A Parametric Study on the Benefits of Drilling Multilateral and Horizontal Wells in Coalbed Methane Reservoirs

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- Coal is an unusual reservoir rock, with highly complex reservoir characteristics.

- A significant amount of gas is stored in the coal rock, rather than the pore space.

- CBM production is a complex phenomenon, which has a unique behavior that needs careful consideration.
motivation > CBM Background

1 Fluid production from natural fractures...

2 Gas desorption from coal surface...

3 Molecular diffusion through the coal matrix...
Phase 1:
- Constant water production
- BHP declines and reaches its minimum.
- Gas rate starts to incline.
motivation > CBM Background

Phase 2:
- Significant decline in water rate
- Negative decline in gas rate
Phase 3:
- Gas rate starts to decline
- Water production becomes negligible
motivation > Unconventional Wells for CBM

- Very large areas of CBM reservoirs can be drained with horizontal well configurations.

- In a very short time, coal system can be dewatered and peak gas rate can be reached.

- Most optimum well direction, shape, and position must be determined after considering economical limits.
motivation > Parametric Studies

- Changing one variable at a time to see its influence.

- With the current computer power, an important optimization tool to analyze behaviors of different types models.

- Helps us to understand and optimize complex processes such as CBM recovery.
Objectives

Conducting parametric studies in order to:

1. Investigate different horizontal and multilateral well configurations for the most optimum CBM recovery.

2. Investigate influences of different types reservoir characteristics on CBM recovery.
Flow chart

CBM reservoir model

Study on well configurations
- Well shapes
- Total horizontal length
- Spacing between laterals

Identify the most optimum well configuration

Study on reservoir characteristics
- Permeability
- Time constant
- Gas content

Study on thickness
The Model

- A dual-porosity, homogeneous reservoir model with Cartesian grid system.

- Model properties:
  - 31*31 grid block system, each block: 120*120 ft$^2$
  - Constant vertical depth = 1,000 ft
  - Constant drainage area = 320 acres
  - Production period = 15 years.
  - Initial default thickness = 4 ft
Study 1
Well Configurations
- Five horizontal well shapes have been identified to investigate:

- Single lateral
- Dual lateral
- Trilateral
- Quad lateral
- Pinnate
Investigated Parameters

1. Total Horizontal Length (THL)
2. Spacing Between Laterals (SBL)
Total Horizontal Length (THL)
Methodology

1. Determine the Spacing between Laterals (SBL)

2. Determine the well shape (single, dual, tri, quad, pinnate)

3. Change the Total Horizontal Length from min. to max.
Single-lateral
Tri-lateral

- SBL = 170 ft
- SBL = 340 ft
- SBL = 680 ft
- SBL = 1,360 ft

**Graph Details:**
- **Y-axis:** Gas Recovery, %
- **X-axis:** Horizontal Length, ft

**Legend:**
- SBL = 170 ft
- SBL = 340 ft
- SBL = 680 ft
- SBL = 1,360 ft
Pinnate (Fish-bone)

SBL = 120 ft
SBL = 240 ft
SBL = 360 ft
SBL = 480 ft
SBL = 600 ft
SBL = 720 ft

Horizontal Length, ft

Gas Recovery, %
Suggested configuration for gas recovery:
Quadlateral, with SBL = 680 ft, THL = 8,000 ft.
Now, let’s look at economics.
After considering economics:
Quadlateral, with SBL = 680 ft, THL = 3,100 ft.
Study 2
Reservoir Characteristics

- Permeability
- Time constant
- Gas content
Permeability

Gas Recovery vs. Permeability, md
Time Constant

- Time required for gas to be desorbed off the coal surface and diffuse through the coal into the cleat system.

- Also known as sorption time, and an important parameter for time-to peak-gas.

- May vary from less than a day, to 300 days based on the coal composition, rank, and cleat spacing.
Time constants ranging between 10 days to 200 days brought a recovery range of 0.26-0.29.
Time Constant

Different gas recoveries were caused by the difference in the amount of cumulative gas production occurred in the 1st year production.
Difference in 1st year cumulative production yielded a $\approx 200,000$ difference in the Net Present Value.
Gas Content

- Very critical parameter that influences the gas recovery from coal.

- Gas content values: 350 scf/ton, 395 scf/ton, 450 scf/ton

- Five different isotherms were generated by changing Langmuir pressure and volume constants.
## Gas Content

<table>
<thead>
<tr>
<th>Modification</th>
<th>$V_L$, scf/ton</th>
<th>$P_L$, psi</th>
<th>Gas content, scf/ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modification 1</td>
<td>480</td>
<td>167.5</td>
<td>350</td>
</tr>
<tr>
<td>Northern App.</td>
<td>542.03</td>
<td>167.5</td>
<td>395</td>
</tr>
<tr>
<td>Modification 2</td>
<td>480</td>
<td>96.84</td>
<td>395</td>
</tr>
<tr>
<td>Modification 3</td>
<td>617.5</td>
<td>167.5</td>
<td>450</td>
</tr>
<tr>
<td>Modification 4</td>
<td>480</td>
<td>30</td>
<td>450</td>
</tr>
</tbody>
</table>
Gas Content

The graph depicts the relationship between pressure (psia) and gas content (scf/ton) for different modifications and regions. The modifications include:
- Modification 1
- Northern Appalachia
- Modification 2
- Modification 3
- Modification 4

The graph shows the following:
- The gas content increases with increasing pressure.
- Each modification and region has a distinct curve.
- Northern Appalachia has the highest gas content at higher pressures compared to the other modifications.
- The curves for Modification 3 and Modification 4 are very close, indicating similar gas content trends.

The x-axis represents pressure (psia), and the y-axis represents gas content (scf/ton).
Study 3
Thickness

\[
\begin{align*}
&h_1 \\
&h_2
\end{align*}
\]
**Thickness**

Case 1

Single layer, \( h = 4 \text{ ft} \)

Case 2

Single layer, \( h = 12 \text{ ft} \)

Case 3

Three layers, each \( h = 4 \text{ ft} \)

Total \( h_{\text{TOTAL}} = 12 \text{ ft} \)
**Thickness**

Well Configuration 1

- Single well

Well Configuration 2

- Four-spot

Well Configuration 3

- Horizontal
Thickness

![Graph showing gas recovery in different well configurations](image)

**Well Configuration**

- Single vertical well
- Four-spot vertical
- Horizontal

**Gas Recovery**

- 4 ft
- 12 ft
- 3 x 4 ft
 Thickness

<table>
<thead>
<tr>
<th>Well Configuration</th>
<th>Net Present Value (NPV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single vertical well</td>
<td>$1,000,000.00</td>
</tr>
<tr>
<td>Four-spot vertical</td>
<td>$1,500,000.00</td>
</tr>
<tr>
<td>Horizontal</td>
<td>$2,500,000.00</td>
</tr>
</tbody>
</table>
Summary

- A parametric study to determine benefits of horizontal and multilateral wells is presented.

- Different well configurations such as single-, dual-, tri-, quad-laterals, and pinnate were investigated by changing:
  - Spacing between laterals (SBL)
  - Total horizontal length (THL)

- Influences of some reservoir characteristics were investigated by changing:
  - Permeability
  - Time constant
  - Gas content
  - Thickness
Conclusions

- CBM recovery can significantly benefit from unconventional well configurations.

- Considering a 320 acres of drainage area, the optimum configuration that the results of this study suggests is:
  - Quadlateral well configuration:
    SBL = 680 ft, and THL = 3,100 ft.

- Time constant has a significant effect on the first year production, although it does not have a considerable effect on overall recovery.
Acknowledgements

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