Problem Description/Data/Reference: Final Project (RTA) - SPE 114947 (Ilk)

Problem Description:

Elements:
- This is a production analysis with variable rate + changing flowing bottom hole pressure (FBHP)
- This is a gas well with finite conductivity fracture (bilinear flow).
- Require the use of material balance pseudo time $(\bar{t_a})$
- Require the use of pseudo-pressure integration

Challenges:
- Need to guess initial gas-in-place (IGIP) and compute average reservoir pressure, pseudo time (t_a), and material balance pseudo time $(\bar{t_a})$, using SPE 17708.
- Need to plot flowing material balance equation, correct for the transient flow production and iterate for initial gas-in-place (IGIP), using the procedure in SPE 17708.
- Need to use 'De-superposition technique to incorporate finite conductivity element from Lee-Brockenbrough trilinear flow model into Ozkan's fracture well solution. Then use the convolution theorem to convert it to the rate solution to obtain Pratikno's type curve.

Results from publication/reference:
- The time-rate-pressure for the entire history is given
- The preliminary analysis is provided in SPE 84287.
- The permeability and fracture half-length are obtained previously from pressure build up test (PBU)

Data Description:
- There are 5,039 data points (t, q, P_{wf}) with noise.
- Need to manually clean the data and take out some outliers from the shut-in events. The edited data set has only 4,416 data point.

Reference:

Pratikno, H., Rushing, J. A., and Blasingame, T. A. (2003) Decline Curve Analysis Using Type Curves - Fractured Wells. Society of Petroleum Engineers. doi:10.2118/84287-MS

Table of Properties

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Fluid Properties:
 REF. GAS FVF, MSCF/STB                 = 0.5483
 REF. GAS VISCOSITY, cp                 = 0.03605
 REF. TOTAL COMPRESSIBILITY, 1/psia     = 5.0975E-5
 TEMPERATURE, deg F                     = 300

Reservoir Properties:
 RESERVOIR THICKNESS, ft                = 170
 WELLBORE RADIUS, ft                    = 0.333
 POROSITY, fraction                     = 0.088
 EQUIVALENT POROSITY, fraction          = 0.07647 (*)

 (*) Adjusted to the irreducible water saturation
     Swi = 0.131

Production Properties:
 INITIAL PRESSURE (Pi), psia            = 9330
 PSEUDO INITIAL PRESSURE (Ppi),psia     = 7540.13
 INITIAL GAS-IN-PLACE (G), BSCF         = 3.23 (*)

 (*) INTIAL GUESS FROM SPE 17708 METHOD


Properties to be Solved: (Final Estimates)

 (from Python Program)

 (Finite-conductivity fracture in a bounded
  reservoir model)

 PERMEABILITY (k), md                   = 0.016
 FRACTURE HALF-LENGTH (xf), ft          = 112
 EQUIVALENT SKIN (S), Dim-Less          = -5.12 (*)
 FRACTURE COND.(FcD), Dim-less          = 27
 RESERVOIR RADIUS (re), ft              = 491
 INITIAL GAS-IN-PLACE (G), BSCF         = 3.20 (**)

 (*) Calculated from S = -ln(xf/2rw)
 (**) Use volumetric calculation from reservoir
 properties and matched reservoir radius (re)
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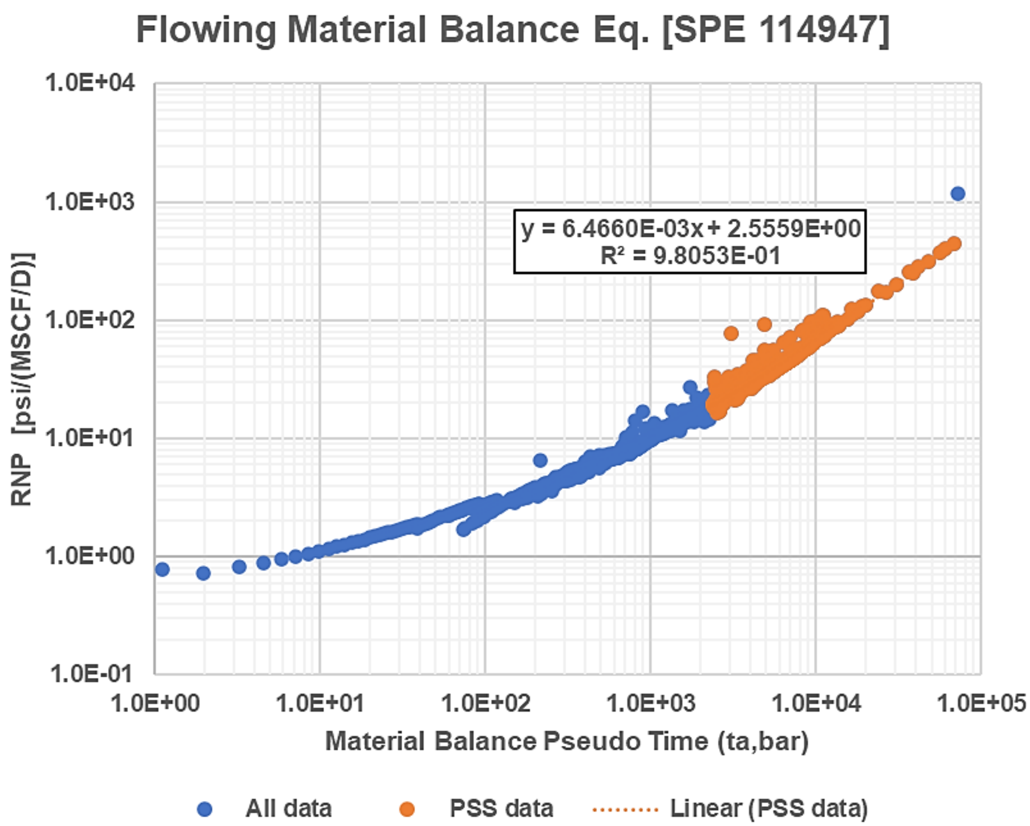
Material Balance Pseudo Time ($\bar{t}_a$) and Initial Gas-In-Place Iterations (G)

Diagnostic Plot [log-log]:



IGIP Iterations (BSCF)	
G (guess)	G (cal)
3.2	3.2085
3.21	3.2185
3.22	3.2220
3.23	3.2293
3.24	3.2387
3.3	3.2734

Calculations:

1) Estimate IGIP = 3.23 BSCG

2) Estimate productivity index = 1 / 2.5559 = 0.391 psi / (MSCF/D)

3) IGIP is sensitive to curve-fitting, depending on how the time to stabilized flow (t_{PSS}) is selected. I will cross-check this IGIP with the one obtained from RTA type curve matching

Workflow Plot (SPE 17708 - Blasingame):

1) Estimate (guess) initial gas-in-place (G)
2) Calculate average reservoir pressure, using the material balance equation. For Gp, use the trapezoid rule of qg. Note that z-factor is in a function of reservoir pressure $\overline{p_r}$

$$\frac{\overline{p_r}}{\overline{z}} = \frac{p_i}{z_i}\left(1 - \frac{G}{G_p}\right), \qquad G_p = \int_0^t q_g dt$$

3) Calculate pseudo time (t_a) based on $\overline{p_r}$

$$\mathrm{t_a} = \mu_{gi} c_{ti} \int_0^t \frac{1}{\mu_g(\overline{p_r}) c_t(\overline{p_r})} d(\tau)$$

4) Calculate material balance pseudo time $(\bar{t}_a)$ as follows;

$$\bar{t}_a = \frac{1}{q_g} \int_0^{t_a} q_g(\tau_a) d(\tau_a)$$

5) Calculate pseudo-pressure (P_{pwf}) as follows;

$$P_{pwf} = \frac{\mu_{gi} z_{gi}}{P_i} \int_0^t \frac{P}{\mu_g(\overline{p_r}) z_g(\overline{p_r})} d(P)$$

6) Plot the flowing material balance equation (between rate-normalized pseudo-pressure and material balance pseudo time to obtain initial gas-in-place and the reciprocal of productivity index from slope and intercept, respectively.

$$RNP = \frac{P_{pi} - P_{pwf}}{q_g} = \frac{1}{\mathrm{J}} + \frac{\bar{t}_a}{c_{ti} G}$$

$$J = \frac{kh}{70.6 \mu_{gi} B_{gi} \left[ln\left(\frac{4A}{e^{\gamma} C_A r_w^2}\right) + 2S \right]}$$

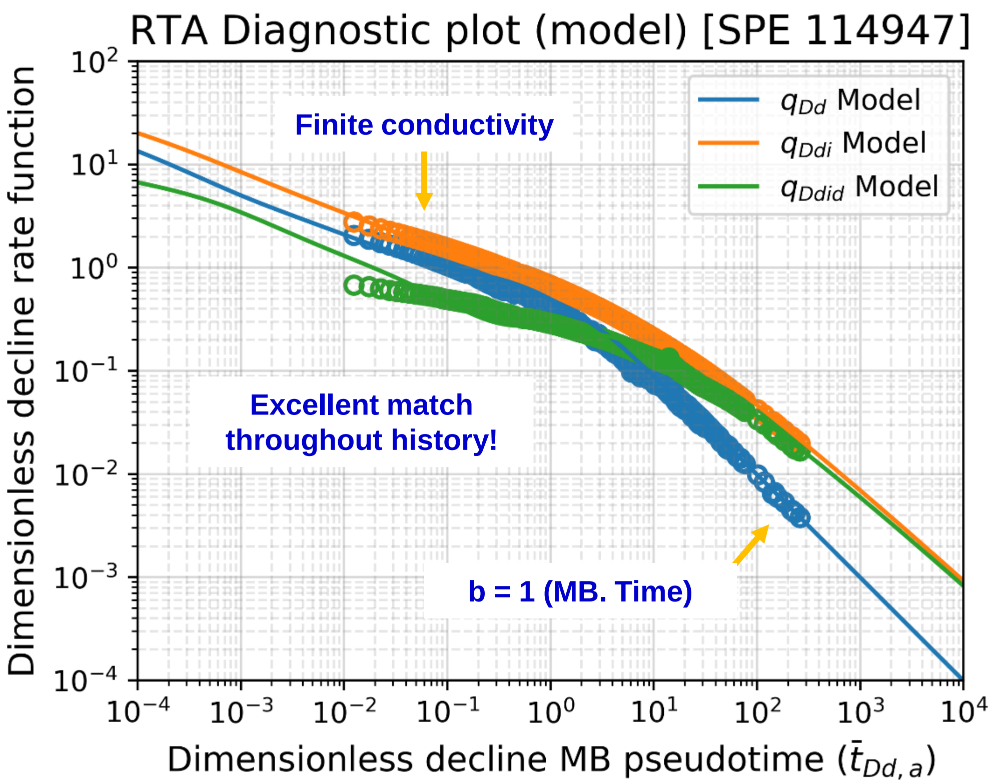
7) Need to correct extra production from a transient flow

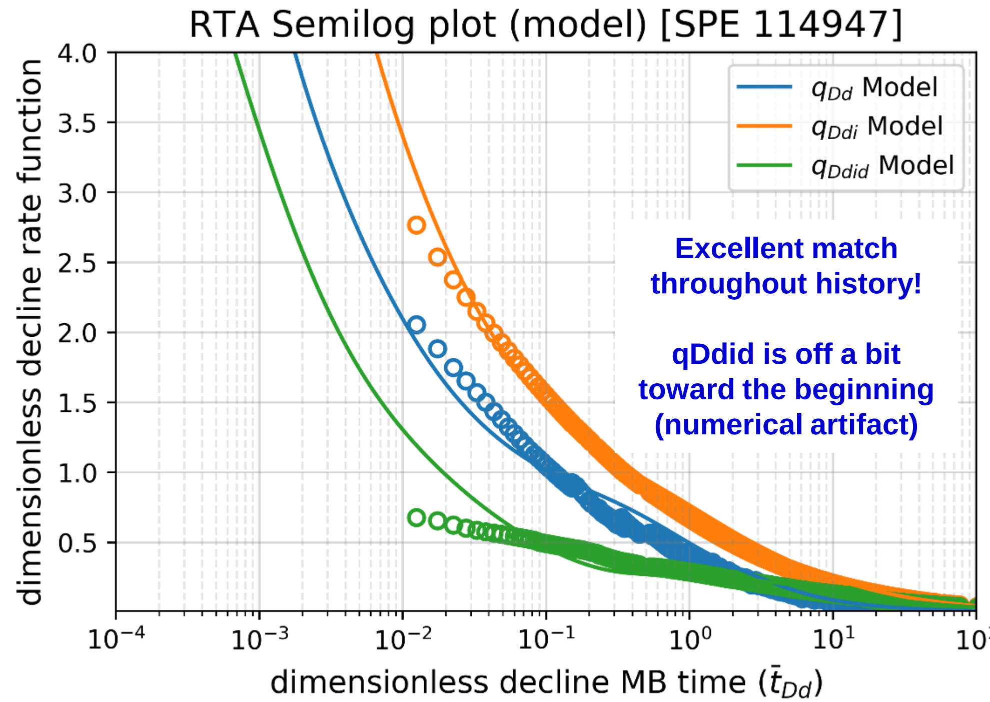
$$q_{trn} = \frac{\Delta \mathrm{p_{obs}}}{b + m\bar{t}_a}, \qquad G_p(trn) = \int_0^{t_{PSS}} q_{trn}(\tau) d(\tau)$$

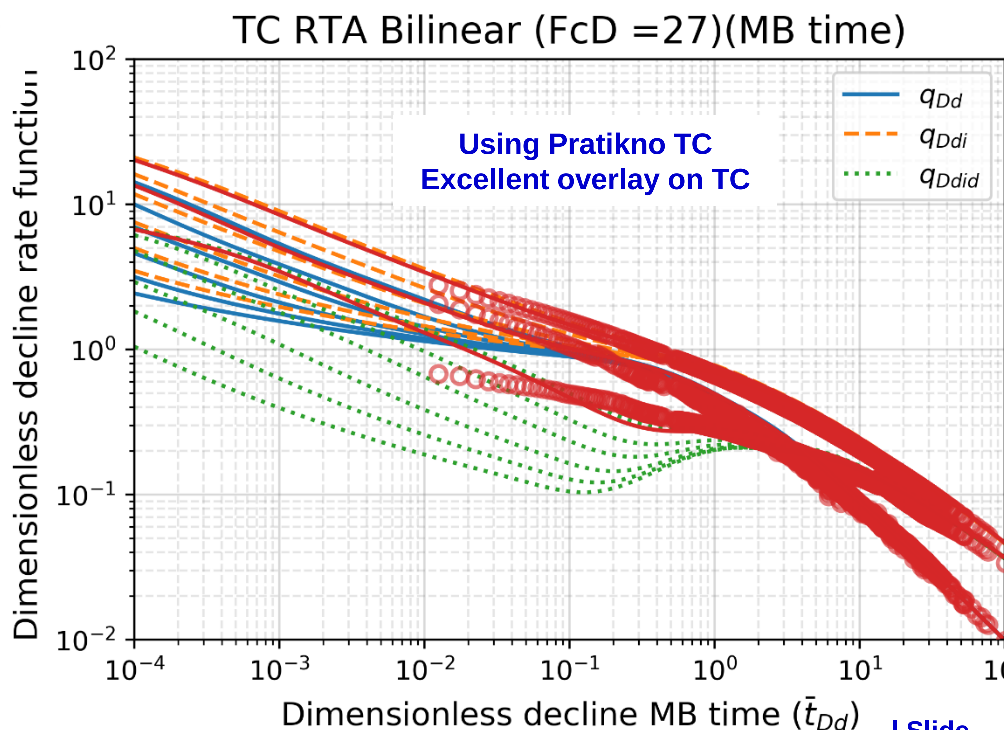
$$G = \frac{1}{m c_{ti}} + G_p(t_{PSS}) - G_p(trn)$$

Analysis Summary Plots (Model)

"Model" matching: **(by Python)**







Type curve matching results:

$$k = 0.016\,md, \qquad x_f = 112\,ft$$
$$F_{cD} = 27, \qquad r_e = 491\,ft$$

Calculation check for IGIP:

$$G = \frac{\pi r_e^2 h\phi(1-S_{wi})}{B_{gi}\left[\frac{rb}{MSCF}\right]\times 5.6146} = \frac{\pi(491^2)(170)(0.088)(1-0.131)}{0.5483\times 5.6146}$$
$$G = 3.198\times 10^6\ MSCF\ \approx 3.20\ BSCF$$

This result agrees well with G obtained from pseudo time calculation, using the method in SPE 17708 (3.23 BSCF)

Method of Work / Discussion of Results

Method of Work:

Starting Point:

- Type curve matching requires Stehfest's algorithm.
- Need to follow IGIP and $\overline{t_a}$ calculation shown in slide 2

Governing Equations:

Blasingame-Poe Desuperposition "Trilinear Pseudo radial"	$\bar{p}_{TPR,inf}(C_{fD}, s_f) = \bar{p}_{LBD,inf}(C_{fD}, s_f) - \bar{p}_{LBD,inf}(C_{fD} = \infty, s_f = 0) + \bar{p}_{ORD,inf}(\lvert x_D(C_{fD})\rvert \leq 1, y_D = 0)$
Lee-Brockenbrough Trilinear flow equation	$\bar{p}_{LBD,inf}(C_{fD}, s_f) = \frac{\pi}{\mu C_{fD}} \frac{1}{\psi \tanh(\psi)}$, $\psi = \sqrt{\frac{2}{C_{fD}} \frac{\alpha}{1+\alpha s_f} + \frac{\mu}{\eta_{fD}}}, \alpha = \sqrt{\mu + \sqrt{\mu}}$
Infinite Cond. Fracture soln. (Okzan/Laplace)	$\bar{p}_{sD}(x_D = 0.732, y_D = 0, \mu) = \frac{1}{2\mu\sqrt{\mu}}\left[\int_0^{\sqrt{\mu}(1+x_D)} K_0(z)dz + \int_0^{\sqrt{\mu}(1-x_D)} K_0(z)dz\right] + \frac{1}{2\mu\sqrt{\mu}} \frac{K_1(\sqrt{\mu} r_{eD})}{I_1(\sqrt{\mu} r_{eD})}\left[\int_0^{\sqrt{\mu}(1+x_D)} I_0(z)dz + \int_0^{\sqrt{\mu}(1-x_D)} I_0(z)dz\right]$
$b_{D,PSS}$ Correlation	$b_{D,PSS} = f(r_{eD}, F_{cD})$ (check SPE 84287 Eq.5)
Dimensionless rate from q_g and P_{pwf}	$q_D = \frac{141.2\mu_{gi}B_{gi}}{kh}\left(\frac{q_g}{P_{pi} - P_{pwf}}\right) = \frac{141.2\mu_{gi}B_{gi}}{kh}(PNR)$
Dimensionless *decline* function	$\begin{Bmatrix} q_{Dd} \\ q_{Ddi} \\ q_{Ddid} \end{Bmatrix} = \begin{Bmatrix} q_D \\ q_{Di} \\ q_{Did} \end{Bmatrix} [b_{D,PSS}]$
Dimensionless *decline* material balance pseudo time	$\overline{t_{Dd,a}} = 2t_{Df}\left\{b_{D,PSS}\left[\left(\frac{r_e}{x_f}\right)^2 - 1\right]\right\}^{-1}$

Challenge & Issues:

- [De-superposition] Blasingame and Poe added "Finite-conductivity" element of trilinear solution to Okzan's solution which includes the pseudo radial flow at the late time. Use $s_f \approx 0$ and $\eta_{fD} \approx 200 \times C_{fD}$

Discussion of Results:

Diagnostics:

- The bilinear flow at early time is clear. The q_{Dd} function in the transient stem has slope of ¼.
- The depletion stem follows the harmonic solution because the material balance pseudo time is used.
- Excellent match on qDd and qDdi
- Some numerical artifact in qDdid toward the beginning

Analyses:

- Permeability from RTA is identical to the one from PTA (k = 0.016 md).
- Fracture half-length from RTA (xf = 112 ft) agrees extremely well with the one from PTA (xf = 119 ft)
- The well is stimulated (negative skin = -5.12)
- According to RTA, fracture is finite fracture-conductive (FcD = 27) In PTA, FcD = 4. Bilinear flow regime is more pronounced in PBU.
- Gas in-place estimates from SPE 17708 iteration and type curve match agree within 0.03 BSCF.

Assessment:

- Use L = 0.1-0.15 to smooth the data provides even better-quality rate-integral derivative (qDdid)

Recommendations/Extra work:

Technical developments that would help?

- The augmented plot for β-derivative
- Try log-log plot by 'flipping' TC upside down and work with "rate-normalized pressure (RNP)" instead of "pressure-normalized rate (PNR)"
- The p_D vs $\sqrt[4]{t_D}$ plot or "Bi-linear flow" specialized plot could yield the straight-line in case of finite-conductivity fracture.