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

Problem Description:

Elements:
- This is the high-frequency pressure buildup test (PBU) with 13,898 data point for a gas well with a finite conductivity fracture. The bilinear flow regime dominates PBU.
- The gas well requires pseudo-pressure and pseudo-time calculations, which I decided to compute it from scratch.
- Need to account for phase redistribution in early time
- The equivalent producing time is used instead of super-position time.

Challenges:
- Need to compute pseudo-pressure and pseudo-time.
- Need to use 'De-superposition technique to incorporate finite conductivity element from Lee-Brockenbrough's trilinear flow model into Ozkan's fractured well solution.

Results from publication/reference:
- Shut-in pressure (P_{ws}) is provided as a time series
- The preliminary analysis is provided by Dr. Blasingame.
- The use of well-test derivative helps identify flow regime. (Exhibit a quarter slope (1/4) which indicates bilinear flow)

Data Description:
- There are 13,898 data points $(\Delta t, P_{ws},)$ with excellent quality.
- The maximum shut-in pseudo time (Δt_a (max) =136.26 hr) is shorter than the (pseudo) producing time (2339 hr), so the superposition could be neglected. For this work, I decided to use Agarwal's effective pseudo time $(\Delta t_{sa},)$ to minimize producing time effect.

Reference:
Ilk, D., Perego, A. D., Rushing, J. A., and Blasingame, T. A. (2008) Integrating Multiple Production Analysis Techniques to Assess Tight Gas Sand Reserves: Defining a New Paradigm for Industry Best Practices. Society of Petroleum Engineers. doi:10.2118/114947-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
 FBHP AT SHUT-IN (Pwf [tp]), psia         = 1521
 PSEUDO INITIAL PRESSURE (Ppi),psia       = 7540.13
 PSEUDO FBHP AT SHUT-IN (Ppwf),psia       = 389.649

Properties to be Solved: (Final Estimates)

 (from Python Program)
 (Bilinear flow model)

 PERMEABILITY (k), md                     = 0.016
 FRACTURE HALF-LENGTH (xf), ft            = 119
 EQUIVALENT SKIN (S), Dim-Less            = -5.19 (*)
 WBS COEF. (C),Dim-less                   = 4.73E-3
 DIM-LESS WBS COEF. (CDf),Dim-less        = 4.5E-4 (**)
 FRACTURE COND.(FcD),Dim-less             = 4

 (Extra work on phase redistribution)

 P PHASE-REDISTRIBUTION (Cφ),psi          = 320
 T PHASE-REDISTRIBUTION (α),hr            = 0.035

 (*) Calculated from S = -ln(xf/2rw)
 (**) Normalized to fracture half-length square
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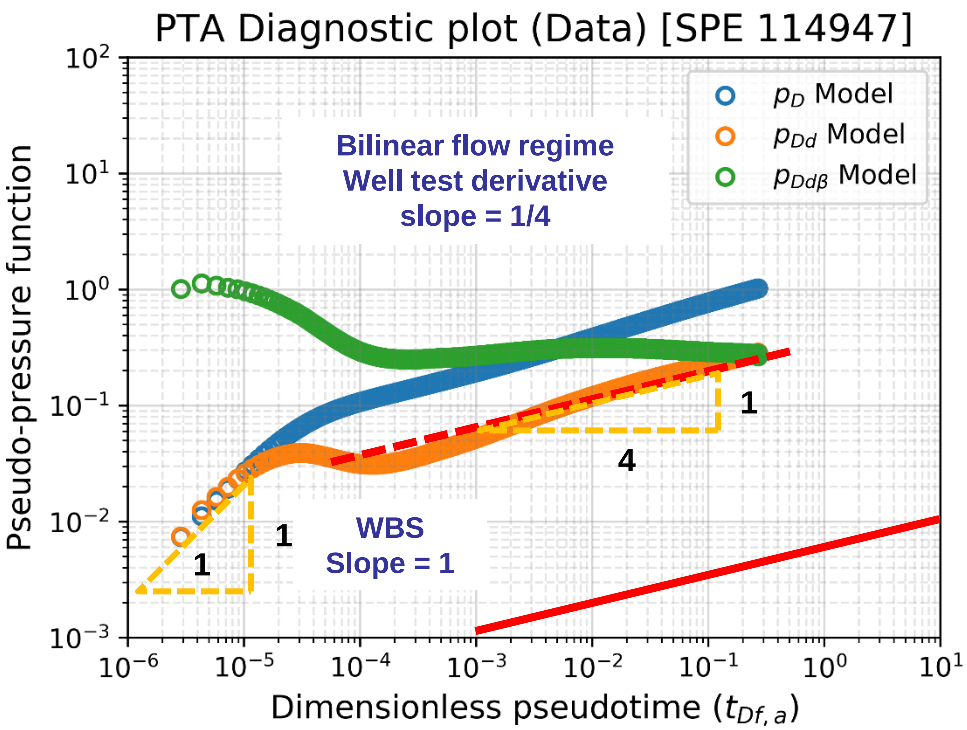
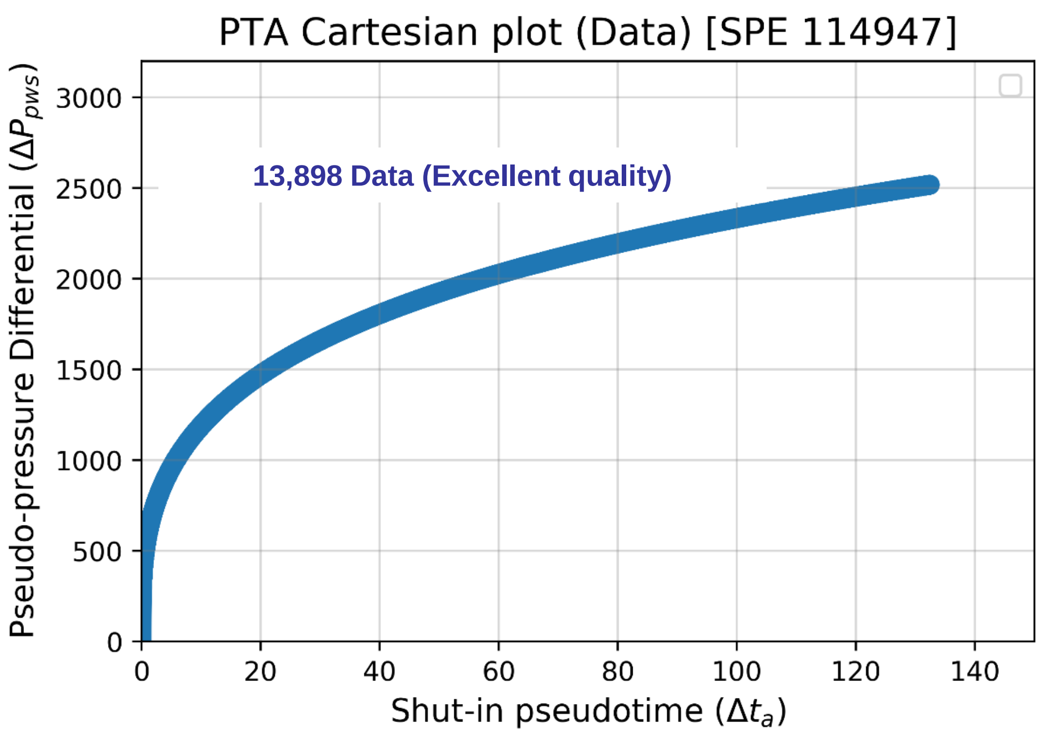
Diagnostics / Hand analysis plots

Diagnostic Plot [log-log]:



Cartesian Plot:



Comment:

1) This is not a perfect 1/4 slope line, but it is close enough.
2) This is obviously not linear flow (slope = 1/2). Bilinear flow is more pronounced in PTA Data
3) The wellbore storage is changing in the beginning, as there is some hump in well test derivative during the early time due to phase redistribution. Fair's exponential phase redistribution is used.
4) Use a power law trick integral for the first panel when calculating gas property integration.

Pseudo-pressure/ Pseudo-time calculations:

1) Note that pseudo-pressure (P_{pws}) and effective shut-in pseudo-time (Δt_{as}) must be used to calculate these dimensionless variables. Use well shut-in pressure when calculating pseudo-time.

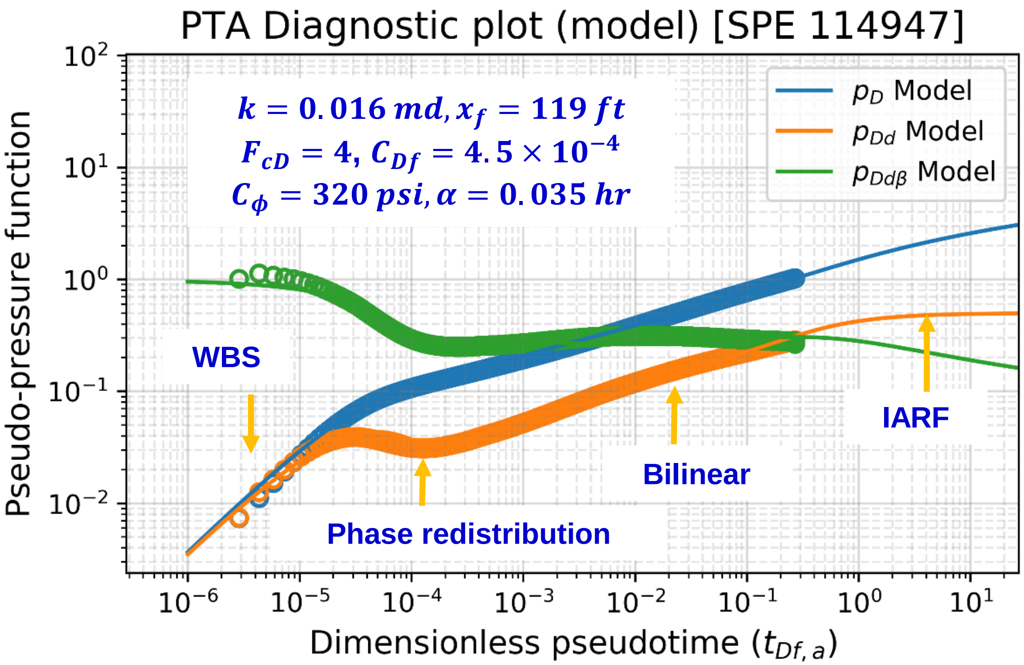
$$\Delta t_a = \mu_{gi} c_{ti} \int_0^{\Delta t} \frac{1}{\mu_g(P_{ws}) c_t(P_{ws})} d(\Delta\tau)$$

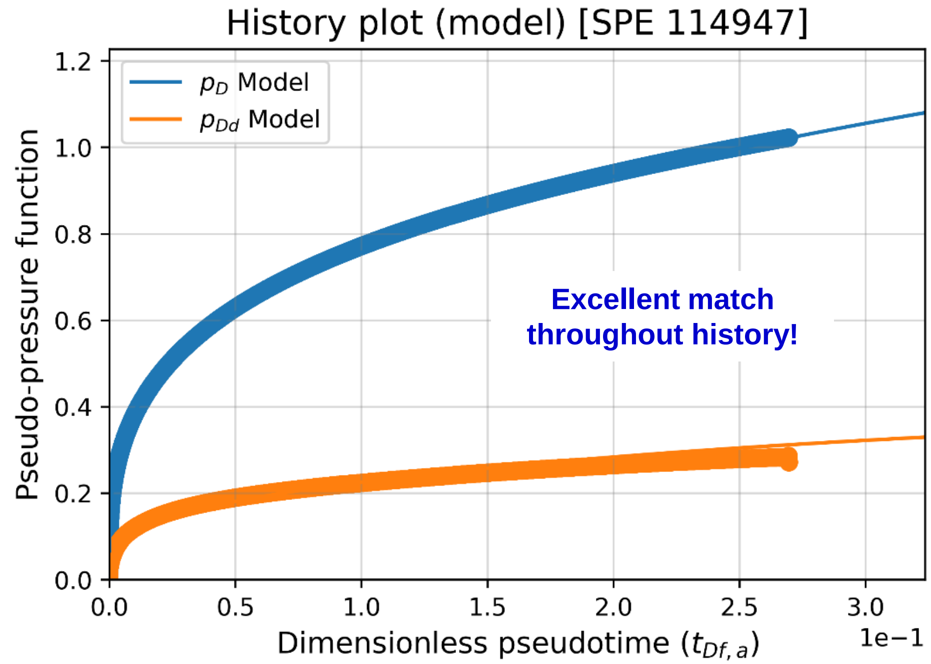
2) Producing pseudo time is approximately producing time $\Delta t_{pa} \approx t_p = 2339\ hr$
3) Effective shut-in pseudo time

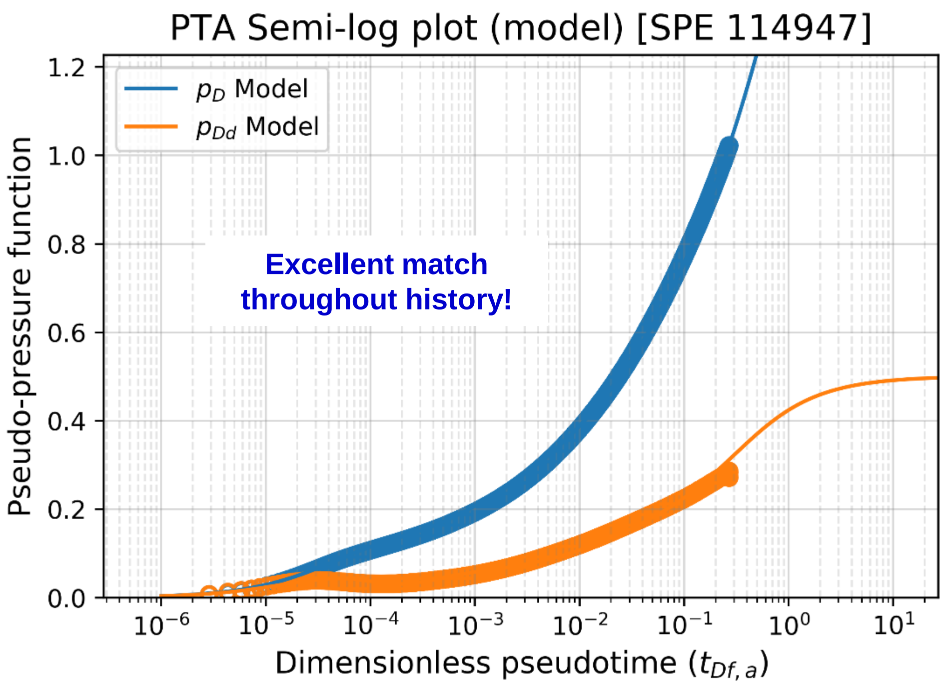
$$\Delta t_{sa} = \frac{t_p \Delta t_a}{t_p + \Delta t_a}$$

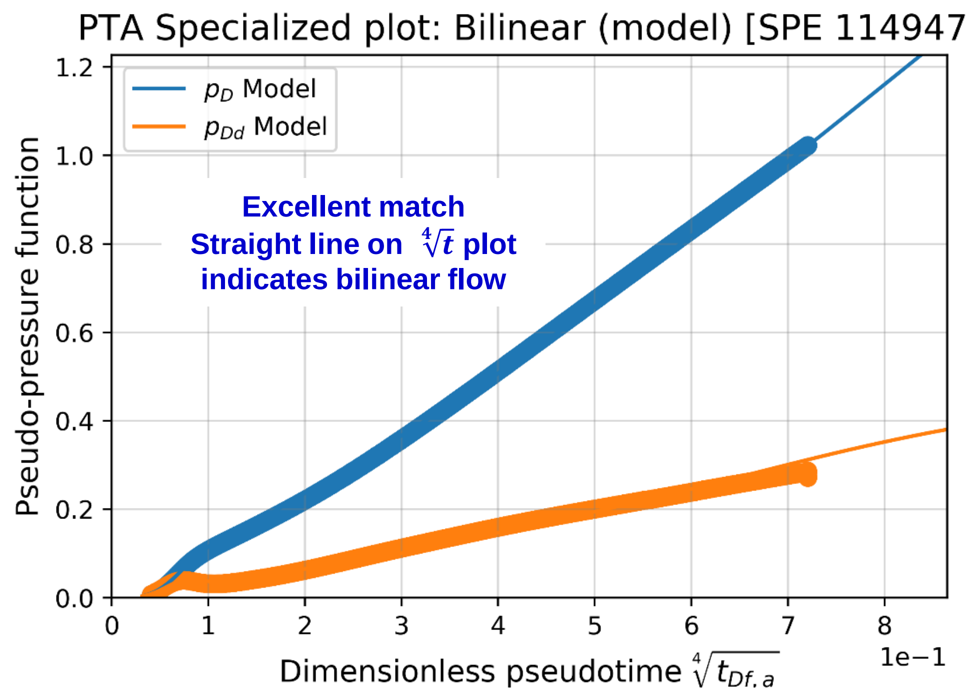
Analysis Summary Plots (Model)

<u>"Model" matching</u>: (by Python)









Method of Work / Discussion of Results

Method of Work:

Starting Point:

- The buildup test requires the adjustment of the time and pressure plotting functions. In diagnostic plot, Agarwal effective shut-in pseudo time is used.
- Type curve matching requires Stehfest's algorithm.

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)	$\bar{p}_{sD}(x_D = 0.732, y_D = 0, \mu) = \frac{1}{2\mu\sqrt{\mu}}\left[\int_0^{\sqrt{\mu}(1+x_D)} K_0(z)dz + \int_0^{\sqrt{\mu}(1-x_D)} K_0(z)dz\right]$
Classic Semi-log	$\Delta p_{pws} = \frac{70.6\mu_o q_o}{kh}\left[\ln(\Delta t_{sa}) + \left(\ln\left(\frac{1}{1688}\frac{k}{\phi\mu c_t r_w^2}\right) + 2S\right)\right]$
Finite Cond. Fracture soln. (real-domain)	$\Delta p_{pws} = \frac{44.1\mu_o q_o B_o}{h\sqrt{k_f w_f}} \sqrt{\frac{\Delta t_{sa}}{\phi\mu c_t k}}$
Phase redistribution (Check Fair's paper: $P_{\phi Df} = C_{\phi Df}(1 - exp(-t_{Df}/\alpha_{Df}))$	

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. This de-superposition technique requires multiple solutions and longer computational time.
- Use $s_f \approx 0$ and $\eta_{fD} \approx 200 \times C_{fD}$

Discussion of Results:

Diagnostics:

- Wellbore storage is changing, as the hump in the early time is seen. (= phase redistribution). The early portion of data has slope close to 1.
- The bilinear flow is clear. The well test derivative p_D' has slope of 1/4.
- The IARF data is still 1 log cycle away from the last data point, but the match is excellent.

Analyses:

- Permeability from PTA is identical to the one from RTA (k = 0.016 md).
- Fracture half-length from PTA (xf = 119 ft) agrees extremely well with the one from RTA (xf = 112 ft)
- IARF period is expected after bilinear flow.
- According to PTA, fracture is finite fracture-conductive (FcD = 4) In RTA, FcD = 27 (still finite-conductive). Bilinear flow regime is more pronounced in PBU.

Assessment:

- IARF inferred, permeability estimate is good.
- Xf is solved implicitly from tDf matching
- Use L = 0.1-0.15 to smooth the data provides even better-quality well test derivative

Recommendations/Extra work:

How can the methodology be improved?

- The β-derivative is also computed. It is helped to spot out the flow behavior (1/4 for bilinear flow)

Technical developments that would help?

- The augmented plot for β-derivative
- The Δp_{pws} vs $\sqrt[4]{\Delta t_{sa}}$ plot or "Bi-linear flow" specialized plot could also be used to illustrate "Finite-conductivity" quantitatively by having the priori knowledge of permeability.