

Fracture Spacing Optimization

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Optimizing Fracture Spacing in Unconventional Reservoirs

Based on SPE 163833 & URTeC 1581809

Motivation

Maximize HC Recovery Factor while Minimizing Cost:

- Optimize the number of fractures per well (stages/entry points)
- Optimize horizontal well spacing (well count)

Solution

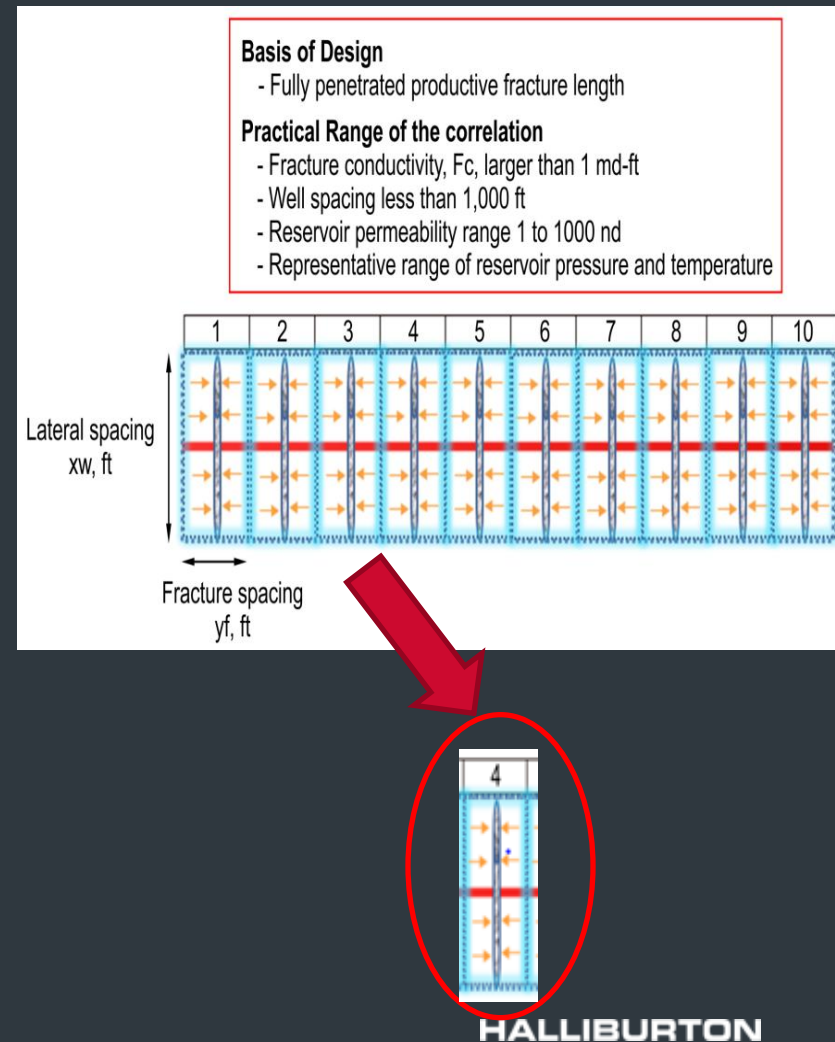
- Introduce a quick “back of the envelope” practical methodology as a function of:
 - Reservoir properties and drawdown
 - Fracture parameters (conductivity, proppant distribution, stress sensitivity etc.)
- Initially for gas then expanded to light oil

Best Ways to Optimize Fracture Spacing and Horizontal Well Spacing

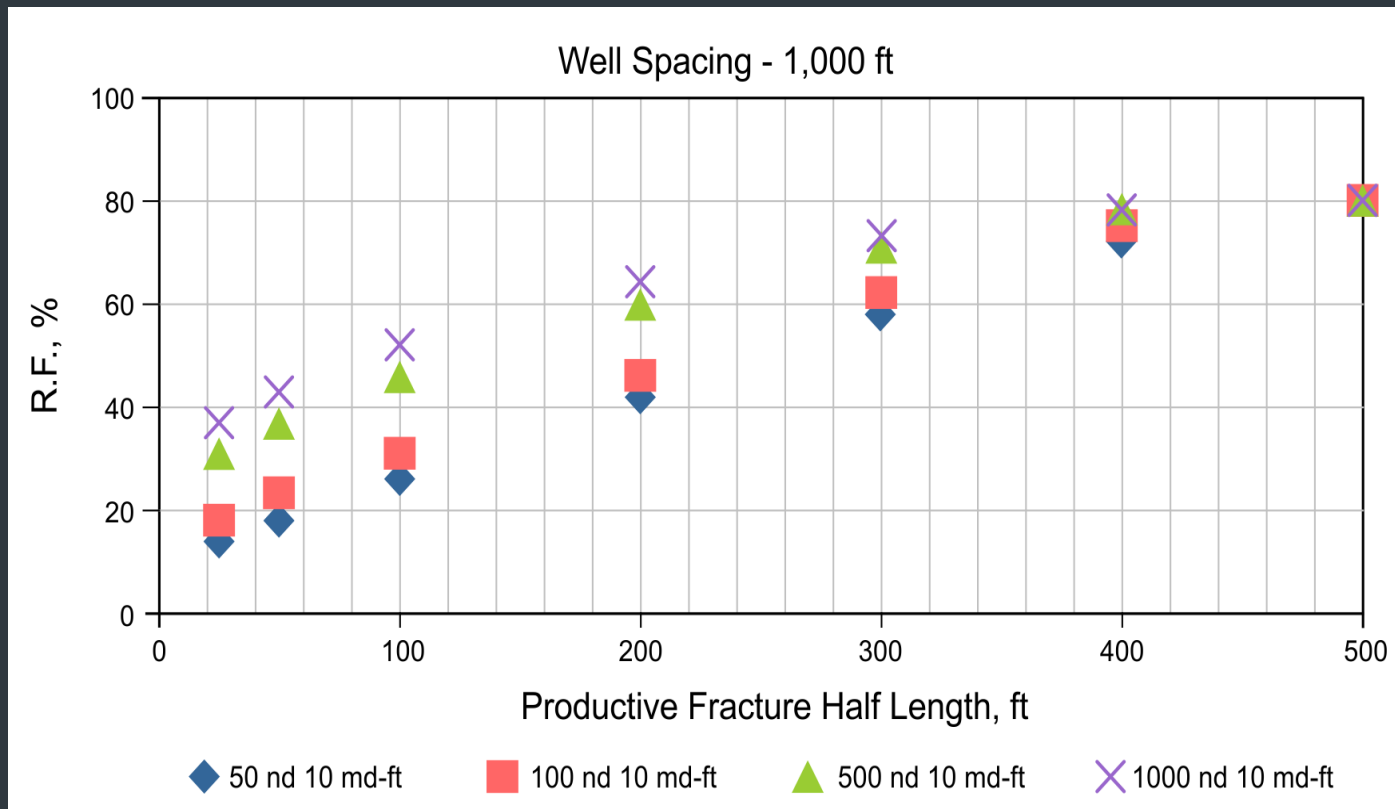
- If detailed reservoir, rock mechanics, reservoir fluid, and hydraulic fracture properties, etc. are available (locally or for the area); reservoir simulation is the best option to optimize number of fractures and lateral well spacing.
- Numerical simulators can include more details on fracture properties such as accounting for proppant settling, stress sensitive conductivity, multi-phase flow, non-Darcy flow etc.
- But.... Detailed reservoir simulation can be time consuming and labor intense.

Quick Practical Correlation for Optimizing Fracture Spacing in Horizontal Gas Wells

- Develop a simple correlation between optimum fracture spacing and basic reservoir properties (permeability, fluid viscosity) based on series of simulations
- No economic optimization included!
- Estimates required fracture spacing to achieve 80% gas RF after 30-year well life



Effective Fracture Length vs. Well Spacing



- Reduced effective length has significant effect on gas recovery factor!
- For $k < 1$ microdarcy well spacing needs to be equal to effective length

Quick Practical Correlation for Optimizing Fracture Spacing in Horizontal Wells

- A series of simulations for a wide range of reservoir and fracture parameters
- Effective x_f =well half-spacing

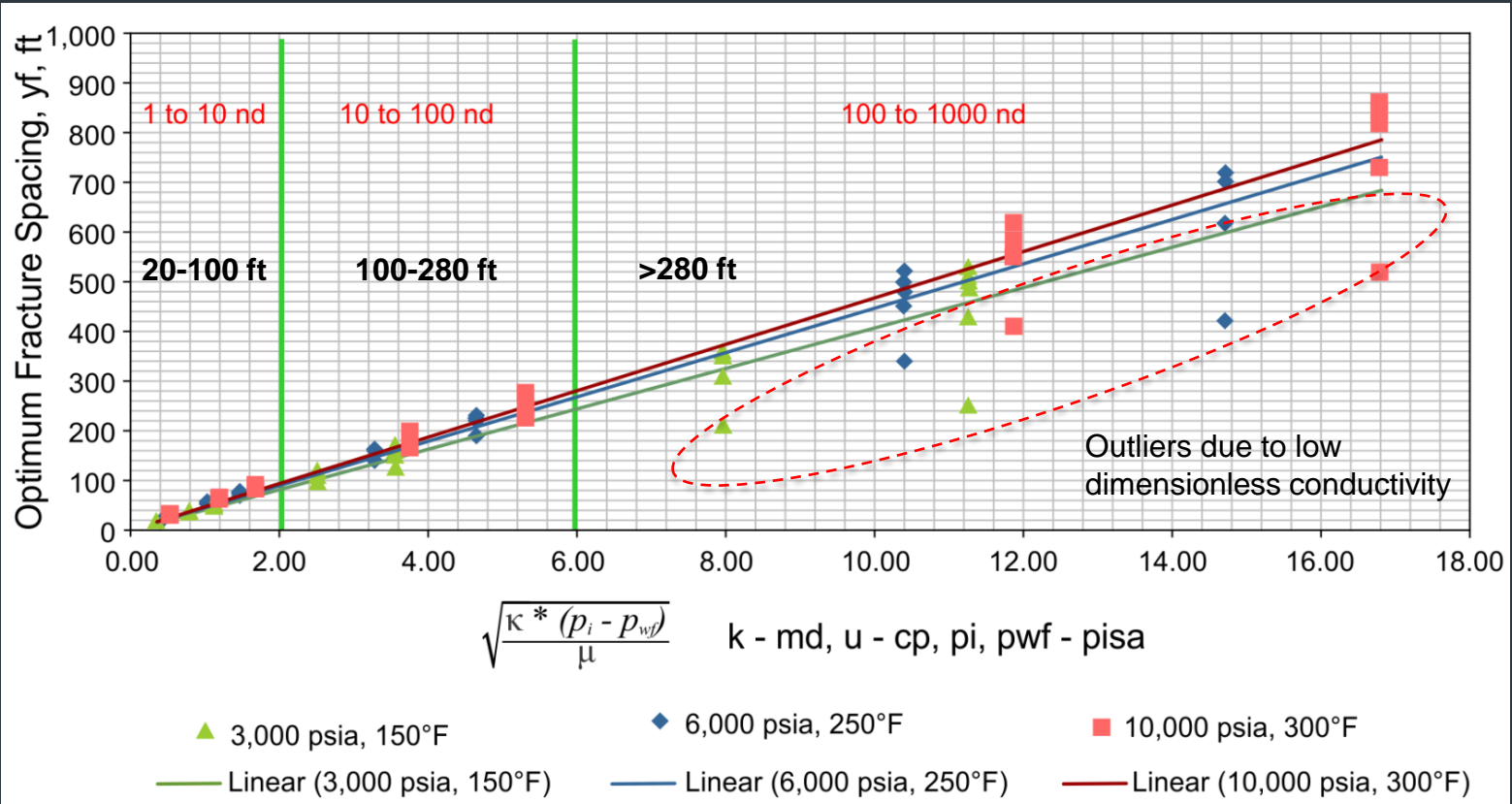
TABLE-1: SIMULATION CASES

<u>Permeability - k, nd</u>	<u>Frac Cond, md-ft</u>	<u>Well Spacing ft</u>
1 to 1,000	1 to 100	500 to 2000

3 cases to cover a wide range of properties :

1. 3,000 psi - 150° F
2. 6,000 psi - 250°F and
3. 10,000 psi - 300°F

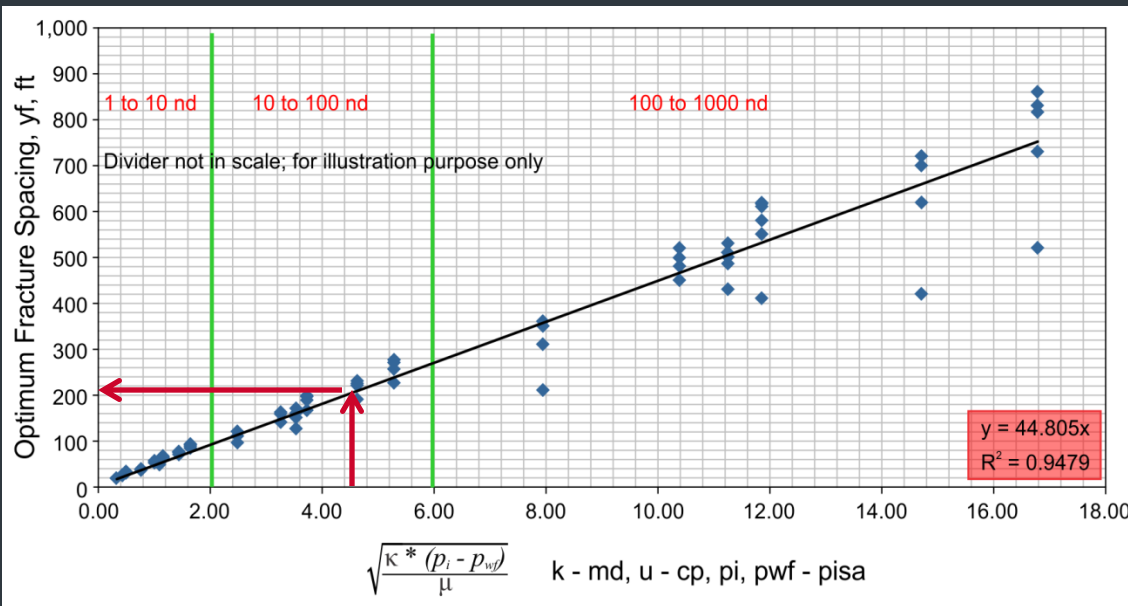
Quick Practical Correlation for Optimizing Fracture Spacing in Horizontal Gas Wells



Proposed correlation is valid for:

- Effective Fracture half-length < 500 ft
- Fracture conductivities higher than 1 md.ft

Example: Fracture Spacing Optimization in Unconventional Gas Reservoirs



Correlation: Dry Gas Case

$$y = 44.805 x \quad R^2 = 0.9479$$

where:

$$x = \sqrt{\frac{k * (p_i - p_{wf})}{\mu}}$$

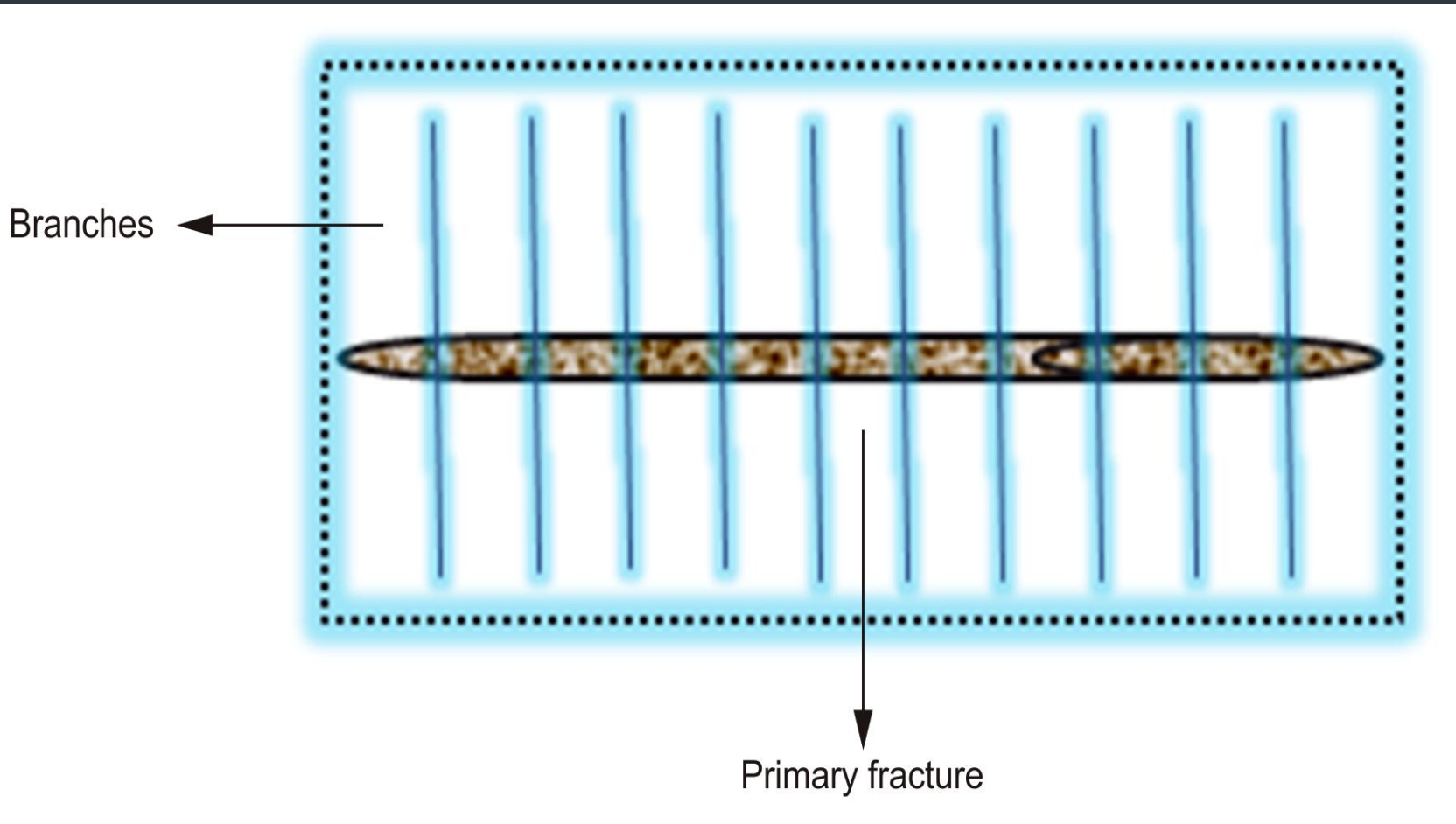
$y = y_f$, Fracture Spacing

Input Data

Reservoir Perm, k	0.0001	mD
Gas Viscosity, μ @ P_i, T_i	0.0254	cP
Reservoir Pressure, P_i	6000	psia
FBHP, p_{wf}	500	psia

➔ Optimum Fracture Spacing = 208 ft

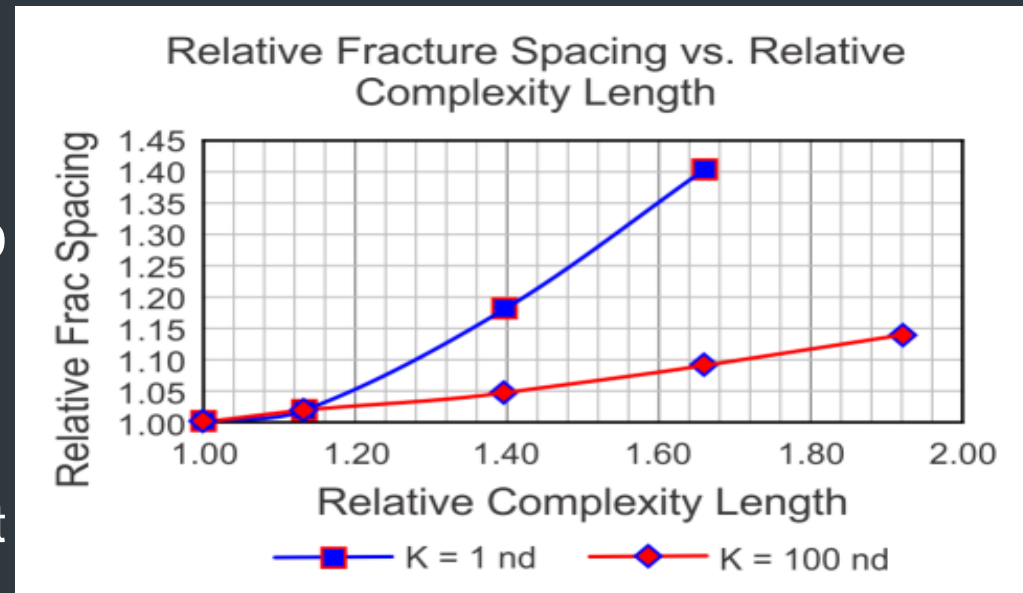
Fracture Complexity Effect on Fracture Spacing and RF Optimization



Fracture Complexity Effect on Fracture Spacing and RF Optimization

- With high complexity fracture spacing can be increased (e.g. 40% for 1-nD permeability)
- And only 10% for higher 100-nD permeability

This shows that achieving fracture complexity becomes less important at >100 nd permeability

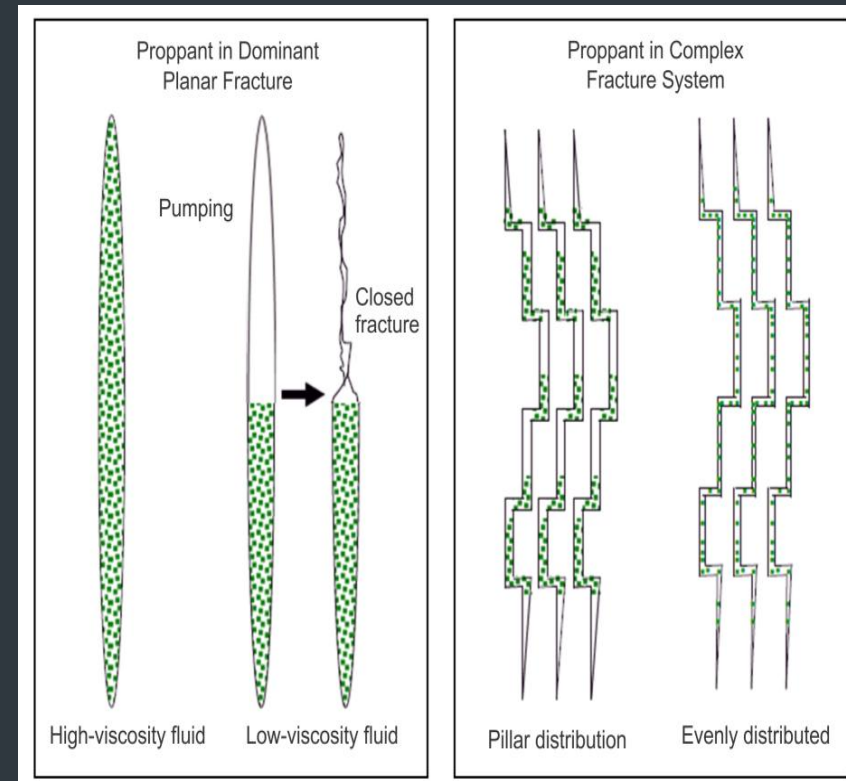


**Base Example @ 40% complexity
Spacing = 218 ft**

Vertical Proppant Distribution or Proppant Settling

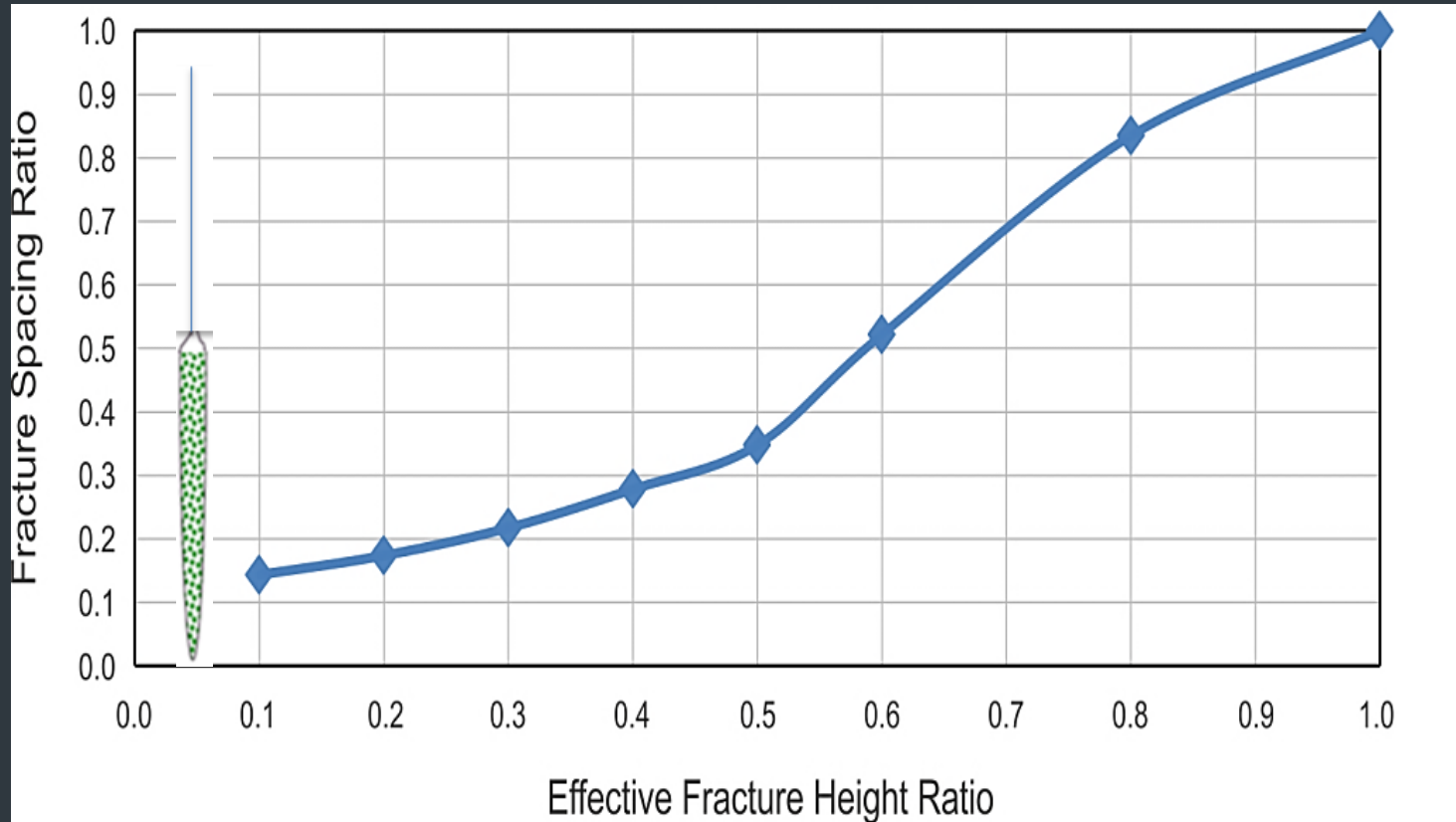
Picture shows the possible proppant distribution and settling scenarios for planar or complex fractures.

The exact distribution of proppant is still not totally understood



From SPE 115769, Cipolla et al.

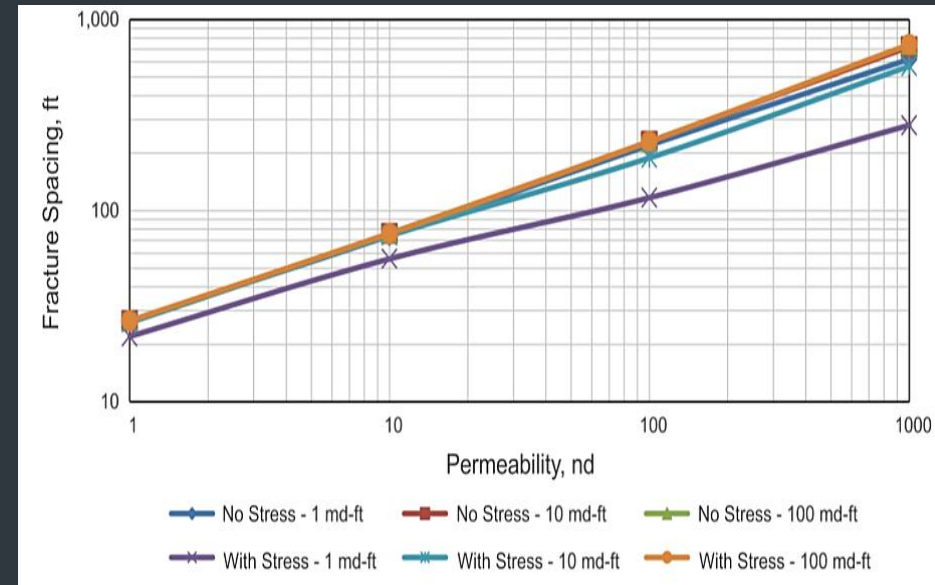
Proppant Settling Effect on Fracture Spacing and RF Optimization



**➔ Base Example @ 50% effective height
Spacing decreases to 73 ft !**

Effect of Stress Dependent Fracture Conductivity on Optimum Fracture Spacing

- Only meaningful for fracture conductivities lower than 1 mD-ft
- In branched fractures, the stress effect could be significant because the proppant concentration and conductivity are lower.
- Stress effect could be minimized when generated fracture conductivity is \Rightarrow 10 md-ft for the entire permeability range.



Stress Dependent Reservoir Permeability and Its Effect on Optimum Fracture Spacing

- Meaningful impact on the optimum fracture spacing for all permeabilities
- For assumed stress dependence fracture spacing should be corrected by at least 50%.

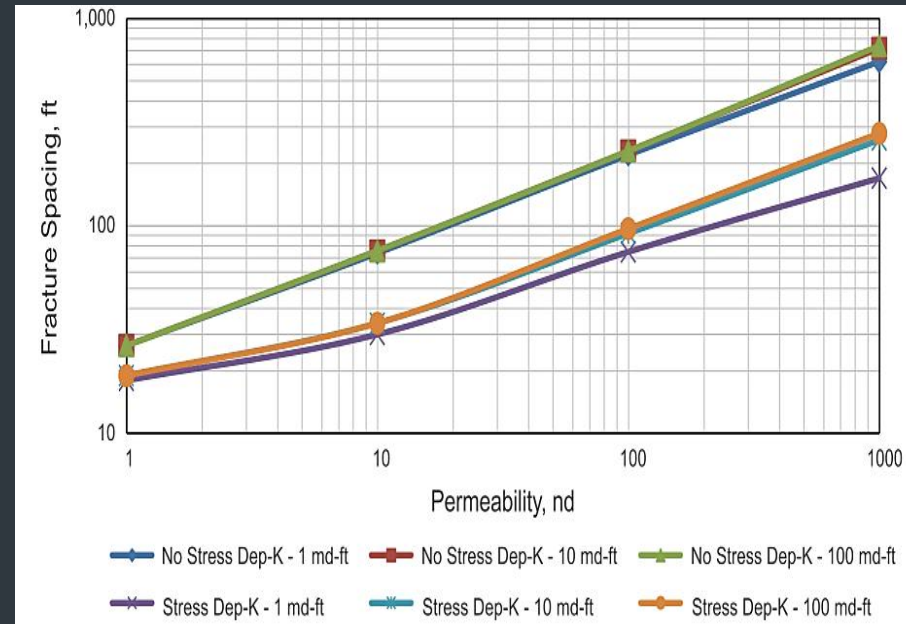


TABLE 7—ASSUMED STRESS DEPENDENCE OF RESERVOIR PERMEABILITY

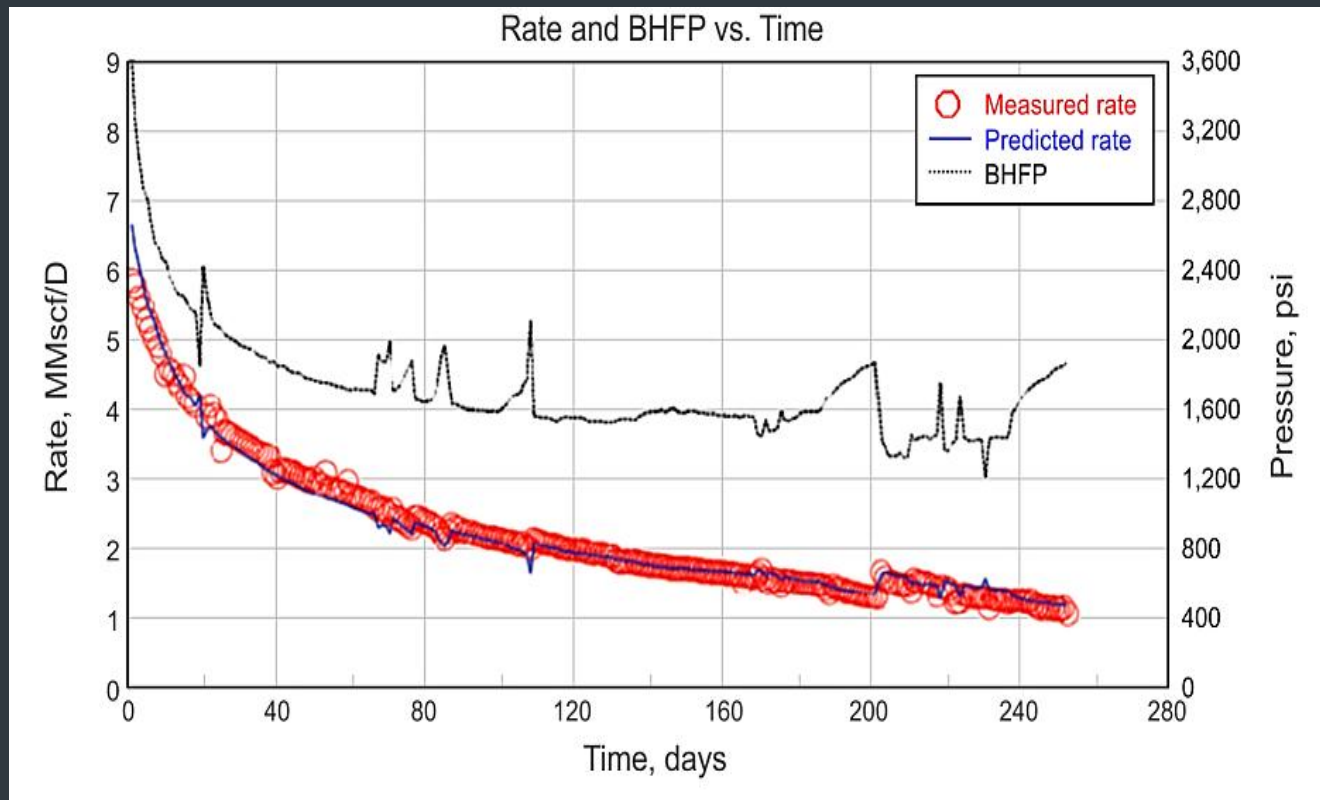
Primary Permeability Multiplier Table				
	Pressure, psia	P_x	P_y	P_z
1	14.70	0.05	0.05	0.05
2	2,000.00	0.20	0.20	0.20
3	4,000.00	0.40	0.40	0.40
4	6,000.00	0.70	0.70	0.70
5	8,000.00	1.00	1.00	1.00

Eagleford Case Study

TABLE 9—PROPERTIES OF THE SELECTED WELL^a

Lateral length, ft	4,000
Payzone height, ft	283
Depth (TVD), ft	10,875
Porosity, %	5.8
Reservoir pressure, psi	8,350
Temperature, °F	285
Gas gravity	0.621
Gas compressibility, 10⁻⁵ psi⁻¹	6
Viscosity, cp	0.03334
Number of fractures stages	10
Clusters/stage	4
Number of expected transverse fractures	40
^a From Bazan et al. 2010.	

Eagleford Case Study



- Production history match (from Bazan et al. 2010)
 $k=17$ nD; $x_f=250$ ft; 200 ft spacing
- Alternate history match (from Xu et al. 2012)
 $k=125$ nd; $x_f=75$ ft; 200 ft spacing.

Eagleford Case Study

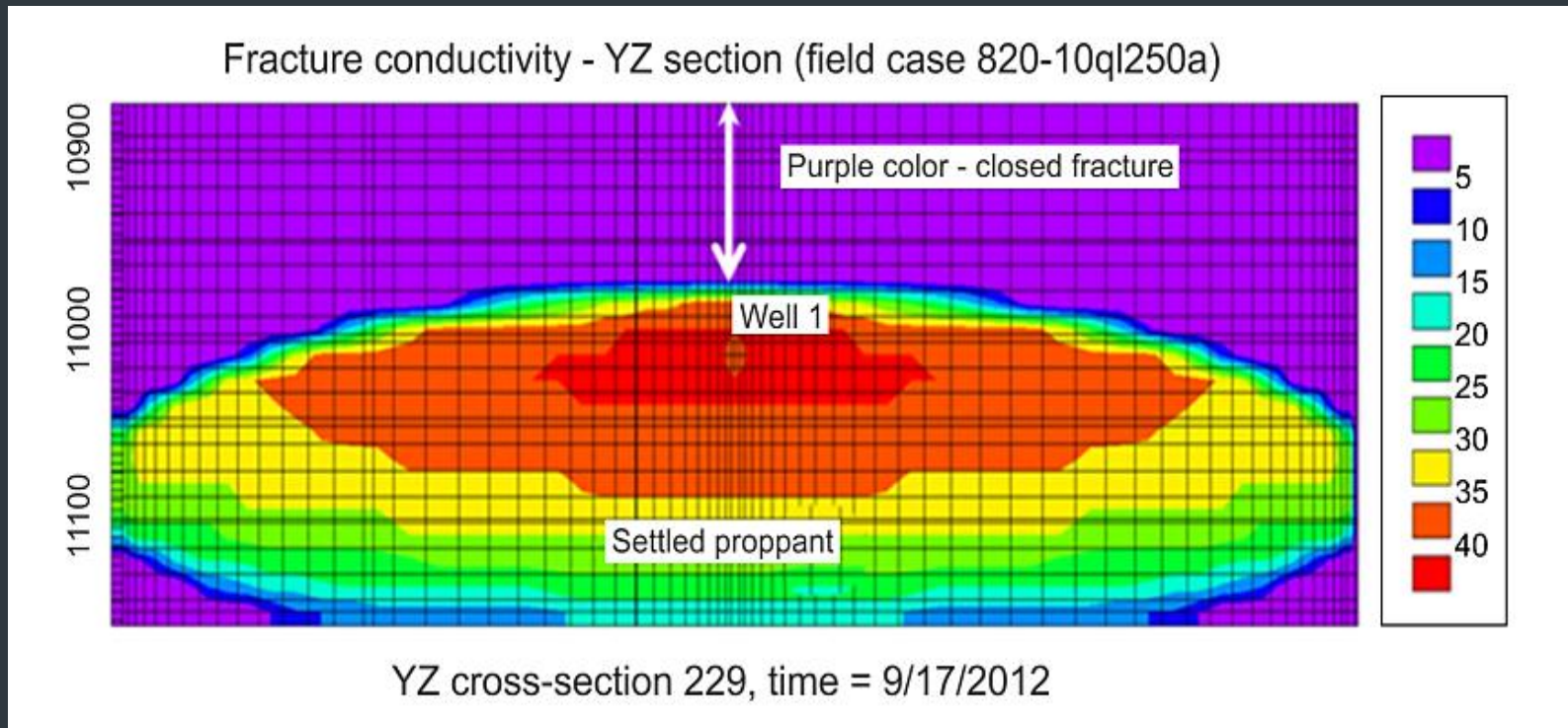
From “frac spacing correlation”:

 Optimum Fracture Spacing= 243 ft for 125 nD

 Optimum Fracture Spacing= 90 ft for 17 nD

Simulated Proppant Distribution and Fracture Conductivity Profile for Eagle Ford Case Study

Waterfrac Design



- 30% of pay not covered (closed fracture)
- $X_f \sim 500$ ft

Effect of Incomplete Zonal Coverage

- 243-ft fracture spacing could be corrected by up to 71% (1% due to stress-dependent fracture conductivity and 70% due to proppant settling effects).
- The new optimum fracture spacing would then decrease to 72 ft (125 nD) & 27 ft (17 nD) or 55 & 148 transverse fractures
- Well was perforated with 75 ft cluster spacing but based on history matches/ PLT only 1 to 2 clusters are likely effective (e.g. 200 ft effective spacing)
- The new RF is still only 66% for the entire pay zone. This shows that the problem of a partially fractured pay zone cannot be fully compensated by reduced fracture spacing alone!

Conclusions from Eagle Ford Case Study

Recommendation scenarios for this case study:

- If perm is 125 nD - one cluster per stage (200 to 250 ft stage spacing) and ensure zonal coverage with larger cross-linked gel hybrid treatment



Cost-efficient but riskiest scenario from reserves recovery & production perspective (assumes higher k is correct and no stress dependent permeability)

Conclusions from Eagle Ford Case Study

Recommendation scenarios for this case study:

- If perm is 17 nD and/or coverage issues, continue with 75 ft cluster spacing and try to increase chances of actually achieving one effective fracture at this spacing

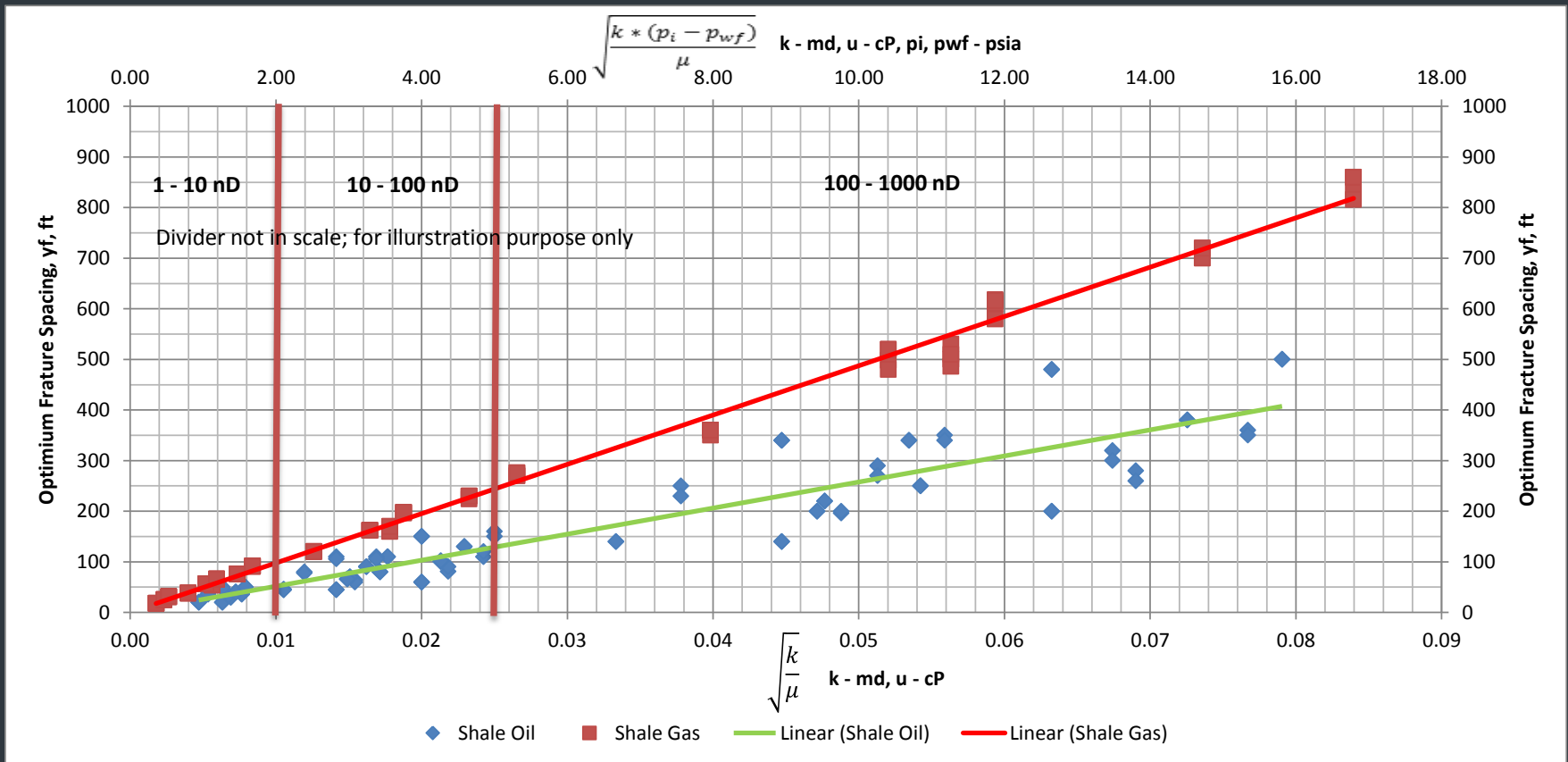


Implies improvements on:

- cluster efficiency (diversion, larger treatments)
- proppant distribution (hybrid)
- staging (more stages with less clusters to ensure cluster efficiency)

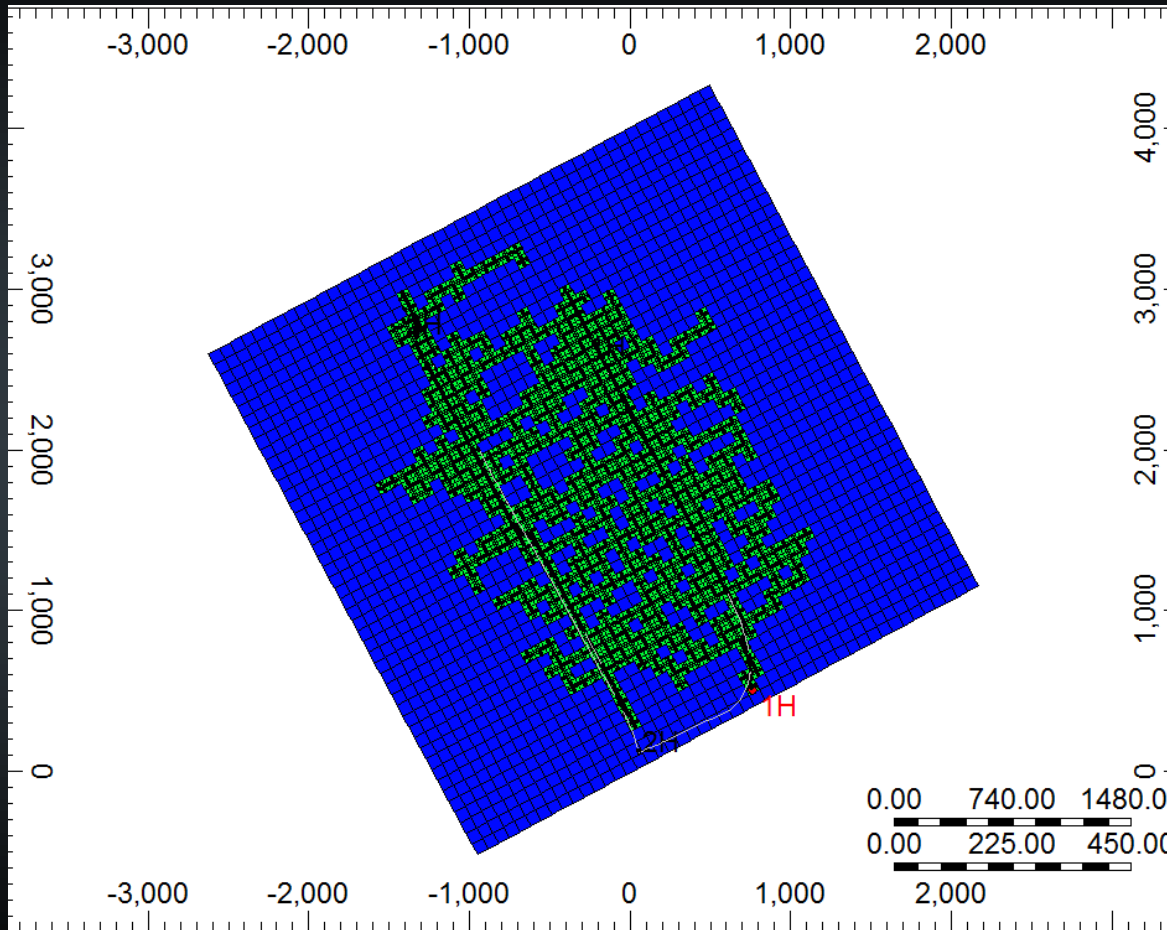
Higher cost but higher chances of ensuring reserves recovery & accelerated production

Fracture Spacing: Gas vs. Light Oil



For the same range of initial conditions and permeabilities the optimum fracture spacing for light oil is 50% of gas (Achievable Oil RF is only 10 – 30%)

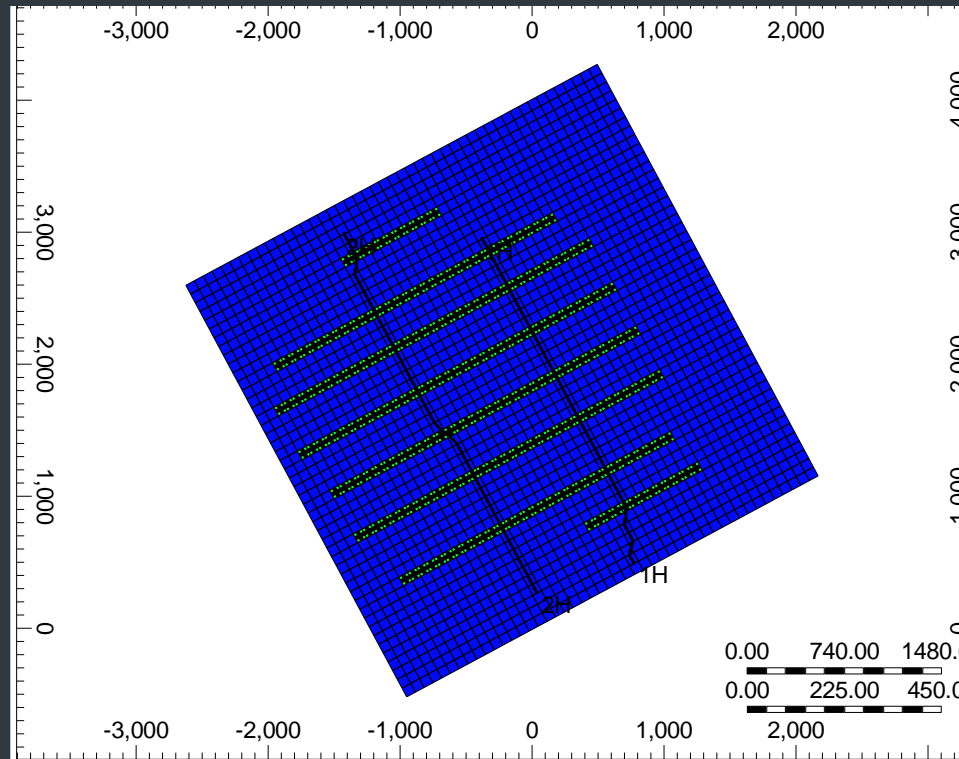
Marcellus Case Study: Is a Complex Fracture Network Needed?



Marcellus Case Study

From “frac spacing correlation”:

➔ **Optimum Fracture Spacing ~ 310 ft for 30-yr Recovery**
($k = 300$ nD; $p_i = 3,900$ psi; $\mu_g = 0.021$ cp; $p_{wf} = 500$ psi)



Thank You

