Predicting Cumulative Production of Devonian Shale Gas Wells from Early Well Performance Data, Appalachian Basin of Eastern Kentucky

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A “shale” well is…?

- Top Sunbury to top underlying carbonates

Sunbury
Berea

Cleveland
Three Lick Bed
Upper Huron

Middle Huron

Lower Huron

Olentangy

Rhinestreet
Early Performance Data

• Well log and completion report
  – Initial Open Flow
  – Rock Pressure

• Monthly production *(805 KAR 1:180, KRS 353.205)*
  – Maximum monthly production (Mcf)
  – First year cumulative production
  – 5 year cumulative production
Data Sets

- **KGS online well completion data**
  - Location, completions, IOF, RP
- **Division of Oil and Gas**
  - Public production data by month (1997)
- **Gas Technology Institute (GRI)**
  - Historic, long-term production data
  - *Proprietary*, available to members and contractors
Production Data Selection

- Completed since 1-Jan-97
- Devonian shale only (not commingled)
- 60 or more months of non-zero data
- 310 wells
Initial Open Flow Data

- Exhibits only weak trends
- No uniform method of acquiring
Reported “Rock Pressure”

- High and low open flows occur in areas of both high and low rock pressure.
Five-year Cumulative Production

• Again, weak trends
• Areas with higher and lower production are often adjacent
**Initial Open Flow**

Correlation is statistically significant, but weak

\[ y = 0.0886x + 43.204 \]

\[ R^2 = 0.25 \]
GTI Cumulative Production

Industry rule of thumb is 300 MMcf per well

Proprietary data
Cumulative Gas Production

Billion Cubic Feet vs. Years in Production

Class 1
Class 2
Class 3
Class 4

GTI data
Cumulative Production Over Time

\[ y = 1.8887x + 7.0426 \]

\[ R^2 = 0.9278 \]

GTI data
General Decline Model (Arps)

Hyperbolic:

\[ q_t = \frac{q_i}{\left(1 + b D_i t\right)^b} \]

Best fit parameters:
- \( q_i \) – initial production
- \( D_i \) – nominal decline
- \( b \) – decline exponent

Special cases:

Exponential, \( b = 0 \):

\[ q_t = \frac{q_i}{e^{D_i t}} \]

Harmonic, \( b = 1 \):

\[ q_t = \frac{q_i}{\left(1 + D_i t\right)} \]
Solving

Exponential:

Least squares

\[ \ln(q_t) = \ln(q_i) + D_i t \]

Hyperbolic:

Optimization

Linear Programming

Both can easily be done with the built-in functions supplied with spreadsheets, but…
Best Case: Textbook Data

Natural fracturing is key to production

Deplete free gas in fractures

Desorbs from fracture faces

Desorption and diffusion through shale matrix

$\text{Recno: 115246, } q_i=0.964, \ b=1.642, \ di=-0.3887 \ (HYP)$

$\begin{align*}
\text{At } t=1 \\
\text{HYP: } q(t) &= 1.00*(1.0 - 2.278*(-0.831)t)**(-1.0 / 2.278) \\
r^2 &= 0.9882
\end{align*}$
Challenges

- Noisy data (no trend)
- Shut-in
- Operational changes
- Apparent incline
Monthly Rate (Mcf/month)

r^2 = 0.9917, qi = 0.9561 × 10^4
No better fit found at alternate start times

Recno: 120560, qi = 1.000, b = 2.646, di = -1.5235 (HYP)
Normalized

\[ q_t = \frac{q_{obs}}{q_{\text{max}}} \]

Reino: 120560, qi=1.000, b=2.646, di=-1.5235 (HYP)

r^2 = 0.9917, qi=8565.11 (Mcf)
No better fit found at alternate start times
Recno 120560: Rate-Cumulative Curve

Rate-Cumulative
All declines, r > 0.25 and di > 0.5%

Semi-log plot
Rule of thumb:

\[ b \approx 3 \text{ to } 4 \]
Many data sets have a “decline” (i.e., slope) that is not statistically different from 0 (no correlation).
Max production is the initial period

For exponential decline, \( Q_i \) is often less than max production

For hyperbolic decline, \( Q_i \) is often greater than max production
Qi and maximum production are not correlated.
Basis of classification

- 25th percentile
- 50th percentile
- 75th percentile

Public data from the Kentucky Division of Oil and Gas
First Six Months of Production

\[ 6\text{moCum} = 101.7\times\text{MaxAvg} + 1938 \]

\[ r^2 = 0.87 \]

Public data from the Kentucky Division of Oil and Gas
Type Declines

Five-year cumulative production in million cubic feet

- Type 1: 143 MMcf
- Type 2: 78 MMcf
- Type 3: 46 MMcf
- Type 4: 23 MMcf
Conclusions

- Shale production data is messy
- Decline curve analysis and reserves projection is an art
- Maximum average daily production during the first 6 months is an adequate indicator of future well performance
- Best wells can be expected to make:
  - 20 MMcf in first year
  - 100 MMcf after 5 years
Thanks

- www.uky.edu/kgs
- bnuttall@uky.edu
- Oil and gas well search with production data
  - kgsweb.uky.edu/DataSearching/OilGas/OGSearch.asp
- Oil and gas well interactive mapping
  - kgsmap.uky.edu/website/KGSGeology/viewer.asp
- Project web page
  - www.uky.edu/KGS/emsweb/devsh/production/index.htm