Enhanced Gas Recovery: Devonian Shale

KYCCS Focused Research

11-Jan-2008
HB-1, Section 57

- Specifies: “At least one of the wells will test the Devonian shale for enhanced gas recovery and sequestration potential.”

- Encourages: the Survey to “…use these funds to match available federal and private funds to the extent possible.”
Geology of Devonian Shale

Key

- Limit of shale occurrence
- 1000 ft drilling depth
- Area of thick and deep shale
- Major fault trends

Structure elevation (ft)
- High: 955.077
- Low: -4144.95

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Devonian Shale Reservoir

- Low permeability (microdarcies)
- Micro-porosity
- Organic-rich (up to 25% TOC)
- Thickness
  - > 1,600 feet (eastern Kentucky)
  - > 400 feet (western Kentucky)
- Kentucky’s most active and prolific gas producer
A “shale” well is...

• Top Sunbury to top underlying carbonates
Cross Section

Shading based on density (RhoB)

<2.4

More organic

2.4 - 2.8

More clastic

>2.8

72 miles

W

1,600 feet

E

More organic

More clastic
Cross Section Notes

- Perry to Pike Counties, eastern Kentucky
- Thickens across the Big Sandy Gas Field
- More organic-rich zones (blue & green)
- Grayer, less organic shales (yellow & red)
- Some organic-rich zones pinch out
Hyperbolic Decline

Deplete free gas in fractures

Desorbs from fracture faces

Desorption and diffusion through shale matrix

Natural fracturing is key to production

Recno: 115246, qi=0.964, b=1.642, di=-0.3887 (HYP)

Data
Best fit, t=0
Optimum
GTI Cumulative Production

Industry rule of thumb is 300 MMcf per well
Cumulative Production Notes

- 50% of shale wells produce at least 692 million cubic feet (MMcf) in 50 years
- Long production history indicates large adsorbed gas content
Why Test the Devonian Shale?
CO$_2$ Enhanced Gas Recovery

• Demonstrated in coal
  – Low-permeability
  – Organic-rich
  – Fractured
  – Continuous

• Potentially huge storage volume
  – > 25 billion tonnes
Production Data

Long-term, nearly flat decline

Production for some wells inclines

GTI Proprietary Data
Production Data Notes

- Long-term, nearly flat production suggests diffusion of adsorbed gas over time
- Some wells exhibit production incline, again suggesting adsorbed gas
- Indicates large volume of gas available to trap CO$_2$ as an adsorbed gas
Isotherms Indicate Preferential Adsorption

Expected reservoir pressure

Average CO$_2$: 42.9 scf/ton
Average CH$_4$: 8.1 scf/ton

CO$_2$ = 5.3 x CH$_4$

@400 psia
Isotherm Notes

- At a given temperature, as pressure is increased, the amount of gas adsorbed increases.
- 5.3 volumes of \( \text{CO}_2 \) could displace a single volume of natural gas (\( \text{CH}_4 \)).
CO$_2$/Sand Frac Study

• Yost, Mazza, & Gehr, 1993, SPE 26925
• Fast flowback (2 to 3 days)
• Preliminary production
  – 56% > N$_2$ frac wells
  – 4.8 x shot wells
• Consistent with CO$_2$ adsorption
Testing CO$_2$ Injection for Enhanced Gas Recovery in the Shale
Well Selection Criteria

• Standard of open-hole nuclear logs
• Uncased for logging and sampling
  – Rotary sidewall cores, ECS, and others
• Detailed production data (line pressures?)
• Preferred: Nitrogen/foam or slickwater frac, sand propped (or not yet stimulated)
Site Selection Criteria

- Sufficient size pad for equipment
- Access for CO$_2$ delivery
- Operated by company willing to risk future production (assume liability)
  - Surface, royalty, and working interest owners agree
- Control of all wells within “area of review” for EPA Class V permit
Pre-injection: Data Acquisition

- **Well sampling**
  - Digital Logs, $\Phi$, $k$, mineralogy, TOC, cores
  - Gas composition
  - Microseismic (VSP) or logging for fracture identification

- **Stimulation**
  - Injection rate, volume, pressure, breakdown pressure, flowback period

- **Background MMV**
Pre-injection: Modeling

- Simulation
  - Multi- $\Phi$, multi-$k$ model
  - Production history match
  - Cyclic Huff-’n’-puff (single well)
  - CO$_2$ flood (multi-well)
  - Determine optimum shut-in (soak) times and injection rates
- EPA permitting (must submit required data)
- Background MMV
Injection

- Injection volume, rate, pressure, and shut-in times
- Production data
  - Continuous, for injection and monitor wells
  - Rate & composition (variations in CO$_2$ content)
  - Pressure
  - Mass balance calculations
Post-injection

- History match & model verification
- Assessment & analysis
- MMV continues
- Reporting
Indicators of Success

• Increase in gas production rate
• Mass balance indicates CO$_2$ adsorption
• After flowback and cleanup, pipeline quality gas
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