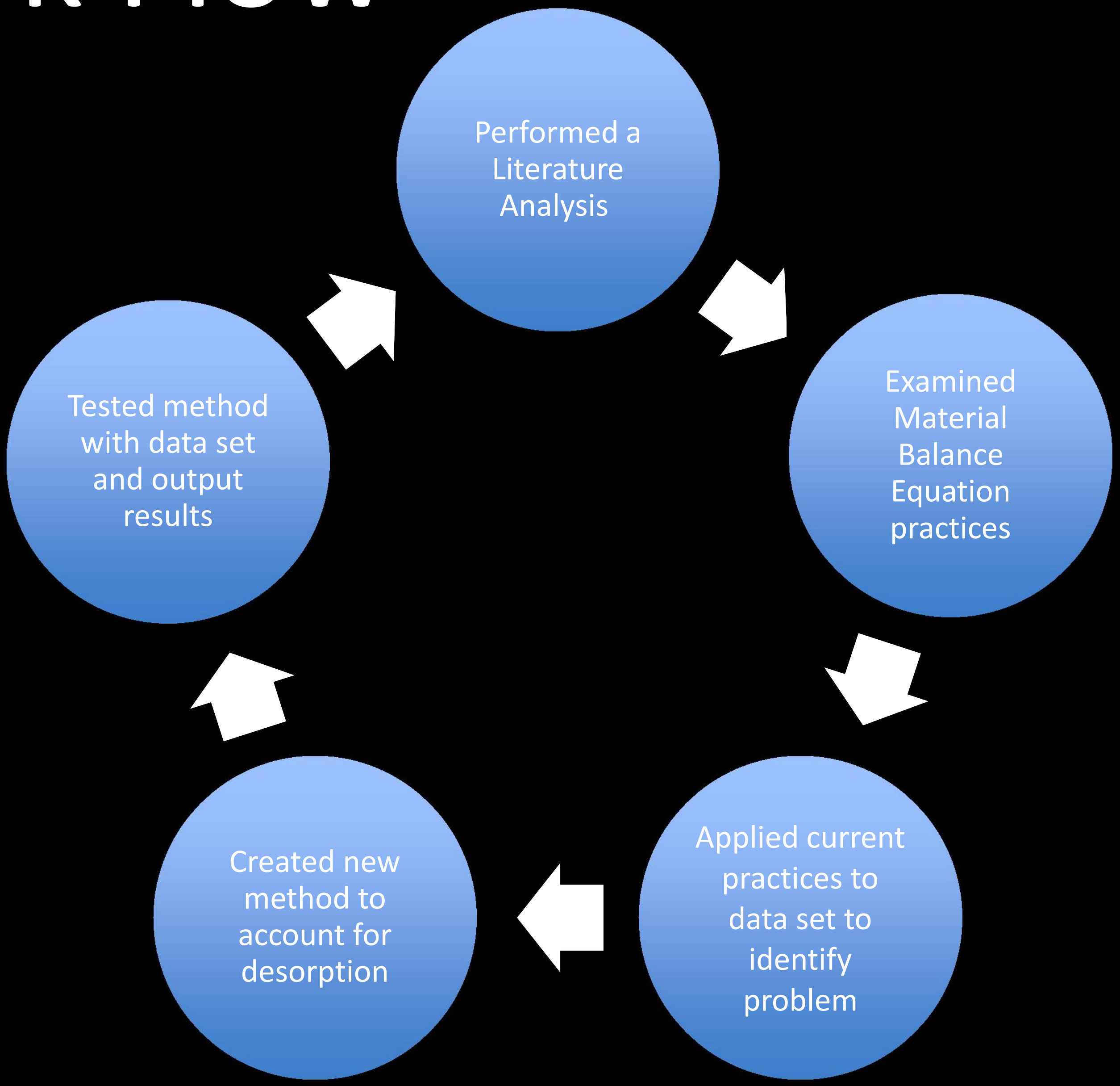
Personal Background

Project Introduction

Objective: Increase the effectiveness of the material balance equation (MBE) for shale gas reservoirs.

- Quick and easy method to evaluate:
  - Initial adsorbed gas in place, G_a
  - Initial free gas in place, G_f
- Create an equation that generates a linear-line

Work Flow


Performed a Literature Analysis
Examined Material Balance Equation practices
Applied current practices to data set to identify problem
Created new method to account for desorption
Tested method with data set and output results

Material Balance Equation

The MBE is an equation based on:

- Fluid Production = Δreservoir volume due to drive mechanisms

Volumetric Gas MBE

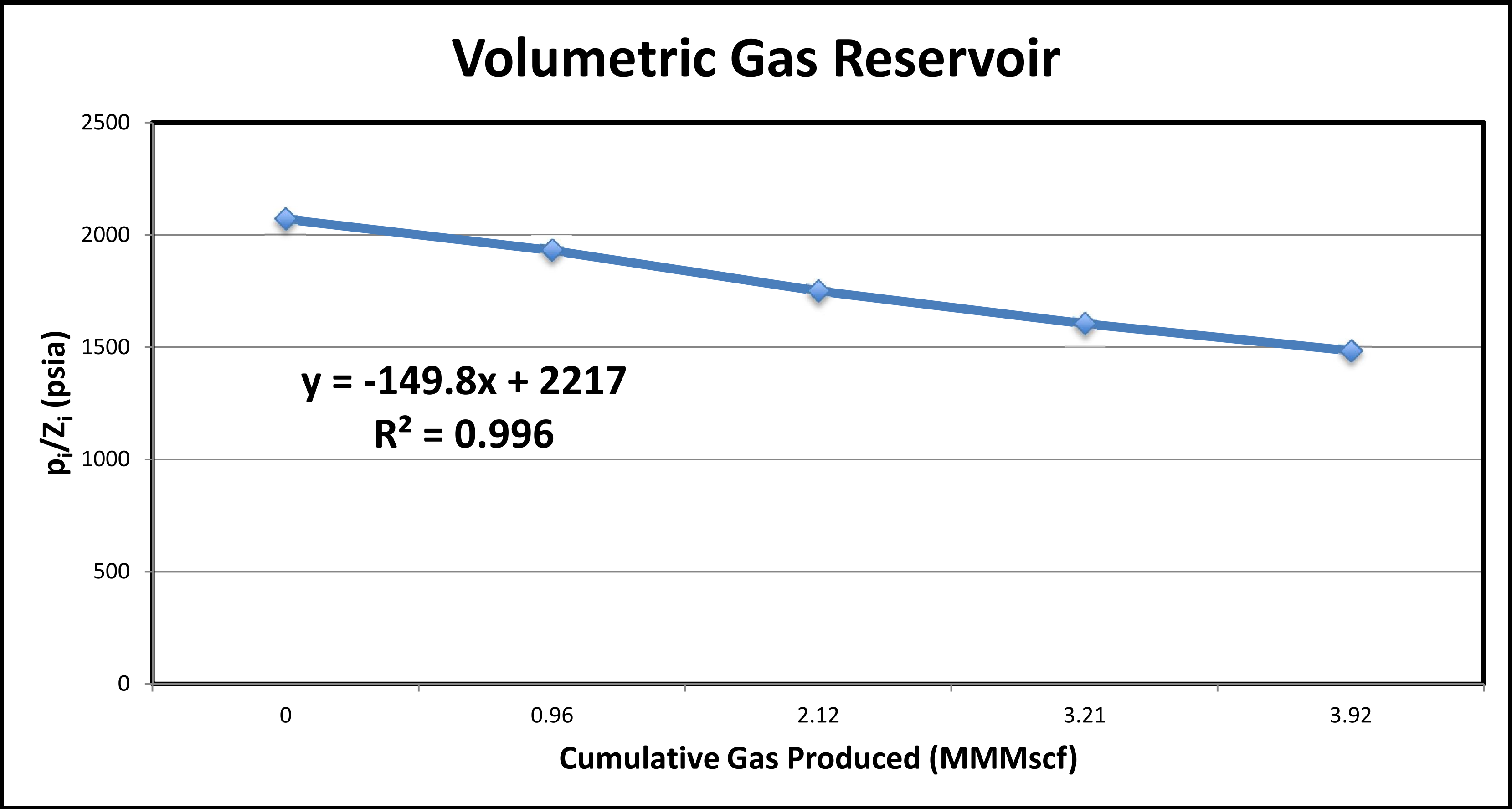
- Underground Removal = Gas Expansion Drive
- $G_p B_g = G(B_g - B_{gi})$

By replacing B_g and rearranging:

- $$\frac{p}{Z} = \frac{p_i}{Z_i}(1 - \frac{G_p}{G})$$

Volumetric p/Z vs. G_p

A graph can be generated by plotting p/Z vs. G_p.

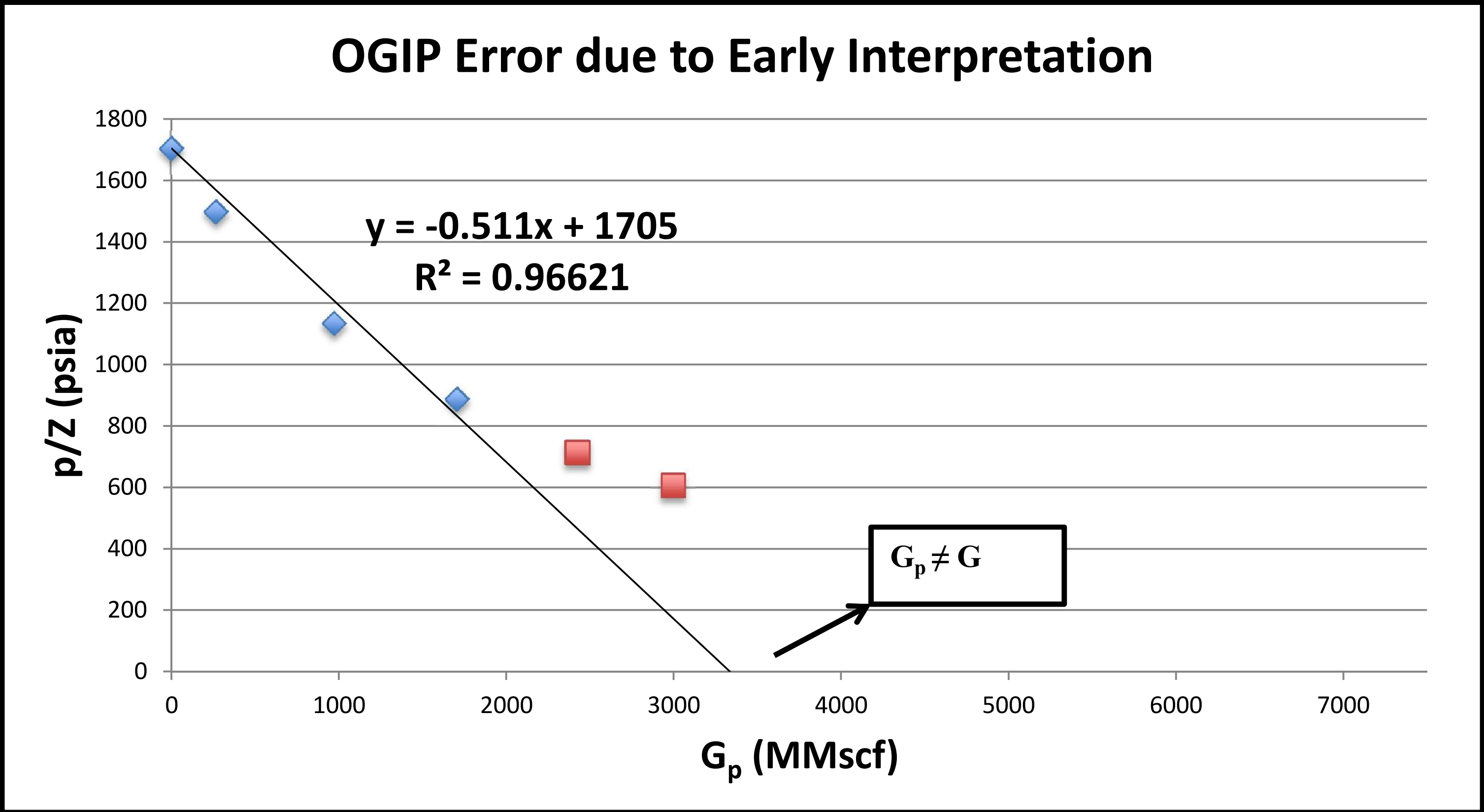


$G = G_p$ when $p/Z = 0$, therefore $G = (2217/149.8) \approx 14.8$ MMMscf

p/Z vs. G_p Error

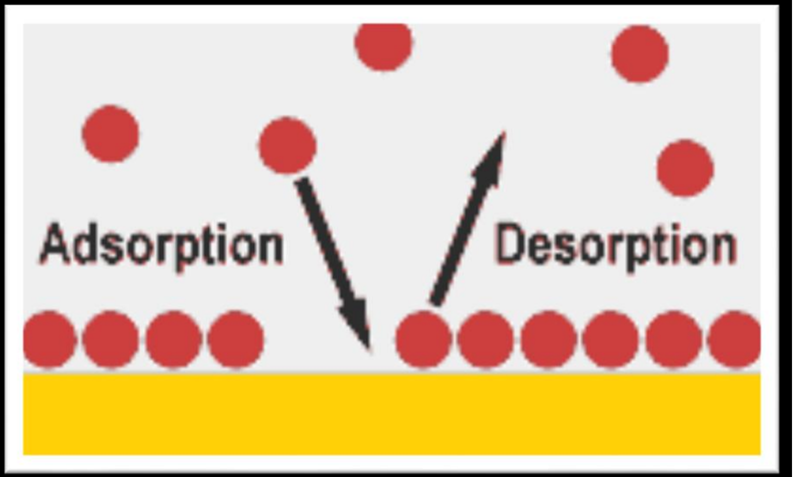
The p/Z vs. G_p plot is ineffective for shale res.

- Data displays linear trend initially (blue points)
- Over time data trends upward (red points)



Adsorption/Desorption

Adsorption is the adhesion of gas to the face of the shale.



Desorption is the release of gas from the face of the shale.

- Deviation from trend line during the p/Z vs. G_p
- The Langmuir Isotherm

Langmuir Isotherm

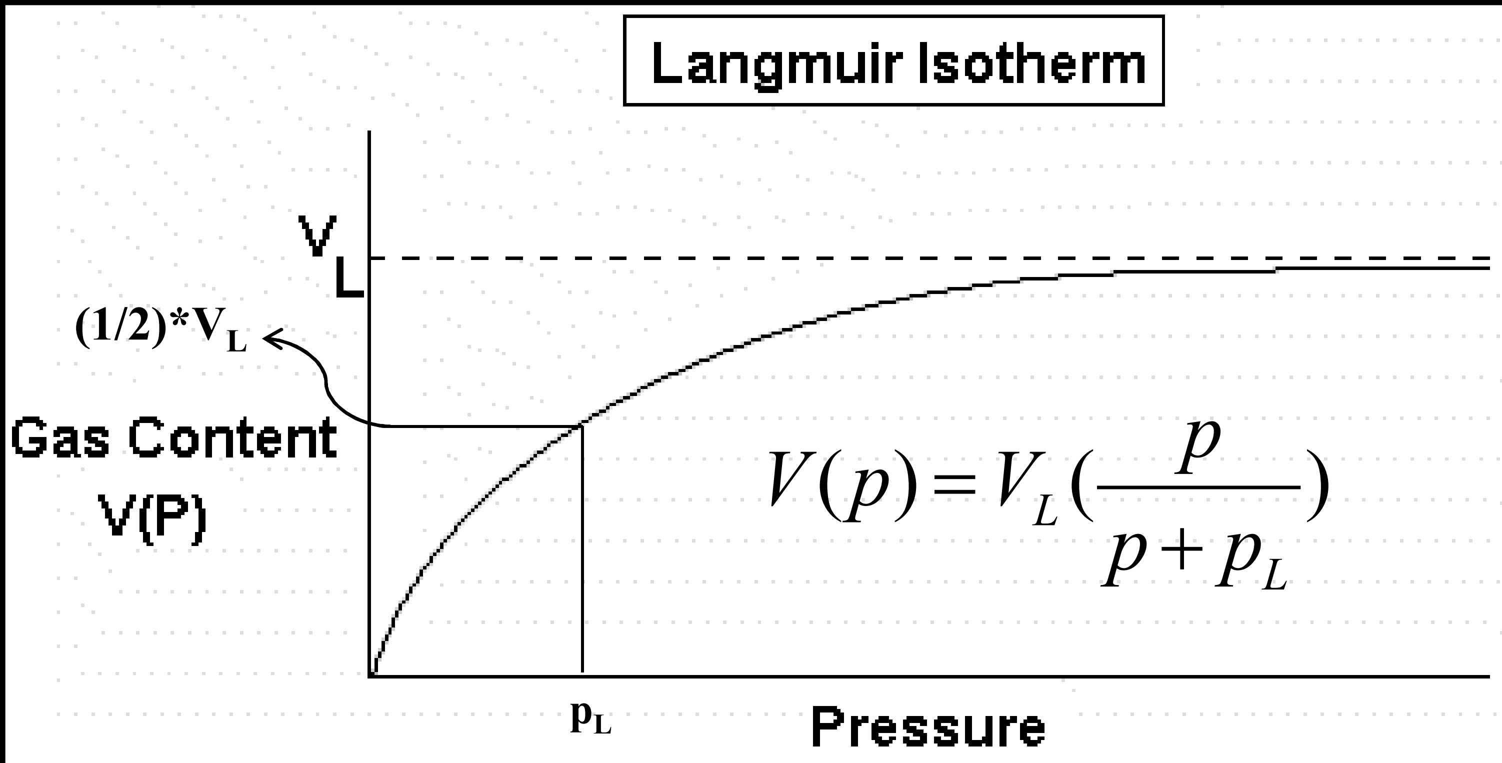
Assumptions:

- Monolayer of gas on shale surface
- Equilibrium established between the free gas and adsorbed gas for a given temperature and pressure

Reasoning:

- Mathematically easy to calculate
- Desorption estimates will be conservative

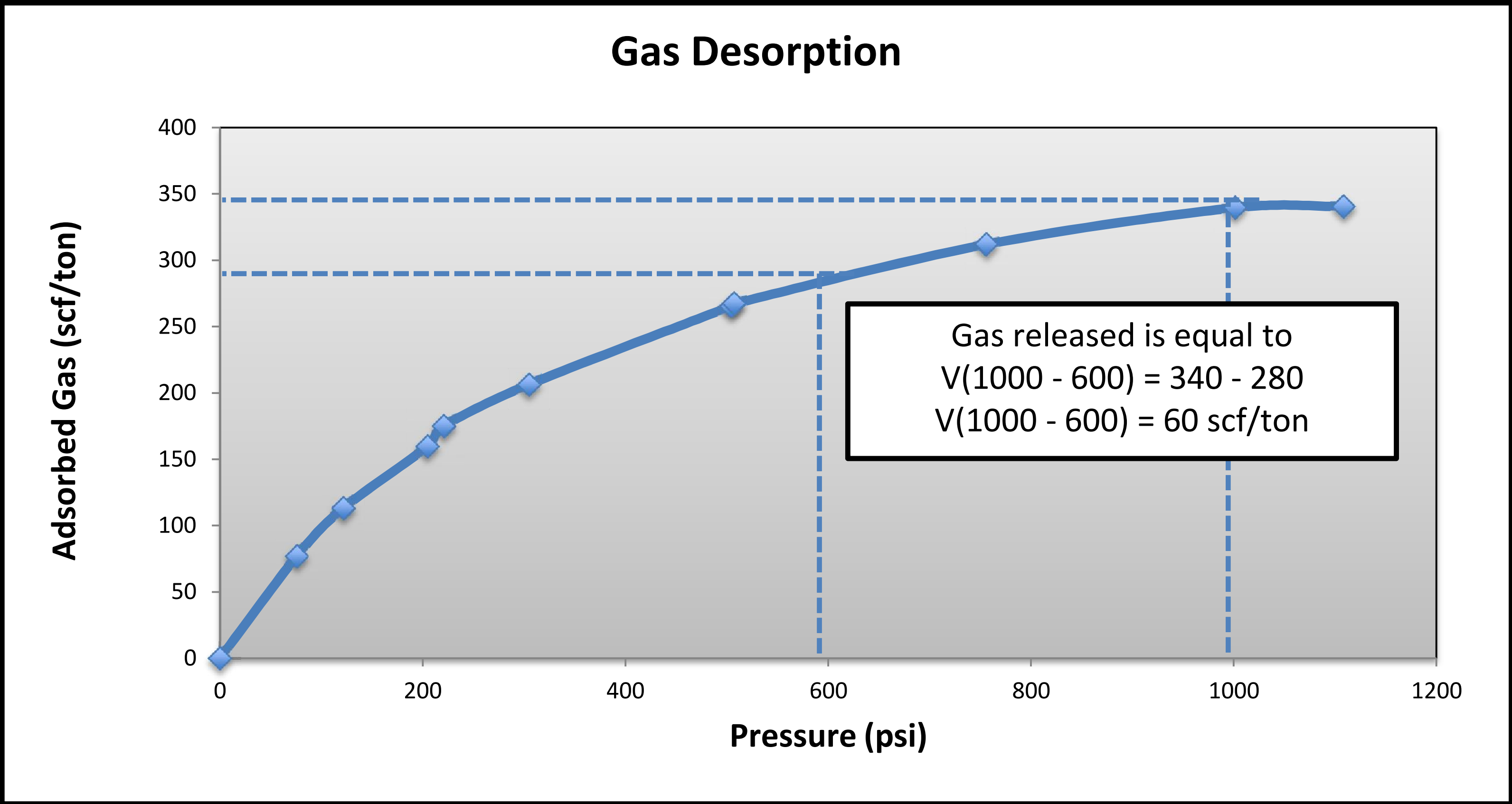
Langmuir Isotherm cont.



$$V(p) = V_L\left(\frac{p}{p + p_L}\right)$$

V_L is Langmuir's volume, max gas volume at infinite pressure
p_L is Langmuir's pressure, pressure corresponding to one-half V_L
V(p) is the volume of gas adsorbed per unit mass (scf/ton)

Desorption



$$V(p_i - p) = V_L\left(\frac{p_i}{p_i + p_L} - \frac{p}{p + p_L}\right)$$

Shale Gas MBE

Original Havlena-Odeh Gas MBE

$$G_p B_g + W_p B_w = G(B_g - B_{gi}) + G B_{gi} \frac{S_{wi} c_w + c_f}{1 - S_{wi}} \Delta p$$

My approach:

Production terms = reservoir drive mechanisms

Desorption

Nomenclature for drives

Desorption Drive

Each drive mechanism = reservoir barrels (rb)

Starting point: rb ⟷ (scf/ton) x ?

Reservoir bbls = desorption (scf/ton) * bulk density (ton/ft^3) * bulk volume (ft^3)*Gas FVF (rb/scf)

$$V_L\left(\frac{p_i}{p_i+p_L}-\frac{p}{p+p_L}\right) \quad 0.0312144\rho_b \quad \frac{G_a}{0.0312144\rho_b G_c} \quad B_g$$

*G_a = initial adsorbed gas in place (scf)

G_c = initial adsorbed gas content (scf/ton)

Desorption Drive cont.

Reservoir barrels due to desorption:

$$rb = V_L\left(\frac{p_i}{p_i + p_L} - \frac{p}{p + p_L}\right)0.0312144\rho_b \frac{G_a}{0.0312144\rho_b G_c} B_g$$

In simplified form:

$$rb = G_a B_g \frac{V_L}{G_c}\left(\frac{p_i}{p_i + p_L} - \frac{p}{p + p_L}\right)$$

*G_a = initial adsorbed gas in place (scf)
G_c = initial adsorbed gas content (scf/ton)

Reservoir Drive Alterations

Gas Expansion Drive

– Changed G to G_f

$G(B_g\text{-}B_{gi}) \rightarrow G_f(B_g\text{-}B_{gi})$

Pore Compaction/Water Expansion Drive

– Changed G to G_f for water exp./pore compaction

$$GB_{gi}\frac{S_{wi}c_w + c_f}{1 - S_{wi}}\Delta p \rightarrow G_f B_{gi}\frac{S_{wi}c_w + c_f}{1 - S_{wi}}\Delta p$$

*G_f = initial free gas in place (scf)

Proposed Shale Gas MBE

$$G_pB_g + W_pB_w = G_f(B_g - B_{gi}) + G_fB_{gi}\frac{S_{wi}c_w + c_f}{1 - S_{wi}}\Delta p + G_aB_g\frac{V_L}{G_c}\left(\frac{p_i}{p_i + p_L} - \frac{p}{p + p_L}\right)$$

Reformatted using Havlena-Odeh nomenclature:

$F = G_pB_g + W_pB_w$ (rb); net production

$E_g = B_g - B_{gi}$ (rb/scf); gas expansion

$E_{f,w} = G_fB_{gi}\frac{S_{wi}c_w + c_f}{1 - S_{wi}}\Delta p$ (rb/scf); pore & water exp.

$E_d = B_g\frac{V_L}{G_c}\left(\frac{p_i}{p_i + p_L} - \frac{p}{p + p_L}\right)$ (rb/scf); desorption

Proposed Shale Gas MBE cont.

The equation can be rewritten in the format:

$F = G_f E_g + G_f E_{f,w} + G_a E_d$

Simplified

$F = G_f(E_g+E_{f,w}) +G_a E_d$

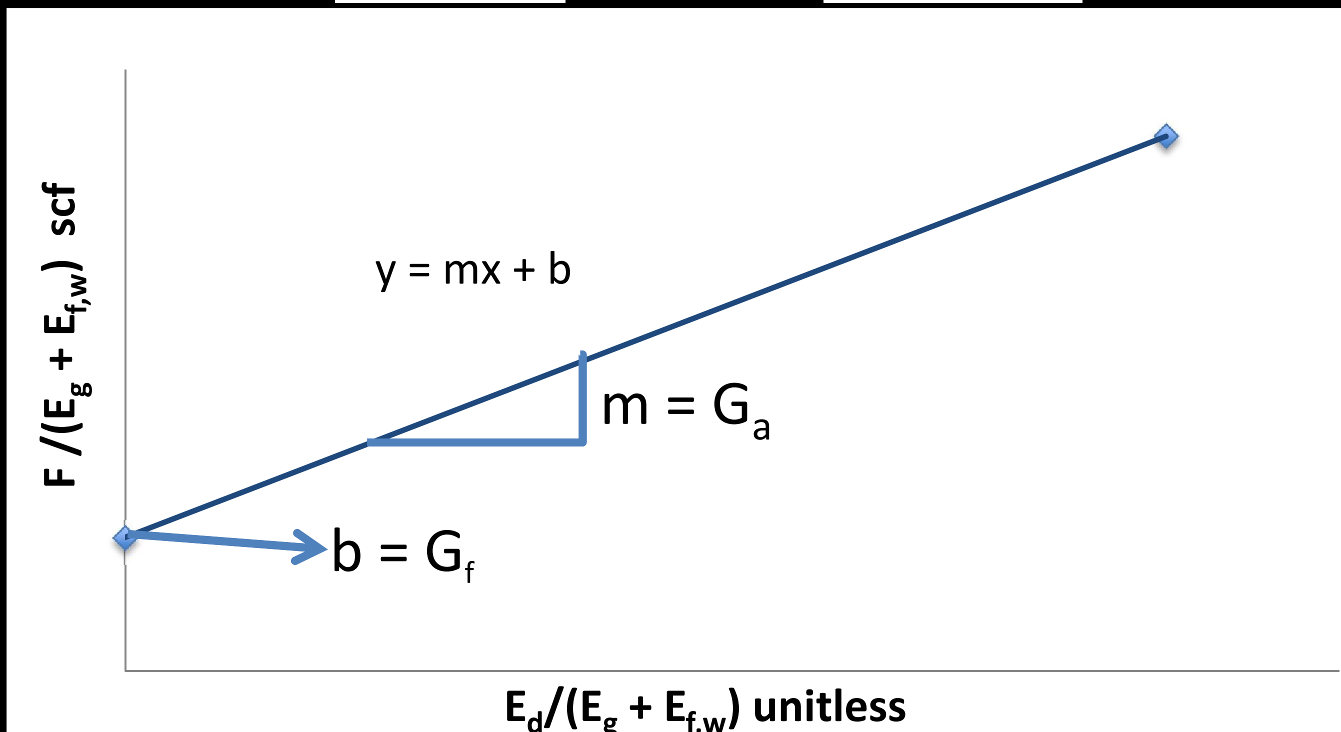
Dividing $(E_g+E_{f,w})$ to create:

$$\frac{F}{E_g + E_{f,w}} = G_a\left(\frac{E_d}{E_g + E_{f,w}}\right) + G_f$$

Straight Line Interpretation

A straight line can be generated by graphing:

$$\frac{F}{E_g + E_{f,w}} \quad \text{vs.} \quad \left(\frac{E_d}{E_g + E_{f,w}}\right)$$



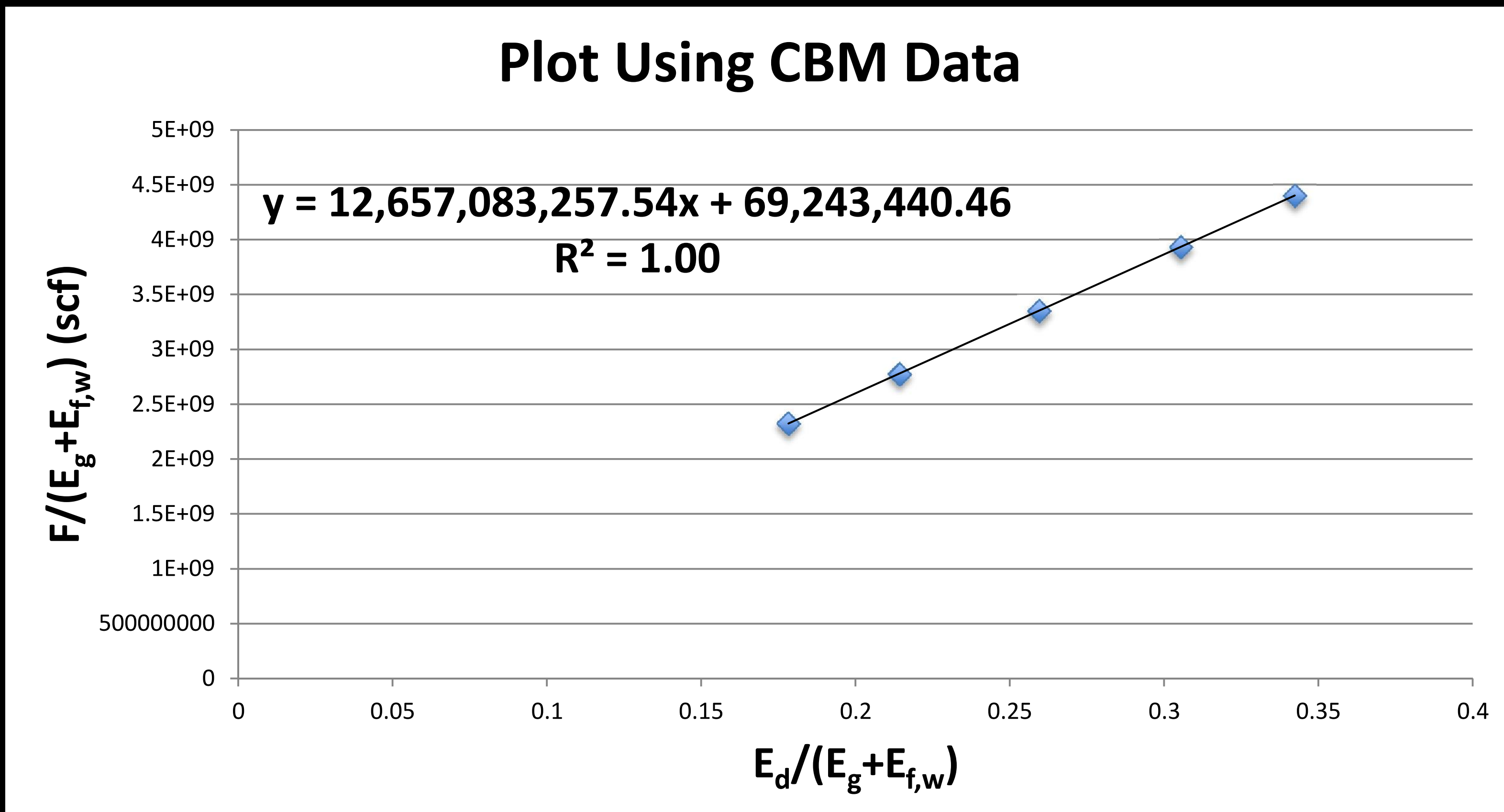
Coal Bed Methane Analogy

Assumptions:

- Similar Reservoir drive mechanisms
- Geological characteristics not a factor
- High water production does not affect analysis

Desorption is present in both reservoirs!

Example Plot Using CBM data



- Graph: G_a = 12,657 MMscf and G_f = 69,243 Mscf
- Volumetric: G_a = 12,763 MMscf and G_f = 37,189 Mscf

Project Findings

Results

- Created MBE analysis
- Was not able to estimate G_f
- Method appropriate for dry and wet gas
- Increase accuracy of reserve estimates

Recommendations

- Apply method to Marcellus/Utica dry or wet gas reservoir
- Determine effect of pore compaction/water expansion drive for shale reservoirs
- Attempt to Generate adsorption isotherm

Questions

Conclusion

- ✓ Material Balance Equation
- ✓ Errors Associated with p/Z method
- ✓ Adsorption/Desorption
- ✓ New method to estimate reserves
- ✓ Recommendations for moving forward
- ✓ Thank You!

Rearranging for p/Z

Initial: $G_pB_g = G(B_g - B_{gi})$

$G_p = G\ (B_g - B_{gi})/B_g$

Substitute:

$G_p = G - GpZ_i/(p_iZ)$

Multiply Each side by p_i/Z_i

$G_pp_i/Z_i = Gp_i/Z_i – Gp/Z$

$G_p/Z = p_i/Z_i(G - G_p)$

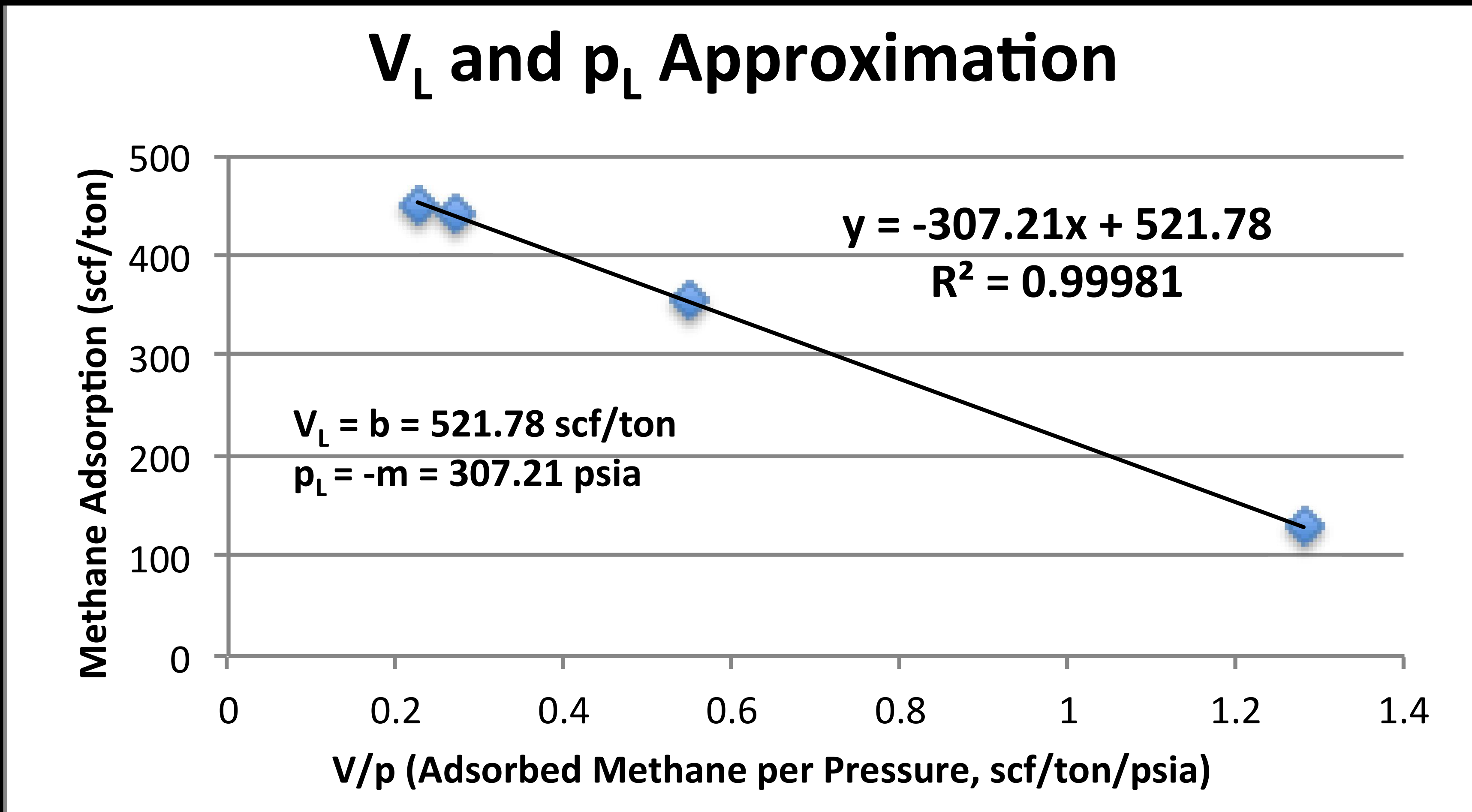
Divide out G

$p/Z = p_i/Z_i(1 - G_p/G)$

Final:

$$\frac{p}{Z} = \frac{p_i}{Z_i}\left(1 - \frac{G_p}{G}\right)$$

Approximating Langmuir Volume and Pressure



Bulk Volume Calculation

Start: $G_a = 1359.7Ah\rho_b G_c$

Where

CF = 0.0312144 (ton/ft^3) per (g/cc)

G_c = initial adsorbed gas content (scf/ton)

ρ_b = bulk density (g/cc)

1359.7 = 43560*0.0312144

End: 43560Ah (ft^3) = $G_a/(0.0312144\rho_b G_c)$

BET Isotherm

- Mathematical equation:

$$V(p) = \frac{V_{mono} C(\frac{p}{p_o})}{(1 - \frac{p}{p_o})(1 + C(\frac{p}{p_o}) - \frac{p}{p_o})}$$