Calculating Inflow Performance Relationships for Gas Wells

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Methods for Predicting Gas Well Inflow Performance or Deliverability

- Single-Phase Flow Methods
- Multi-Phase Flow Methods
- Vertical vs. Horizontal Well Configurations
Darcy’s Law

Four-Point Methods
- Conventional Backpressure Test
- Isochronal Test
- Modified Isochronal Test
- Forscheimer/Jones-Blount-Glaze/Houpert /LIT Equation

Single-Point Methods
- Analogy
- Guess
- Dimensionless IPR Methods
Darcy’s Law for Pseudosteady State Flow

• Must know reservoir rock and fluid properties

• Must calculate pseudopressures or approximate them with $P^2$

\[ Q_g = \frac{(0.000703) k_g h (\Psi_r - \Psi_{ws})}{T \left[ \ln(x) - \frac{3}{4} + S + DQ_g \right]} \]
Conventional Backpressure Test

- Developed by U.S. Bureau of Mines (1937)
- Requires 4 flow rates maintained to stabilization
Isochronal Test

- Must run 4 flow tests of equal duration
- Shut in well and build up to original reservoir pressure in between each flow test
- Must maintain one point to stabilization

\[ Q = C \times \left( P_r^2 - P_{ws}^2 \right)^n \]

 Isochronal Deliverability
Bubba Gump #1

\[ y = 0.3432x^{1.7113} \]
Modified Isochronal Test

- Four flow tests separated by shut in periods, all of equal duration
- One flow test must be maintained to stabilization

\[ Q = C \times \left( P_r^2 - P_{ws}^2 \right)^n \]
Jones-Blount-Glaze (LIT) Equation

- Just another method of analyzing test data from any 4-point test
- Calculate a & b from equations or empirical method

\[
\Psi_r - \Psi_{ws} = aQ_g^2 + bQ_g
\]

\[
a = \frac{(3.16 \times 10^{-12}) \beta \gamma_g T}{h_p r_w \mu_g}
\]

\[
b = \frac{(1424)T[\ln(0.472x) + S]}{k_s h}
\]

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Data Needed: one flow test only and shut-in average reservoir pressure

- Plot flow test point and assume n value or a and b values from analogy
- Plot flow test point and assume n = 1
- Use dimensionless IPR methods
The Dimensionless IPR Model

\[ \frac{m(P_{wf})}{m(P_R)} = 1 - M^* \left( \frac{Q}{Q_{max@Xe/Xf=1}} \right)^N \]

For \( X_e/X_f < 1E06 \):

\[
\log(M) = 0.004865 + 0.14312 \log(X_e/X_f) - 0.00989 \\
\quad \quad (\log(X_e/X_f))^2 + 0.00039 (\log(X_e/X_f))^3
\]

\[
\log(N) = 0.296498 - 0.0618 \log(X_e/X_f) + 0.00874 \\
\quad \quad (\log(X_e/X_f))^2 - 0.0004278 (\log(X_e/X_f))^3
\]

For \( X_e/X_f > 1E06 \):

\[
\log(M) = 0.0579 \log(X_e/X_f) + 0.3117
\]

\[
\log(N) = -0.0026 \log(X_e/X_f) + 0.1591
\]

Where \( X_e/X_f = 0.37 X_e (e^S)/r_w \) if \( X_e/X_f \) is not known from pressure transient test or if well is not hydraulically fractured.
Comparison of Single and Multi-Point Methods

- Surprisingly good agreement between single-point and multi-point methods

- Better than assuming $n = 1$ in backpressure equation

Figure 3. Dimensionless IPR AOFs and $n=1$ AOFs versus Multi-Point AOFs
Vertical Wells: Multi-Phase Flow Methods for Predicting Gas Well Inflow Performance/Deliverability

- Constant Productivity Index (Linear IPR)
- Darcy’s Law
- Jones-Blount-Glaze/Forscheimer/Houpert/LIT Equation
- Vogel’s Method
- Standing’s Method
- Harrison’s Modification of Standing’s Method
- Klins et al. Method
Constant Productivity Index/Linear IPR

- Flow rate is proportional to pressure drawdown and IPR is linear
- Valid above the bubble point but not below
Darcy’s Law for Pseudosteady State Flow

• Must know reservoir rock and fluid properties

\[ Q = \frac{(0.00708) \, kh \, (P_r - P_{ws})}{\mu \, B \, \left[ \ln(x) - \frac{3}{4} + S + DQ \right]} \]
Jones-Blount-Glaze Equation

- Can calculate a and b from equations or empirically from JBG plot

\[ P_r - P_{ws} = aQ^2 + bQ \]

\[ a = \frac{(2.30 \times 10^{-14}) \beta B^2 \rho}{h_p r_w} \]

\[ b = \frac{\mu B [\ln(0.472x) + S]}{(0.00708)kh} \]
Vogel’s dimensionless IPR Method

- Vogel’s method developed for solution gas drive reservoirs assumes zero skin factor or flow efficiency equal to one.
- Better than assuming linear IPR but not great

\[
\frac{Q}{Q_{\text{max}}} = 1.0 - 0.2 \left( \frac{P_{\text{wf}}}{P_r} \right) - 0.8 \left( \frac{P_{\text{wf}}}{P_r} \right)^2
\]
Standing’s Dimensionless IPR Method

- Vogel’s equation assumes $FE = 1$

- Standing’s allows for skin or $FE$

- Must be corrected for $FE > 1.2$ using third equation shown

\[ Q' = Q_b + Q_{\text{max}} = PI \times (P_r - P'_{\text{wf}}) \]

\[ P'_{\text{wf}} = P_{\text{wf}} + (1 - FE) \left( P_r - P_{\text{wf}} \right) \]

\[ \frac{Q}{Q_{\text{max}(FE = 1.0)}} = 1.2 - 0.2 e^{(1.792 P'_{\text{wf}}/P_r)} \]
Klins et al Method

- Accounts for skin factor
- Accounts for bubble point

\[
\frac{q_o}{(q_o)_{\text{max}}} = M \left[ 1 - 0.295 \left( \frac{p_{wf}}{p_r} \right) - 0.705 \left( \frac{p_{wf}}{p_r} \right)^n \right]
\]

...\(M = \frac{6.835}{(6.835 + s)}\)

...\(n = 1.235 + 0.72 \frac{p_r}{p_b} (1.235 + 0.001 p_b)\)
Retnanto-Economides Horizontal Well IPR Model

\[
\frac{q_o}{q_{\text{max}}} = 1 - 0.25 \left( \frac{p_{\text{wf}}}{p_r} \right) - 0.75 \left( \frac{p_{\text{wf}}}{p_r} \right)^n
\]

where...

\[
n = \left( -0.27 + 1.46 \left( \frac{p_r}{p_b} \right) - 0.96 \left( \frac{p_r}{p_b} \right)^2 \right) \left( 4 + 0.00166 p_b \right)
\]

\[
q_{\text{max}} = \frac{J p_r}{0.25 + 0.75n}
\]

\[
J = \frac{2 \sqrt{k_h k_v X_e}}{887.22 B_o \mu_o \left( p_D + \frac{X_e}{2 \pi L} s \right)}
\]

\[
p_D = \frac{X_e C_H}{4 \pi h} + \frac{X_e}{2 \pi L} s_x
\]

\[
s_x = \ln \left( \frac{h}{2 \pi r_w} \right) - \frac{h}{6 L}
\]

• Only single flow test required

• Wellbore configuration required
CONCLUSIONS

• Numerous methods are available to predict the IPR of a gas well

• Selection of method depends on well configuration (vertical or horizontal); phases flowing (single or multiple); and reservoir rock and fluid properties

• The accuracy of the resulting IPR is a function of the method chosen to calculate it

• Future IPR curves, although not discussed in this presentation, are easy to construct
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