Standard Techniques for Sampling
and Data Analysis to Estimate CMM/CBM Reserves

Workshop on Best Practices in Coal Mine Methane Capture and Utilization

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“You can’t manage what you don’t measure.”

- Peter Drucker
Several key reservoir parameters governing the calculation of CMM/CBM resources and ability to produce these resources have either not been measured or have been measured improperly in Colombia.

Therefore difficult to assess the country’s true CMM/CBM potential.

Presentation seeks to provide an overview of how Colombia can cost-effectively obtain critical reservoir parameters governing storage and flow of methane in coal seams.
## Reservoir Parameters Needed to Accurately Predict CMM/CBM Production

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Potential Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas content*</td>
<td>Core, canister test</td>
</tr>
<tr>
<td>Permeability*</td>
<td>Well test, production data</td>
</tr>
<tr>
<td>Desorption isotherm*</td>
<td>Lab measurements on core</td>
</tr>
<tr>
<td>Coal rank</td>
<td>Lab measurements</td>
</tr>
<tr>
<td>Seam thickness</td>
<td>Logs, core</td>
</tr>
<tr>
<td>Pressure</td>
<td>Well test</td>
</tr>
<tr>
<td>Temperature</td>
<td>Logs</td>
</tr>
<tr>
<td>Cleat spacing</td>
<td>Core samples, outcrop measurements</td>
</tr>
<tr>
<td>Diffusion co-efficient</td>
<td>Canister test</td>
</tr>
<tr>
<td>Compressibility</td>
<td>Production analysis</td>
</tr>
<tr>
<td>Gas saturations*</td>
<td>Gas content/isotherm</td>
</tr>
<tr>
<td>Desorption pressure</td>
<td>Canister test, lab measurements</td>
</tr>
</tbody>
</table>

*Denotes critical reservoir parameter
Key Reservoir Parameters for Storage & Flow of Methane in Coal Seams

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Importance</th>
<th>Status in Colombia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permeability</td>
<td>~40% of Production</td>
<td>No published permeability measurements</td>
</tr>
<tr>
<td>Gas Content/Saturation</td>
<td>~ 40% of Production</td>
<td>Mixed results and reliability</td>
</tr>
<tr>
<td>▪ Gas Content</td>
<td></td>
<td>Measurements often too shallow, not representative of in-situ conditions</td>
</tr>
<tr>
<td>▪ Isotherms</td>
<td></td>
<td>Non-standard curves yield unreliable results</td>
</tr>
<tr>
<td>Other Parameters (Cleat Spacing, Sorption Time, Porosity, etc.)</td>
<td>~20% of production</td>
<td>Mixed availability</td>
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</tbody>
</table>
Permeability

▪ Single most important and variable CBM reservoir parameter.
▪ Hard to measure: Core useless. Well test better. Production simulation best.
▪ Generally about 1.0 mD is minimum necessary for economic CBM production (depends on thickness, gas content, saturation, costs, and gas prices).
▪ Permeability tends to improve over time as reservoir dries out and shrinks, opening cleats.
- Permeability must be measured in situ (core unreliable)
- Permeability generally declines with depth
Variability in Gas Productivity Due to Permeability

![Graph showing cumulative gas recovery over time for different permeability conditions.]

- **Base Case**
  - Low Stress, Naturally Fractured (10 md)

- **Low Stress, Moderately Fractured (2 md)**

- **High Stress, Poorly Fractured (0.5 md)**

Cumulative Gas Recovery, Bcf

Time, Years

- 7.3 Bcf
- 2.7 Bcf
- 0.9 Bcf
Determination of the Gas Content

- **Direct Method**
  - Core desorption measurement – U.S. Bureau of Mines
  - Core desorption measurements – other
  - Drill cuttings desorption measurements

- **Indirect Method**
  - Sorption isotherm/pressure
  - Analogy
    - Gas content/depth relationships
    - Geophysical logs
Desorbing Coal Core for Gas Content

PERCENT TOTAL GAS DESORBED - Bulk Sample

- Q1 Lost Gas
- Q2 Desorbed Gas
- Q3 Residual Gas

Cumulative Volume Gas (%)

Time (Days)

Desorption Record

Lost Gas  Residual Gas
## CBM Gas Content – Final Desorption Analysis

### Q1: Desorbed Gas

<table>
<thead>
<tr>
<th>sample ID</th>
<th>sample weight (g)</th>
<th>air dried basis</th>
<th>dried basis</th>
<th>dry and ash free basis</th>
<th>desorbed gas (cm³)</th>
<th>lost gas (cm³)</th>
<th>residual sample wt (g)</th>
<th>residual gas volume (cm³)</th>
<th>gas content(cm³/g)</th>
<th>methane content(cm³/g)</th>
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<td><strong>Coal Average</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>1007</td>
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<td>9.61</td>
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<td>12.86</td>
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<tr>
<td><strong>Coal Average</strong></td>
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<td><strong>12.07</strong></td>
<td><strong>12.17</strong></td>
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</tbody>
</table>

### Q2: Lost Gas

### Q3: Residual Gas

### Total Gas Content

<table>
<thead>
<tr>
<th>sorption time (days)</th>
<th>12.75</th>
<th>12.92</th>
<th>14.95</th>
<th>11.41</th>
<th>11.57</th>
<th>13.39</th>
<th>15.94</th>
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<tbody>
<tr>
<td><strong>Coal Average</strong></td>
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</tr>
</tbody>
</table>
Sorption Isotherm - Measurement

- Fresh coal samples, preferably from canisters after gas content desorption (>100 g).
- Low-ash (<20%) samples much preferred since less adjustment to d.a.f. basis.
- Run at constant reservoir temperature (“isotherm”). HT = lower sorptive capacity (entropy).
- Langmuir EQN: $V_L = \text{Langmuir Volume (asymptote)}$  
  $P_L = \text{Langmuir Pressure (curviness)}$

- Lab pulverizes coal, allows it to reach equilibrium moisture.
- Inject methane, allow coal to sorb. Measure methane volume.
- Typically run at 6 to 8 different pressures to fit Langmuir curve.
- Try to run various coal ranks and maceral content combinations to bracket reservoir variability.
- Few labs in the world are reliable.
Adsorption/ Desorption Isotherm

Moisture Content = 5.2% (avg)
Temperature = 115°F

\[ V = 685 \times P / (P + 267) \]
Gas Content and Gas Saturation

- Potential Problem: If actual gas content is less than the theoretical storage capacity of the coal, as defined by the sorption isotherm, then gas production would be delayed and reserves reduced.

Saturated coal seam (A) contains the maximum gas content that is theoretically possible, as defined by the sorption isotherm determined in the laboratory. Gas production begins immediately at start of de-watering and pressure drawdown.

Undersaturated coal seam (B) contains less methane than the coal seam can adsorb, due to a prior de-gassing event. Several years of de-watering and pressure drawdown are required even to elicit gas production; ultimate reserves are reduced.

Gas content is a key parameter to measure during an exploration testing phase.
Gas Content and Gas Saturation

- Corehole 1 is highly under-saturated.
- Corehole 2 is saturated below a depth of about 800 m.
- Note data scatter and uncertainty.
Effects of Undersaturation on Gas Production

- Production Decline: Gas production is delayed and lower for under-saturated compared with saturated coal reservoirs, harming economics.
How Can the Required Reservoir Parameters be Obtained?

In many countries, diamond-drill coring rigs used in the mining industry can be used to cost effectively obtain critical reservoir parameter samples.

- Capable of continuously coring to depths up to 1,500 m (BQ or 1.5”)
- Most employ a wireline coring system for quick trip times (<10 min); minimizes errors in measuring gas content
- Allows for low-cost delineation of coal geometry, gas content/gas saturation, and other reservoir properties
Coring the Well

- The core is retrieved with a wireline to minimize gas loss
- **Advantages**
  - Can cut and recover cores without pulling the drillstring
  - Does not require continuous coring
  - Quicker retrieval of the core
  - Usually lower cost than conventional drilling rig

Highly portable mineral coring rig (LF 70), NQ-sized core (1-7/8”), 10 foot core per trip.
Injection Testing Equipment for Permeability

Straddle Packer System

- 2 7/8” tubing – work string
- 2 7/8” pin
- 2 7/8” down hole ball valve
- 2 3/8” x 2 7/8” X-over
- J-sub
- Control sub
- Top straddle packer
- 1/8” SS tubing pigtail
- 2 3/8” x 2 7/8” X-over
- 2 7/8” tubing spacer
- 2 3/8” x 2 7/8” X-over
- 1/8” SS tubing
- 2 3/8” blank plug
- 2 3/8” perforated sub (press gauge carrier)
- 2 3/8” x 2 7/8” X-over
- 1/8” SS tubing pigtail
- Bottom straddle packer
- 2 3/8” perforated sub w/bottom plug or orange peeled

Surface Set Up

Injection Pump

Well Test Manifold

Nitrogen Bottles

Nitrogen Tubing
Down-Hole Injection Testing Set-Up

Selection Criteria

- Number of Zones to Test
- Stratigraphic Control
- Hole Stability
- Drilling Efficiency
- Mud Quality
- Equipment Availability
- Costs
Equipment for Desorption Testing of Coal Samples

Manometric Set-Up

Canister Diagram

- Needle Valve
- Hose Adapter
- O-Ring
- Clamp
- 30 psig Gauge
- Continuous Weld
- 14 inches (0.36m)
Desorbing the Core

Procedures

- Ensure that you are sampling at in-situ conditions
- Gas content team conducts lost gas desorption.
- 10-min reading intervals for first hour.
  - 15-min intervals from hour 1 to hour 2.
  - 30-min intervals from hour 2 to hour 3.
  - 1-hour intervals from hour 3 to hour 6.
  - 2-hr intervals from hour 6 to hour 12.
  - 4-hr intervals from hour 12 to hour 24.
  - 8-hr interval from hour 24 to hour 48.
  - Once daily thereafter.
- Keep canisters in thermal bath inside trailer for at least two weeks.
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