SPE 77550

Direct Estimation of Gas Reserves Using Production Data

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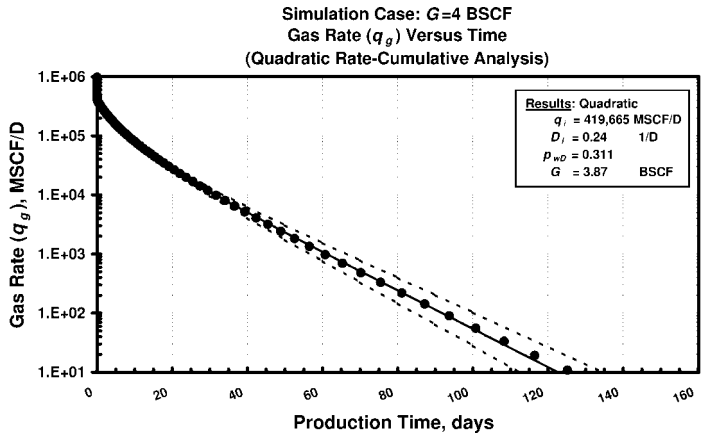
Executive Summary — "Rate-Cumulative" Relation

This work presents analysis and interpretation methodologies based on the "Knowles" rate-time solution for pseudosteady-state gas flow. The result of interest for this work is the quadratic "rate-cumulative" production relation given as:

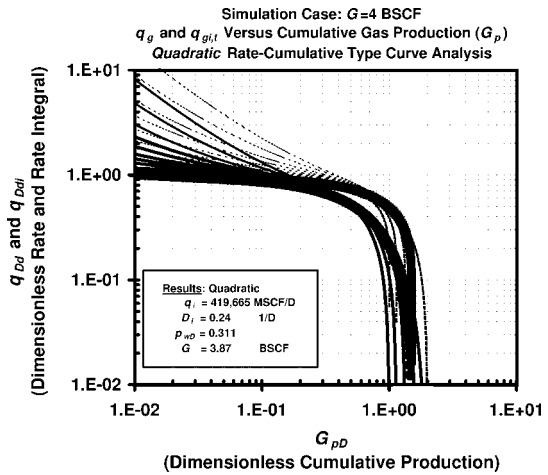
$$q_g = q_{gi} - \frac{2q_{gi}}{\left[1 - \left[\frac{p_{wf}/z_{wf}}{p_i/z_i}\right]^2\right]G} G_p + \frac{q_{gi}}{\left[1 - \left[\frac{p_{wf}/z_{wf}}{p_i/z_i}\right]^2\right]G^2} G_p^2$$

- **"Knowles" rate-time relations for gas flow:**
  - **Approximation valid for p_i<6000 psia.**
  - **Assumes p_{wf} = constant.**
  - **Quadratic "rate-cumulative" is basis for this work.**

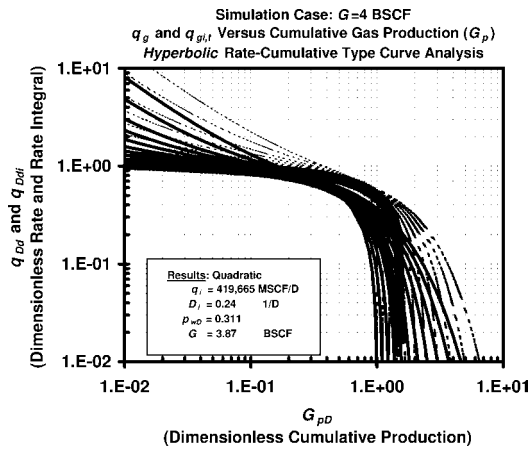
Executive Summary — Rate-Time/Cumulative



a. q_g vs. t: Simulated Gas Case



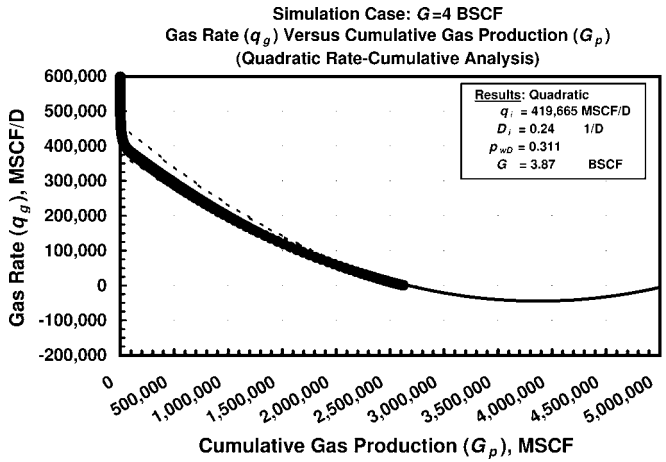
b. q_{Dd} and q_{Ddi} vs. G_{pD} (Quadratic Relation): Simulated Gas Case



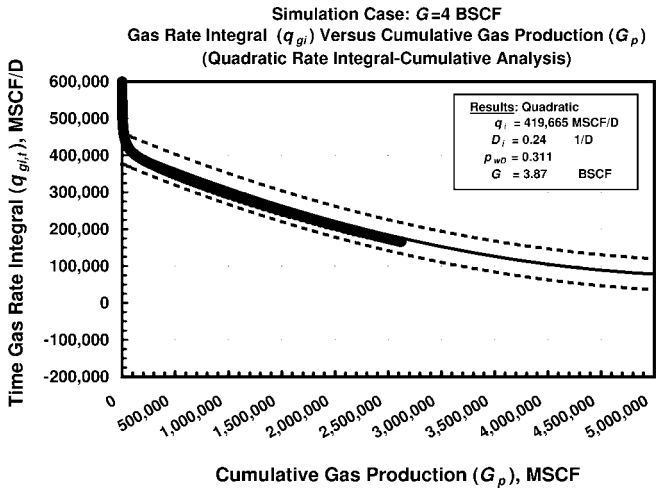
c. q_{Dd} and q_{Ddi} vs. G_{pD} (Hyperbolic Relation): Simulated Gas Case

- **Example Behavior:**
  - **Note that the gas rate-time data are matched extraordinarily well by the Knowles equation.**
  - **Quadratic q_{Dd} and q_{Ddi} vs. G_{pD} type curve reflects gas flow behavior.**
  - **Quadratic q_{Dd} and q_{Ddi} vs. G_{pD} type curve presented for comparison/completeness.**

Executive Summary — Rate-Cumulative Analysis



a. q_g vs. G_p: Simulated Gas Case

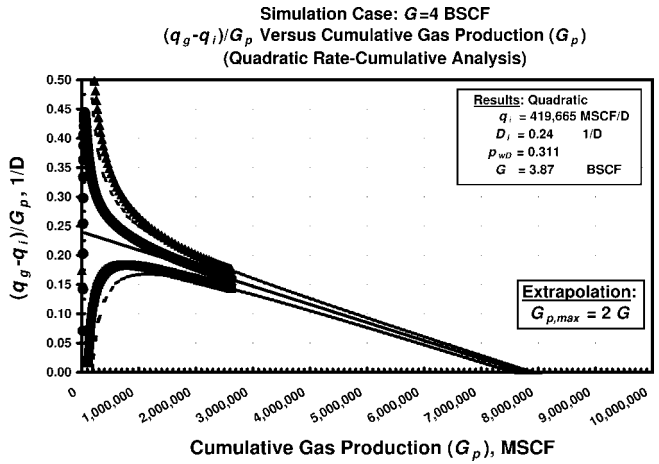


b. $q_{gi,t}$ vs. G_p: Simulated Gas Case

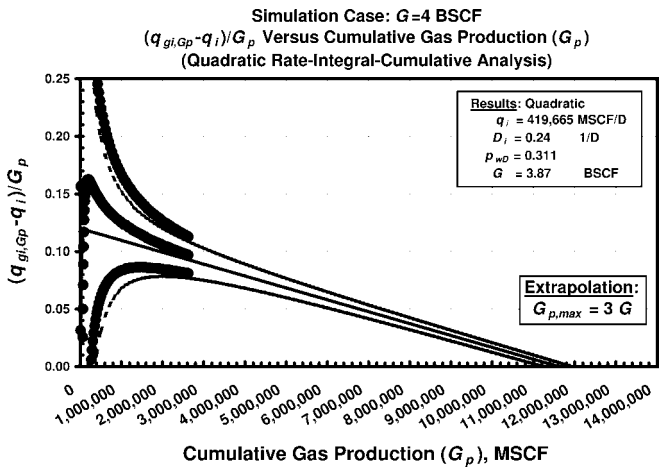
- **q_g vs. G_p:**
  - Used "spreadsheet" approach, with multiple data functions (on different plots) being matched simultaneously.
  - Data match is shown with "high" and "low" trends (+/- 10 percent) as well as the correct trend (over-lain in this figure).
- **$q_{gi,t}$ vs. G_p:**
  - Similar to the q_q vs. G_p plot (and used simultaneously with this plot). Smoother than q_q data.
  - $q_{gi,t}$ — definition:

$$q_{gi,t} = \frac{1}{t}\int_0^t q_g \, dt$$

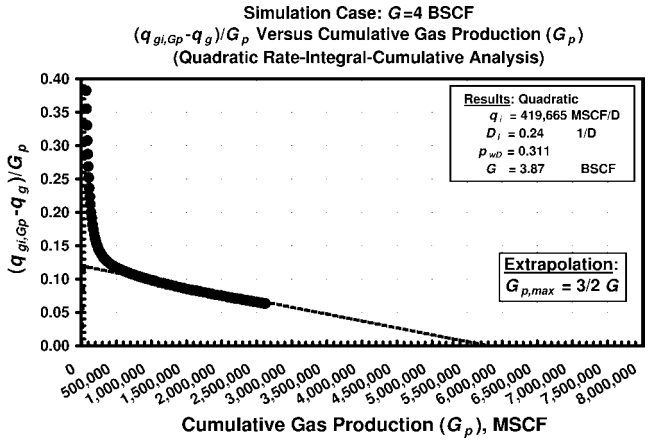
Executive Summary — Extrapolation Functions



a. $(q_g-q_i)/G_p$ vs. G_p: Simulated Gas Case



b. $(q_{gi,Gp}-q_i)/G_p$ vs. G_p: Simulated Gas Case



c. $(q_{gi,Gp}-q)/G_p$ vs. G_p: Simulated Gas Case

- **$q_{gi,Gp}$ vs. G_p:**
  - **A specialized extrapolation function that is tailored to the quadratic rate-cumulative behavior.**
  - **$q_{gi,Gp}$ — definition:**

$$q_{gi,Gp} = \frac{1}{G_p}\int_0^{G_p} q_g \, dG_p$$

Outline

- Executive Summary
- Rationale for This Work
- Orientation
  - Introduction of the new method.
  - Plotting functions for extrapolation.
- Application of the New Method: Field Case
  - Rate-time and rate-cumulative analysis.
  - Extrapolation plotting functions.
  - Type curves for matching q_g (and $q_{gi,t}$) vs. G_p.
- Summary
- Recommendations for Future Work

Rationale for This Work

- The estimation of gas reserves is a major issue — the methodology used and the accuracy of the results are a function of the time of production and available production data.
- Goals:
  - Simple (non-simulation) technique to estimate gas reserves given only rate-time data.
  - Rate-time and rate-cumulative analysis.
  - Specialized extrapolation plotting functions.
  - "Rate-cumulative" function type curves.
- Mechanism:
  - "Knowles" gas flow equation — derived asssuming a constant p_{wf} and pseudosteady-state conditions.
  - Limited to reservoirs where p_i<6000 psia.

Orientation — Base Relations

- **Governing relation — "Knowles" quadratic "rate-cumulative" equation:**

$$q_g = q_{gi} - \frac{2q_{gi}}{\left[1 - \left[\frac{p_{wf}/z_{wf}}{p_i/z_i}\right]^2\right]G} G_p + \frac{q_{gi}}{\left[1 - \left[\frac{p_{wf}/z_{wf}}{p_i/z_i}\right]^2\right]G^2} G_p^2$$

- **Application/Solution:**
  - **Cannot solve Knowles equation by "hand" (3 coefficients: q_i, p_{wD}, G — $p_{wD}=(p_{wf}/z_{wf})/(p_i/z_i)$ (but p_{wD} is simply treated as a single, "lumped" constant)).**
  - **Created type curve to solve problem by "hand" — but it is better to integrate the rate-time and rate-cumulative plots into this analysis (*...spreadsheet*).**

Orientation — Plotting Functions

- **Time-averaged rate function: $q_{gi,t}$**

$$q_{gi,t} = \frac{1}{t}\int_0^t q_g\, dt$$

- **Cumulative production-averaged rate function: $q_{gi,Gp}$**

$$q_{gi,Gp} = \frac{1}{G_p}\int_0^{G_p} q_g\, dG_p$$

- **Extrapolation Functions:**

Method 1:

$$\frac{(q - q_i)}{G_p} \text{ vs. } G_p$$

Method 2:

$$\frac{(q_{gi,Gp} - q_i)}{G_p} \text{ vs. } G_p$$

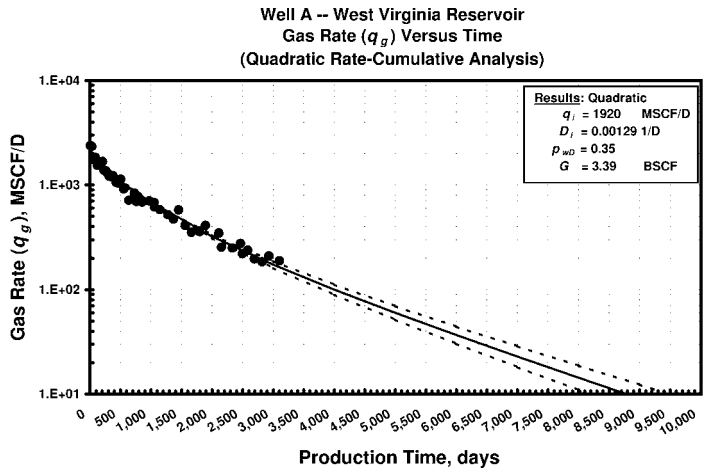
Method 3:

$$\frac{(q_{gi,Gp} - q)}{G_p} \text{ vs. } G_p$$

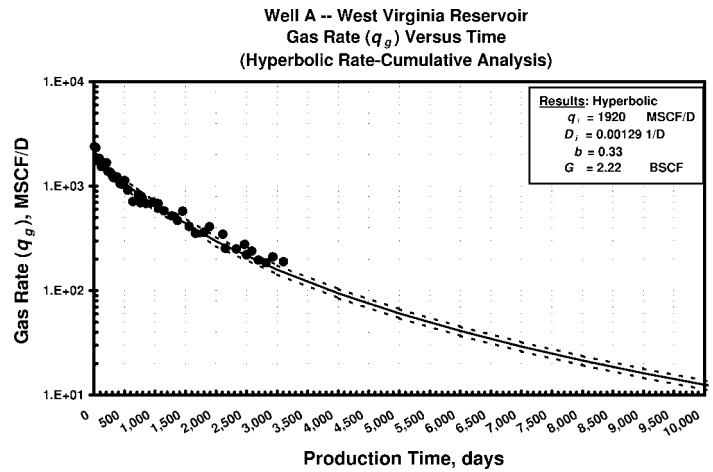
Application of the New Method: Field Case

- Literature case of a gas well produced at a constant pressure in a low permeability reservoir.
- Given:
  - Production history and some well and PVT data.
  - Previous analyses in literature (2.75<*G*<3.3 BSCF).
  - Pressure history assumed constant (not given).
- Issues:
  - Data quality is good.
  - Transient and pseudosteady-state flow regimes are evident (we will only pursue an estimation of gas reserves — no analysis of the transient data).
  - All analyses are consistent and considered accurate.

Application of the New Method: Rate-Time



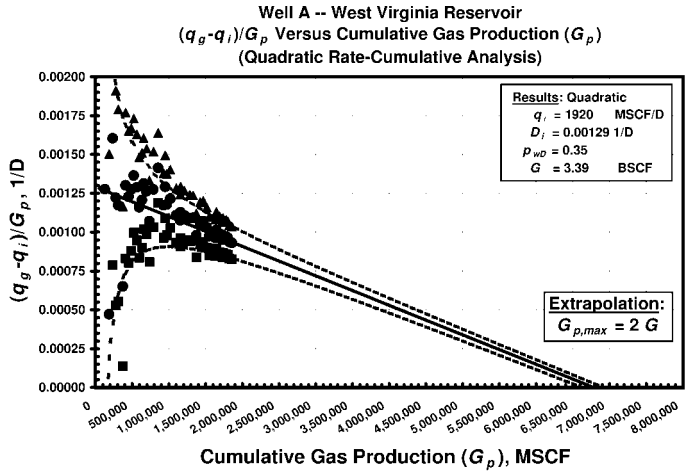
a. q_g vs. t: Quadratic Match of Well A (Field Case)



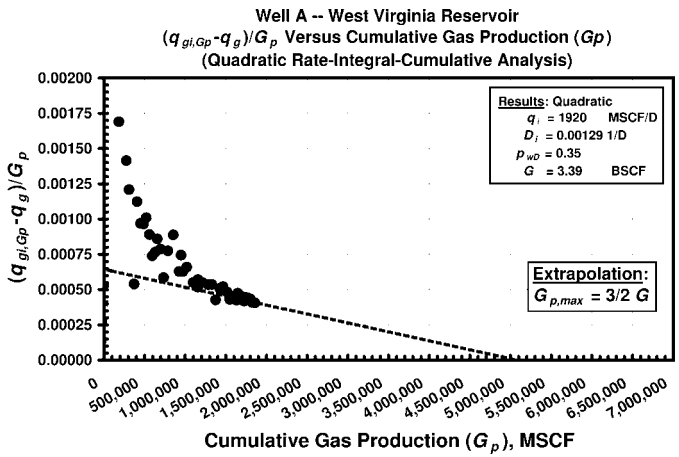
b. q_g vs. t: Hyperbolic Match of Well A (Field Case)

- **q_g vs. t: Quadratic Match**
  - Good data match — data quality provides very clear trend.
  - "High" and "low" q_i cases are +/- 10 percent — assist in orienting analysis in the spreadsheet.
  - Worth repeating that data match is very good — verifies methodology as well as data quality.
- **q_g vs. t: Hyperbolic Match**
  - Good match, some deviation in later data.
  - Hyperbolic formulation has only the q_i and D_i parameters as variables — does not match gas well performance data as well as the quadratic formulation.
  - Hyperbolic analysis gave a conservative estimate of G.

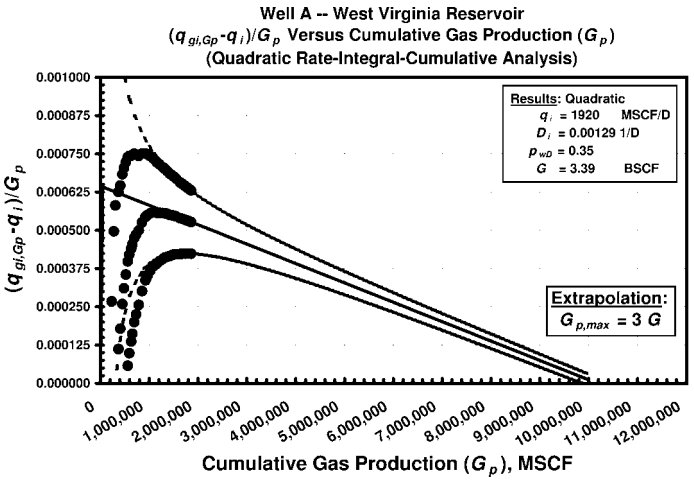
Application of the New Method: Extrapolation



a. $(q_g-q_i)/G_p$ vs. G_p: Well A (Field Case)



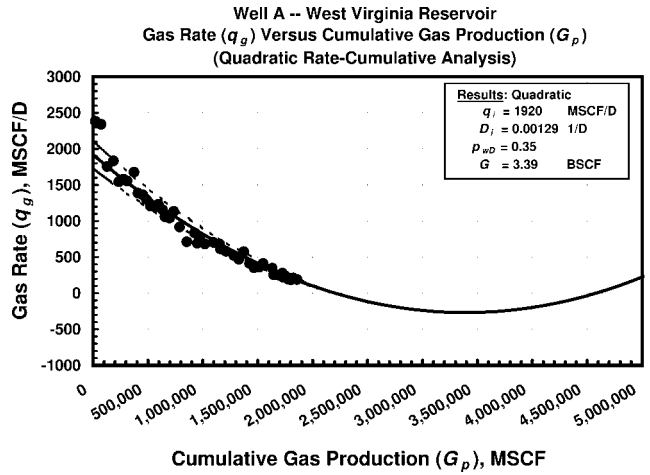
c. $(q_{gi,Gp}-q)/G_p$ vs. G_p: Well A (Field Case)



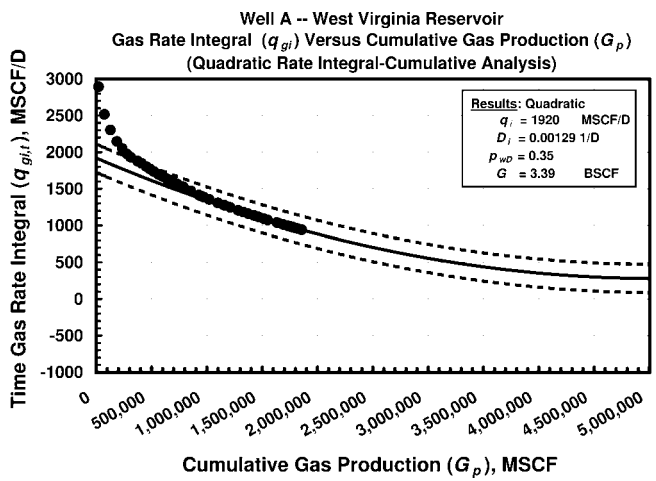
b. $(q_{gi,Gp}-q_i)/G_p$ vs. G_p: Well A (Field Case)

- **Comment: (Center trend is Active)**
  - $(q_g-q_i)/G_p$ vs. G_p: Extrapolates to 2G — good straight-line trend.
  - $(q_{gi,Gp}-q_i)/G_p$ vs. G_p: "Smoother" than the rate function, but this function also gives a linear trend.
  - $(q_{gi,Gp}-q)/G_p$ vs. G_p: Combination of other 2 extrapolation functions — presents a linear trend analogous to the $(q_{gi,Gp}-q_i)/G_p$ function.

Application of the New Method: Rate-Cumulative



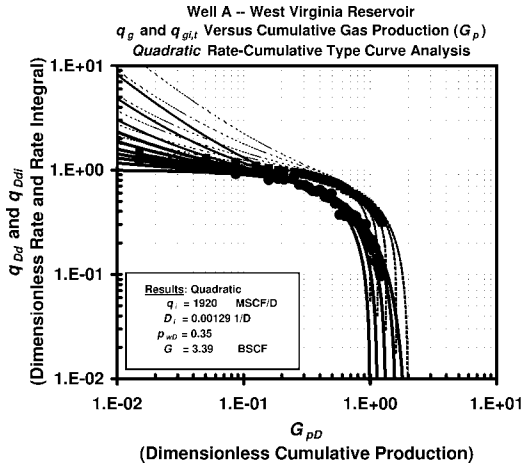
a. q_g vs. G_p: Well A (Field Case)



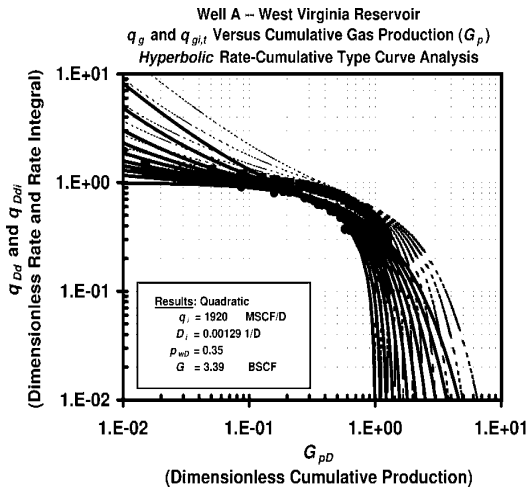
b. $q_{gi,t}$ vs. G_p: Well A (Field Case)

- **q_g vs. G_p: (Center trend is Active)**
  - Good data trend — model fits data quite well.
  - The location of the minimum of the q_g vs. G_p trend is the gas-in-place (G). *This analysis should not be performed using regression* — regression will favor statistics, rather than the physical problem.
- **$q_{gi,t}$ vs. G_p: (Center trend is Active)**
  - Similar to the q_q vs. G_p plot — smoother than q_q data.
  - This function serves to validate/confirm the q_g vs. G_p behavior.
  - The comparison is very clear in this perspective (useful in the distinction of the model trends).

Application of the New Method: Type Curve Analysis



a. q_g and $q_{gi,t}$ vs. G_p: *Quadratic* Type Curve



b. q_g and $q_{gi,t}$ vs. G_p: *Hyperbolic* Type Curve

- q_g and $q_{gi,t}$ vs. G_p: *Quadratic* TC
  - Use to orient/confirm other analyses — use of cumulative production makes this a relatively "insensitive" analysis technique.
  - Good data match for both the q_g and $q_{gi,t}$ data functions.

- q_g and $q_{gi,t}$ vs. G_p: *Hyperbolic* TC
  - Taken as an extension of the original "Fetkovich" (rate-time) decline type curve.
  - Match is "acceptable," but the quadratic model is better.

Summary:

- The semi-analytical methodology presented in this work is a viable alternative for the estimation of original gas-in-place using only production data. The successful application of the method and comparable results obtained with other techniques attests to the viability of this approach.
- Data quality is an issue — data may require editing to extract the desired production profile if the original profile is inconsistent. However, such editing should have a negligible effect on the results if the dominant production data profile is maintained.

Recommendations for Future Work:

- **Extend this methodology to the case of an abnormally pressured gas reservoir (this may be problematic since this methodology requires p_i<6000 psia).**
- **Extend this methodology to the case of a volumetric gas reservoir with water influx/encroachment.**
- **Develop additional plotting functions for data analysis (...may not add much value, but could provide characteristic behavior — *e.g.*, a rate derivative function is possible, but given the quality of production data, such a function may not be practical).**
- **Extend this model (*i.e.*, the "Knowles" gas flow relation to p_i>6000 psia).**

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End of Presentation

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