Research Summary

Analytical Modeling of Fractured Nanoporous Reservoirs

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Problem Statement

- Unconventional reservoirs persevere unique features:
  - Extreme low matrix permeability
  - Discrete/continuous fractures
  - Connected/isolated pores
- Scale and structural heterogeneity can lead to preferential flow paths → complex flow events, variations in pressure and composition.

Approach

- Anomalous Diffusion: Fluid transport in fractured media with complex geometry is similar to diffusion in disordered media.
- Utilize anomalous diffusion to:
    - Describe flow in matrix while flow in natural fractures follows normal diffusion.
    - Describe flow in both matrix and natural fractures.

Approach

- Flux law as presented by Raghavan and Chen (2013)

– Fractional flux:

$$v_x = \frac{k_\alpha}{\mu} \frac{\partial^{1-\alpha}}{\partial t^{1-\alpha}} \left(\frac{\partial p}{\partial x} \right)$$

- $\alpha < 1$
- $\alpha = 2/(2+\theta)$, θ is the anomalous diffusion index.
- Note here that: $k_\alpha = L^2 T^{1-\alpha}$

Approach

- Dual porosity idealization:
  - Cylindrical system
  - Spherical matrix (r_m)
  - Radial flow
  - Line sink
  - Matrix: AD
  - Natural fractures: ND/AD

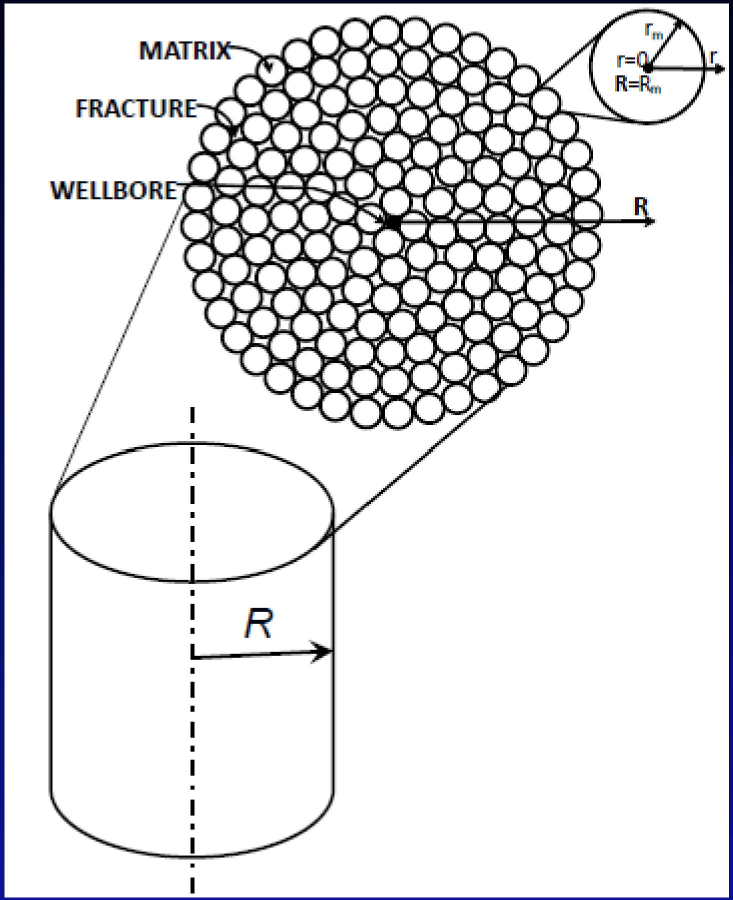

Figure 1: Dual Porosity Medium in Cylindrical System (Ozkan 2011)

Approach

- Extending the solution to:
  - Horizontal well
  - Multi-stage fractured
  - SRV is DP region

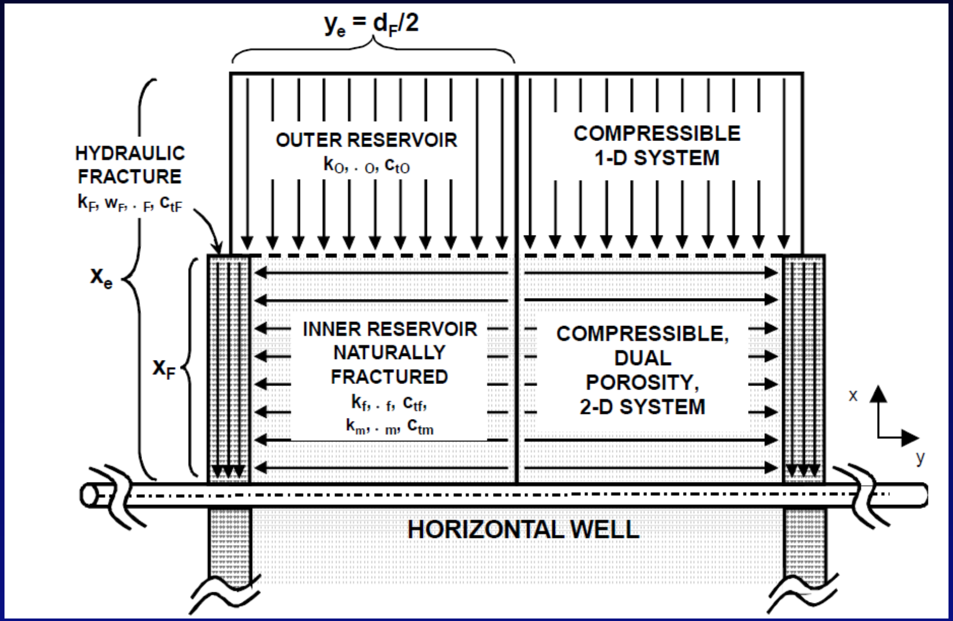

Figure 2: Tri-linear DP Model (Ozkan et al. 2009)

Approach

- Derivation:

1) $$\frac{1}{R}\frac{\partial}{\partial R}\left(R\frac{k_{\alpha f}}{\mu}\frac{\partial^{1-\alpha f}}{\partial t^{1-\alpha f}}\frac{\partial p_f}{\partial R}\right)+\hat{q}_m=(\phi c_t)_f\frac{\partial p_f}{\partial t}$$

2) $$\hat{q}_m=-(4\pi r_m^2)\left[\frac{k_{\alpha m}}{\mu}\frac{\partial^{1-\alpha m}}{\partial t^{1-\alpha m}}\left(\frac{\partial p_m}{\partial r}\right)_{r=r_m}\right]\Big/\left(\frac{4\pi r_m^2 h_f}{2}\right)$$

or,

$$\hat{q}_m=-\frac{2}{h_f}\frac{k_{\alpha m}}{\mu}\frac{\partial^{1-\alpha m}}{\partial t^{1-\alpha m}}\left(\frac{\partial p_m}{\partial r}\right)_{r=r_m}$$

f = natural fractures, m = matrix

Approach

- Derivation:

3) $$\frac{1}{R_D}\frac{\partial}{\partial R_D}\left(R_D\frac{\partial \bar{p}_{fD}}{\partial R_D}\right)-$$

$$\underbrace{s\left\{\frac{2k_{\alpha m}X_F}{h_f k_{\alpha f}}\left(\frac{\eta_f}{X_F^2}\right)^{\alpha f-\alpha m} s^{\alpha f-\alpha m-1}\frac{1}{r_{mD}}\left[\frac{r_{mD}\sqrt{\beta_m}}{Tanh\left(\sqrt{\beta_m}\, r_{mD}\right)}-1\right]+\left(\frac{\eta_f}{X_F^2}\right)^{\alpha f-1} s^{\alpha f-1}\right\}}_{f(s)}\bar{p}_{fD}=0$$

where $\beta_m=\left(\frac{X_F^2}{\eta_m}\right)\left(\frac{\eta_f}{X_F^2}\right)^{\alpha m} s^{\alpha m}$

Approach

- Verification vs. Previous Models

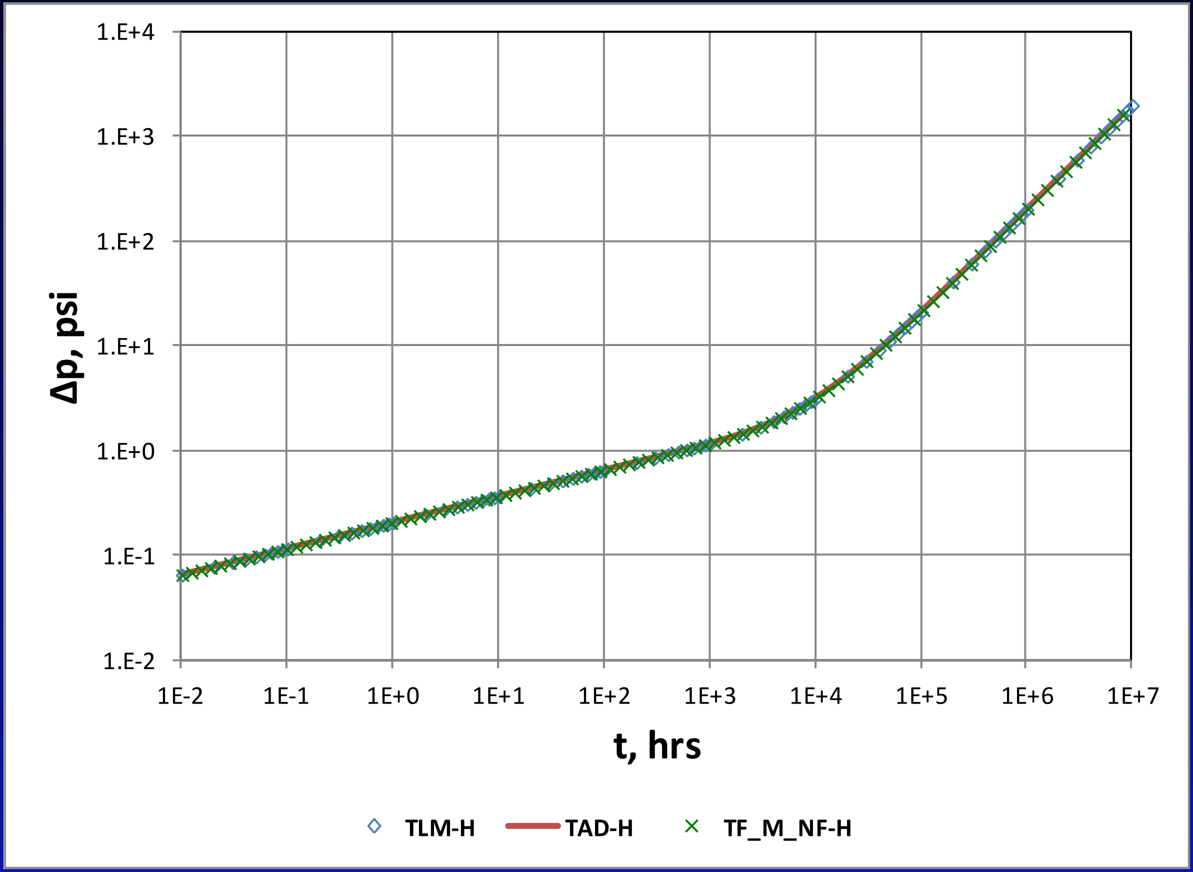

Figure 3: Verification - Homogeneous Reservoir

Approach

- Verification vs. Previous Models

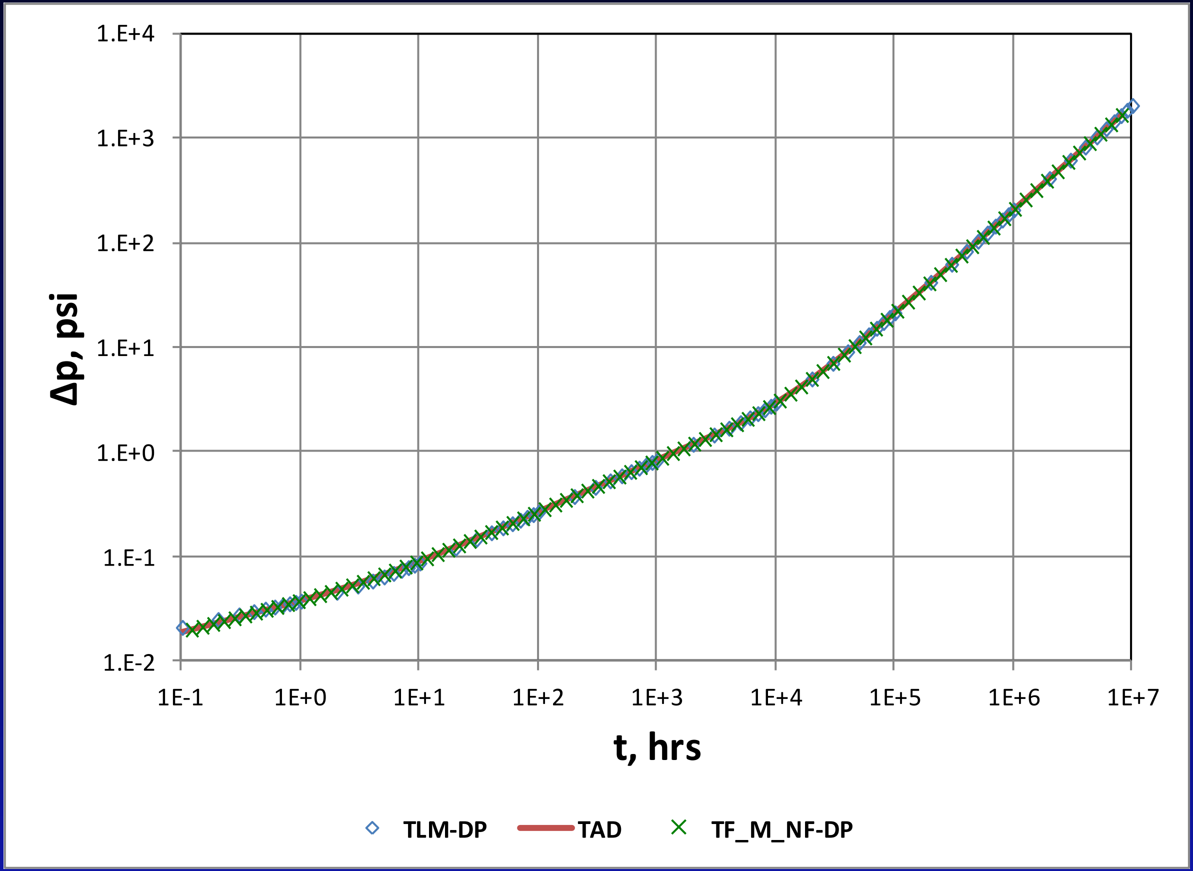

Figure 4: Verification – DP Idealization

Approach

- Verification vs. Tri-linear Model

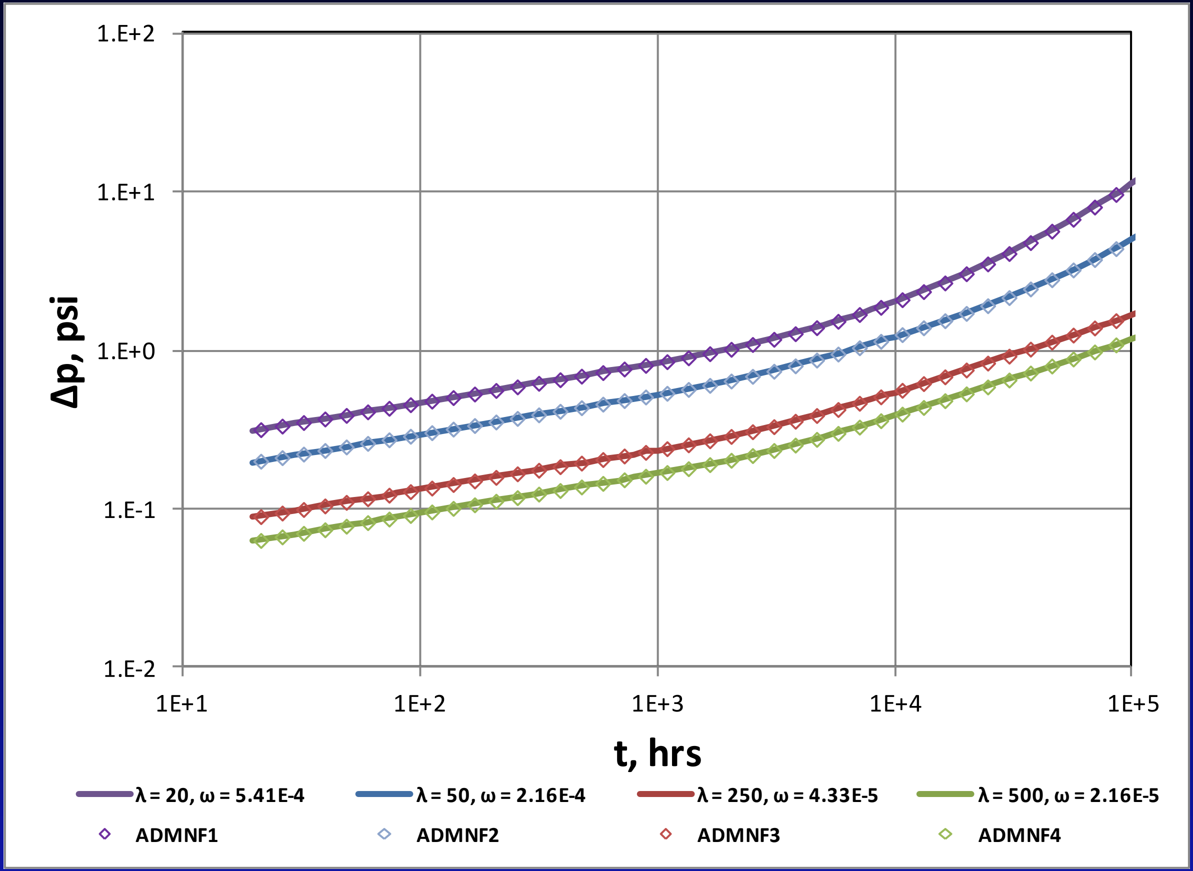

Figure 5: Verification with Tri-linear Model

Planned work

- An elucidation of the anomalous transport in light of petroleum engineering.
- Extend the solution to conventional models.
- Verification and sensitivity analysis.

Conclusion

- Providing alternatives to dual-porosity models for unconventional reservoirs.
- Applying fractals and anomalous diffusion models to unconventional reservoirs (d_f).
- Impact on petrophysical interpretations, pressure transient analysis, description of natural and hydraulic fractures, numerical simulation models and phase behavior studies.

Thank you

References

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