Well Spacing Decisions: How Close is Too Close?

Crisman Meeting
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Ruud Weijermars - Texas A&M University

Thanks to:
Ibere Alves, Darren Crowdy, Rhodri Nelson, David Schechter, Sam Noynaert, Wei Yu, Lihua Zuo, Aadi Khanal, Kiran Nandal, Sergey Parsegov, Arnaud Van Harmelen (to name a few)…
Thank You!

Project Number: 3.02.18
Project Title: Next Generation of Physics-Based Integrated Model of Fracturing and Flow in Porous Media: Unconventional Reservoir Toolbox (URT)

Project Number: 4.01.18
Project Title: Well Interference Toolkit
Flow Cell Factory Model

Permian Basin Well Pads

Stacked Pay Zones

Elementary Flow Cell in Pay Zone

Flow Cell Interference Model for Multiwell Completions

- Interwell Drainage Boundaries (IDB)
- Transverse Flow Separation Boundaries (TFSB)
- Longitudinal Flow Separation Boundaries (LFSB)

Investor presentation
Laredo Energy

- **Flow quantification** based on reservoir properties and fracture treatment parameters
- **Captured in excel sheet**: Optimize Well spacing, Production forecasts and NPV
Structure of this Talk

1. Prior CAM Tool Results
2. Frac Spacing Optimization
3. Depth of Investigation Effects
4. Well Spacing Optimization
5. Conclusions
1. Prior CAM Tool Results
Closed-Loop Optimization

Complex Analysis Methods

5 Producers

5 Injectors

High-perm domain

ECLIPSE

5 Producers

5 Injectors

Single-Phase Flow Fractured Porous Medium

- Complex natural fracture system of the prototype slab
- Streamlines: Magenta
- Time-of-flight contours:
  - Blue = progression after 1 yr
  - Red = progression after 10 yr
- (a) Low permeability contrast ($k_f/k_m \sim 2$) between natural fractures and matrix.
- (b) High permeability contrast ($k_f/k_m \sim 10$); between natural fractures and matrix.

Flow into Well Connected to (Hydraulic & Natural) Fractures

Impact: Enhanced Permeability
Natural fractures

\[ R_k = \frac{k_f}{k_m} \]

- Model shows impact \( R_k \)
- Run time 30 years
- Constant far field flow
- Streamlines in blue
- Red: Time of Flight Contours

(Nandlal and Weijermars, 2019)
Drained Rock Volume (DRV)

DRV after 30 years production around individual hydraulic fractures in Stage 3 of a Wolfcamp Well, Midland Basin (University Lands)

- DRV is in the realm of fluid flow reservoir engineering.
- SRV is the focus of geomechanical fracture treatment engineering (coupled with leak off of frac fluids & proppant concentration)
2. Frac Spacing Optimization
Fractured Well: 2D-Flow Cell Box

a) Permian Basin Well Pads

b) Stacked Pay Zones

c) Elementary Flow Cell in Pay Zone

d) Flow Cells in Single Well

SPE-195544-MS
DCA Scales Reservoir Properties

DCA Curve based on Type Well


SPE-195544-MS
Effect of Frac Spacing Changes

a) Flow Patterns

Type Well

New Well

b) Pressure Profiles

Early Time

Late Time

Cumulative Production

30 ft frac spacing

100 ft frac spacing

CAM

CMG
Economic Optimization

2013 completion cost

2017 completion cost

NPV10 by Frac Spacing

IRR by Frac Spacing

NPV by Frac Spacing

IRR by Frac Spacing

SPE-195544-MS
3. Depth of Investigation Effects
Tracer Speed and Pressure Propagation Speed

a) Conventional Reservoir

- Reservoir Boundary
- Depth of Investigation
- Pressure
- BHP
- $P_0$

All fluid reaches the well

Reservoir pressure drawdown

Distance

b) Unconventional Reservoir

- Reservoir Boundary
- Depth of Investigation
- Pressure
- BHP
- $P_0$

Fluid travels toward well, but much of the fluid never reaches the well on a practical time scale

Distance
Flow Boundary Time

a) Advancing Depth of Investigation

Phase 1: Transient Flow

Phase 2: Boundary dominated flow

b) Flow regimes toward well

Phase 1: Hyperbolic Well Rate Decline

Phase 2: Exponential Well Rate Decline

Interwell Drainage Boundary (IDB)

- **Phase 1**: Well does not “feel” nearby boundary until the Depth or Radius of Investigation reaches the IDB.

- Time to reach the IDB given by:

  \[ t = \frac{1688.7 r_i^2}{\alpha} \]

  Hydraulic Diffusivity:

  \[ \alpha(x) = \frac{k(x)}{\phi(x) \mu c_i} \]

- That’s when **Phase 2** starts

  \( r_i = \text{radius of investigation} \)
4. Well Spacing Optimization

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BERG-HUGHES CENTER FOR PETROLEUM AND SEDIMENTARY SYSTEMS
TEXAS A&M UNIVERSITY
Workflow

Frac Spacing Optimization

Select Type Well

Construct DCA Type Well

Sensitivity DCA to Frac Spacing

Sensitivity Well Economics to Frac Spacing

Optimal Frac Spacing

Well Spacing Optimization

Impact Acreage Dimensions and Lease Boundaries on Well Spacing

Sensitivity DCA to Well Spacing

Sensitivity Multi-well Economics to Well Spacing

Optimal Well Spacing

Field Economics
Production Optimization

Transition points: Phase 1 to Phase 2 Flow

- Operator Used **1250 ft** well spacing
- Is the (Upper) Reference Curve in plots
Economic Optimization

Operator’s 1250 ft well spacing is normalized (1) in plot

Was that a good field development spacing?
5. Conclusions

• Successful use of analytical solution to model flow in unconventional reservoirs.
• Flow insights incorporated in Easy to Use Spreadsheet.
• Uses type curve to scale new well production when changes in frac spacing and well spacing.
• Example shows operator used well spacing that leaves half the acreage value uncapitalized.
• Spreadsheet set (Production sheet & Ecosheet) is very versatile:
  ▪ Accounts for changes in well design parameters
  ▪ Can create any hyperbolic DCA curve, with terminal exponential decline due to depth of investigation
Ruud Weijermars
Professor

Research Interests

- Petroleum economics and decision making
- Reservoir models and production forecasting
- Geothermal reservoir models
- Wellbore stresses and hydraulic fracturing

Selected Publications

Research group website: https://weijermars.engr.tamu.edu
Backup Slides
Let’s Not Forget…

There is no limit to engineering applications!!
“A camel is a horse designed by a committee.”

Camel with Solar-power-cooled Medicine Box for Remote Locations

Compression suit for Camels – Runs Faster!

Petroleum Engineering


http://wonderfulengineering.com/middle-eastern-company-designs-customized-compression-suits-for-camels/

Perdido Spar
Selected Publications


• **Nandlal, K.**, and Weijermars, R., In progress. Impact of Storativity and Enhanced Permeability in Natural Fractures near Hydraulically Fractured Wells on Drained Rock Volume (DRV). Planned for submission to Energies Special Issue, “Improved Reservoir Models and Production Forecasting Techniques for Fractured Wells”.

• Weijermars, R., and **Nandlal, K.**, In progress. Relationship Between Depth of Investigation and Drained Rock Volume (DRV) in Unconventional Reservoirs: Pressure Front Propagation versus Tracer Front Distance

Additional publications and related work on DRV and well interference can be found on research group website: [https://weijermars.engr.tamu.edu/](https://weijermars.engr.tamu.edu/)
Tracer time-of-flight vs Pressure front time-of-flight

- Production data used to determine flux strength to get tracer front
- History matched production gives effective reservoir permeability to determine pressure front time-of-flight

\[ t = \frac{1688.7 r_i^2}{\alpha} \]

Time required to establish depth of pressure depletion region

\[ \tau = \sqrt{t} = r_i \sqrt{\frac{1688.7}{\alpha}}, \]

Depth of investigation from Diffusive TOF

\[ \alpha(x) = \frac{k(x)}{\phi(x) \mu c_i} \]

Hydraulic diffusivity dependent on permeability

(Nandlal and Weijermars, 2019)
Model Verification

Streamlines with drainage contours: a) analytical solutions, b) commercial simulator, c) pressure field. a: Streamlines (blue), time of flight contours (red), stagnation points (green). b: Streamlines and time of flight contours (rainbow colors). c: Analytical pressure field. Fractures represented as black lines: Adapted from Weijermars et al. (2017)
Original Methodology – Reservoir Flow

• All models shown in this talk based on closed-form solutions.

• Can account for:
  - Reservoir Boundaries
  - Internal Faults
  - Heterogeneity
  - 1-Phase Flow Fractured Reservoirs

• Validated in previous studies:
Example: Steady Source Flows Competing for Space

Simple Maths:

\[ W(\zeta) = \left(-\frac{Q}{2\pi}\right)\ln \zeta \]
\[ \zeta = R \exp i\theta \]
\[ W(R \exp i\theta) = \left(-\frac{Q}{2\pi}\right)\ln(R \exp i\theta) \]
\[ = \left(-\frac{Q}{2\pi}\right)(\ln R + i\theta) \]
\[ \Phi = \left(-\frac{Q}{2\pi}\right)\ln R \]
\[ \psi = \left(-\frac{Q}{2\pi}\right)\theta \]

\[ W(\zeta) = W_a(\zeta) + \ldots + W_q(\zeta) \]

Time of Flight Contours (red)

Approach

• Utilize the capacity of DCA as a reservoir model for flow in Hydraulically Fractured Wells
• Throw old myths on flow near fractures (not five flow regimes)
• Come up with something better
• Easy to use
Effect of Natural Fractures