Evaluating Shale Gas Wells Using Rate and Flowing Surface Pressure Data

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OUTLINE

1. Shale Gas Production - What made it possible?
2. Flowing Material Balance - Estimating Contacted OGIP
3. PI Method - Estimating Recoverable Gas
Shale Gas Production
What Made It Possible?

Flow Rate $\propto$ Permeability x Area / Distance

So which of these three parameters did the industry work on?

Conventional Reservoir
- Good K
- Small Area = $2\pi r_w h$
- Large Distance
- Radial Flow

Tight Gas Reservoir
- Low K
- Increased Area = $2Lh$
- Large Distance
- Linear Transient Flow

Shale Gas Horiz Multi-Stage Frac
- Enhanced K in SRV
- Significantly Increased Area
- Significantly Decreased Distance
- Complex Flow with Early BDF

SPE 7490

How about ALL THREE!

SPE 136696 and 145080

SPE 136696 and 145080

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WHAT IS IT?
• Dynamic (performance-based) estimate of contacted OGIP

HOW DO WE DO IT?
• Estimate FBHP from rate and flowing tubing pressure
• Estimate SIBHP from FBHP, rate and productivity index (PI)
• Perform gas material balance

DOES IT WORK?
• Have seen very “linear” FMB trends across numerous wells with as little as 3 months of data for the Haynesville (little longer for the shallower plays)
• Estimated connected OGIP volumes appear reasonable
• Estimated RF’s are typically 50-60% of contacted OGIP
FMB – What is it?

SIBHP estimated from
• Rate
• FTP, FBHP
• PI

FMB Illustration

P/Z and FBHP (PSIA)

Cumulative Gas (BSCF)

Gas Rate (MMSCFD)
Stress Dependent K

- FMB analysis requires a PI model
- A stress-dependent decline in K is used for shale wells
- Stress dependency must be determined independent of FMB analysis – need SIBHP from subject well or analog

\[
\frac{K}{K_i} = e^{-\gamma (p_i - p)}
\]

Yilmaz and Nur

Initial BHP = 11,000 psia
\( K/K_i = 1.0 \)
Rate and FTP vs Time – Example 1

Historical Gas Rate and FTP

Rate is constrained by high FTP

Good pressure build-up indicating SRV effective K is 0.1 md (not nanodarcies!)
Flowing Material Balance Analysis

Plotted points are NOT dependent on OGIP. They point to OGIP!
Solution algorithm is iterative.

Normalized PI data plot on straight line

OGIP = 15 BSCF

SIBHP survey confirmed OGIP trend line from FMB

OGIP = 15 BSCF
Rate and FTP vs Time – Example 2

Historical Gas Rate and FTP

Early rate profile very "flat" due to decline in FTP from opening choke
Flowing Material Balance Analysis

- Straight line (BDF) reached at Gp < 0.5 BSCF (< 3 mths)
- OGIP = 18 BSCF

OGIP = 18 BSCF
Rate and Pressure – Example 3

Profile impacted by multiple large choke changes. Would the method still work?

Rate is increasing or flat
Flowing Material Balance Analysis

- **P/z Ramagost**
- **P/z Ramagost - Calculated from PI**
- **Stress Normalized PI**

Good straight line trend despite multiple choke changes

Workover resulted in contribution from previously “plugged” perforations

OGIP = 19 BSCF
FMB Method – Multiple Examples

MULTIPLE WELLS
FMB Analysis

Cumulative Gas (BSCF)

P/Z (psia) with Ramagost Correction
Observations/Questions?

- FMB method seems to work across multiple shale plays including Haynesville, Eagleford, Niobrara and Marcellus.
- Is it a surprise the method still works with shallow, normally pressured shale plays?
- FMB trends have thus far remained straight suggesting:
  - GIIP is not increasing
  - Negligible contribution from outside of SRV (so far)
  - Free GIIP appears to be key, especially in early years which dominate recovery and NPV.
- Will the lines stay straight?
- Will there be material contribution from outside SRV?
PI Method
**The Motivation**

- Shale gas wells are often rate-constrained during the early years of production.
- Production rates can sometimes be near constant or even increasing as a result of choke changes.
- Decline curve analysis methods that rely only on rate data are not reliable in such circumstances.
- Thousands of US shale wells need to be analyzed each year. We wanted a simple forecast method that gave reliable estimates.

➢ Was there a straight line out there somewhere?
The Search

In Search of the Straight Line
“Let’s apply a little science to understand why the line is straight so we can more confidently predict the future and avoid any cliffs”

Scott Rees – NSAI CEO, March 2011
The PI Method

Why?
- Restricted rate and variable choke settings prohibit DCA
- Productivity Index (PI) trends are predictable
- Can address future operations (e.g. line pressure impact)
- Diagnostic of problems/issues (e.g. offset interference, well damage etc)
- EUR can be observed directly from the plot

How?
- Convert FTP to FBHP using tubing flow equation
- Calculate PVT properties including Pseudo Pressure m(p)
- Calculate PI as follows
  \[ PI = \frac{Q_{gas}}{m(p_i) - m(p_{wf})} \]
- Plot Log(PI) versus Gp
PI Method – Example 1

Rate restricted by high FTP

Transient increase in PI following shut-in

EUR can be “seen” from plot
PI Method – Example 2

**Historical Gas Rate and FTP**

- **Gas Rate:**
  - Historical trend.
  - Good straight line trend reached after < 0.5 BCF (< 3 mths).

- **FTP:**
  - Fluctuating trend.

**PI versus Cumulative Production**

- **PI (MMSCFD / (10^6 psia^2/cp))**
- **Cumulative Gas (BSCF)**
- Trend shows a decreasing PI with increasing cumulative production.
PI Method – Example 3

**Historical Gas Rate and FTP**

- **Profile impacted by large choke changes**
- **Rate increasing!**

**PI versus Cumulative Production**

- **Good straight line trend despite multiple choke changes**
PI Method – Multiple Examples

MULTIPLE WELLS

PI versus Cumulative Production

PI (MMSCFD / (10^6 psia\(^2\)/cp)

Cumulative Gas (BSCF)
Rate vs Time Forecast – Example 3

Historical and Forecast FBHP

Min. FBHP (line conditions)

FBHP forecast

Historical and Forecast Gas Rate and PI

Gas forecast

PI forecast

PI (history)

Gas rate (history)

PI forecast

Historical and Forecast PI

PI (history)

Gas rate (history)

PI (forecast)
Reservoir Simulation
RESERVOIR SIMULATION
K Layout and BHP distribution
RESERVOIR SIMULATION
Pressure Build-up Match – Haynesville Well

ECLIPSE MATCH OF SIBHP SURVEY

Shut-in Time (days) vs. SIBHP (psia)

- Actual
- Simulated
RESERVOIR SIMULATION
Rate Forecast – Haynesville Well

Gas Rate and Cumulative Gas
ECLIPSE versus PI Method

ECLIPSE and PI model are in good agreement.
Observations

- PI method seems to work across multiple shale plays including Haynesville, Eagleford, Niobrara and Marcellus
- Method advantages
  - Incorporates both rate and pressure data
  - Simple to implement - only need Rate, FTP and Initial BHP data
  - Provides EUR estimates with limited production history
  - Easy to convert to rate versus time forecast

➢ Will the lines stay straight?
Happiness is a Straight Line!