In Situ Distribution of Fluid Injected Through Fractures

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Background/Objectives. *In situ remediation is a contact sport. Treatment materials can be directly mixed into tillable soil, placed in trenches to intercept groundwater flow, or delivered through wells. To this last end, several well enhancement techniques have been developed. Among these are fracturing technologies. Fracturing methods create sheet-like permeable pathways in low permeability media that 1) increase the flow capacity of the well and 2) expand the zone of influence around the well.*

Enhancement of well flow rate can be directly measured, or estimated reasonably by comparison to conventional wells. In contrast, in situ distribution cannot be assessed with equal convenience. Rather, practical analysis of injected material distribution relies upon the concepts of hydrology, the geologic structure of the target formation, and the rheology of the injected fluid.

Approach/Activities. *The displacement action of injected fluid can be assessed quantitatively with a material balance / volume balance. These expressions need to incorporate concepts about the flow distribution from the fracture into the surrounding formation. The simplest case assumes uniform flux at the fracture/formation interface, which can be applicable for early time. Divergent flow away from the fracture occurs after longer injection durations, and needs to be considered in the analysis.*

Fluid rheology (principally viscosity) controls the distribution of miscible fluids throughout the permeable media, while capillarity and relative permeability relationships play a significant role for non-miscible fluids(gases or oils) injected into water-bearing zones. Dual porosity systems, such as fractured bedrock, require an approach that reflects the structure on a scale commensurate with the injected volume.

Results/Lessons Learned. *When assuming a single fracture surrounded by homogeneous media, the analysis suggests that more than one fracture pore volume is required to deliver fluid to the fracture tip, and, by extension, to the formation surrounding the tip. Specifically, fluid injected into a fracture causes an equal volume of fluid to exit the fracture into the formation. The exiting fluid includes both formation fluid and injected fluid during later stages of an injection event. For example, injection doses of 165% fracture pore volume were needed to expel all native water from fractures at a site in the Atlantic Coastal province.*

In a similar homogeneous setting, the delivery of vegetable oil through the fracture results in a distribution over greater length than might be anticipated. This occurs because capillarity limits the pore space through which oil can move. Air sparging into a homogeneous formation has been shown to effect varying flux across the fracture surface, with commensurate non-uniform distribution in the surrounding soil.

The radius of influence of bedrock injection wells, as bracketed by offset well performance, corresponded to a volume balance that incorporated the fracture density of the formation.

Introduction

FRx

Passive Remediation Systems

- ISCO, ISCR, Enhanced Bioremediation, etc
- Involves targeted emplacement of solids and/or liquid
- All about CONTACT!

Liquid Injection Approach

- Characterize contaminant distribution, determine amendment mass, implement safety factor (6x, 10x, ?x)
- Only works if assumptions about distribution are accurate

Hydraulic Fracture Facilitated Injection

- Improves injection rates and distribution in low k materials
- Actual distribution depends on formation and liquid properties

Fracturing Process and Resulting Form

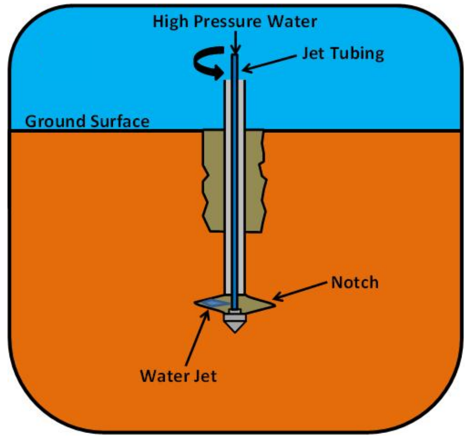
1. Prepare Slurry

Quartz Sand

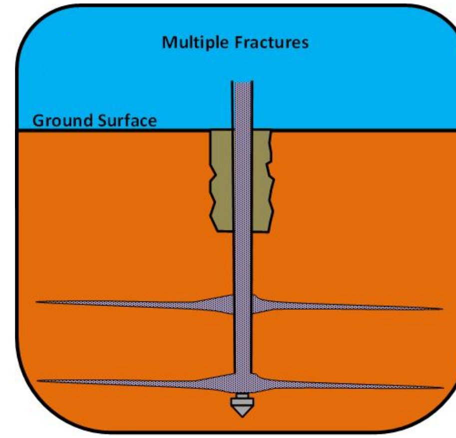
Solid $KMnO_4$

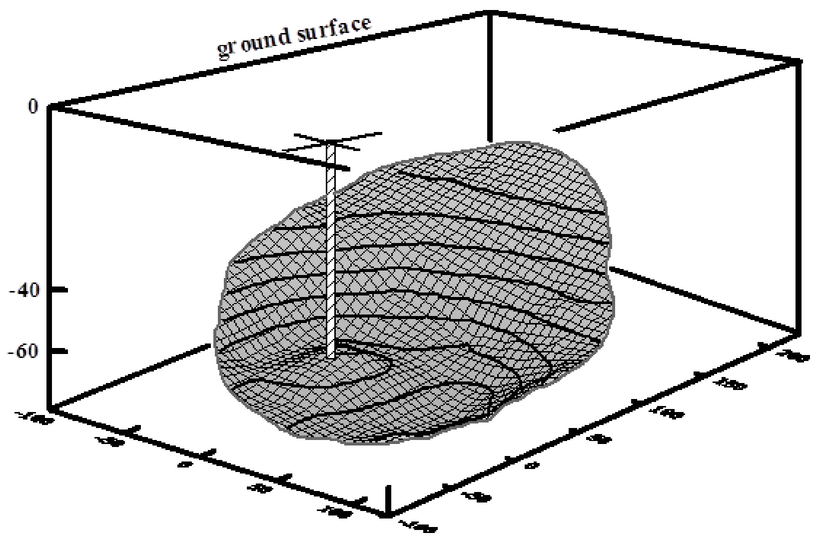
Granular ZVI

2. Prepare Casing



3. Inject Slurry



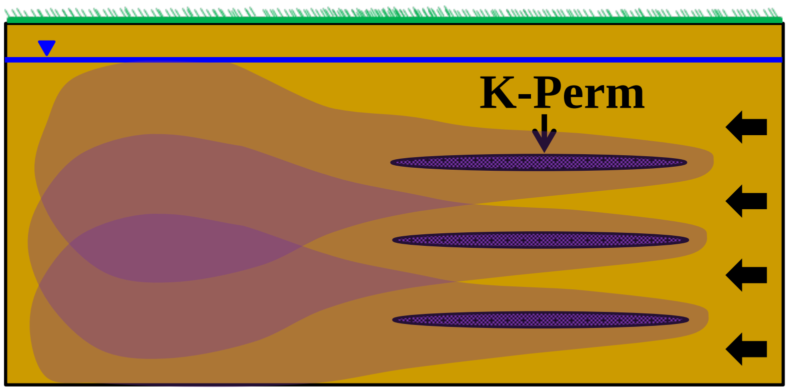


In Situ Access to Contaminants

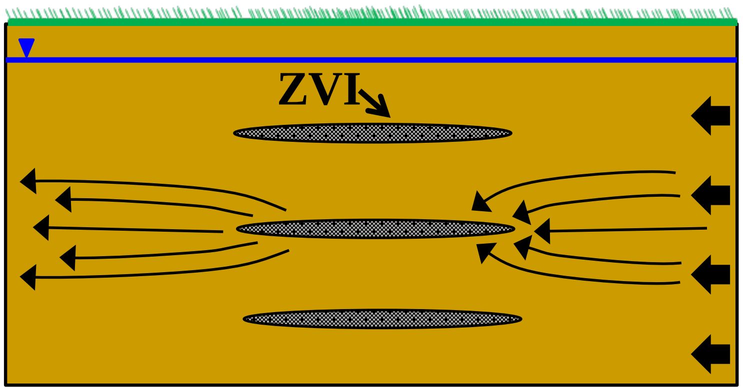
Applications of Hydraulic Fracturing

Reactive Solids:

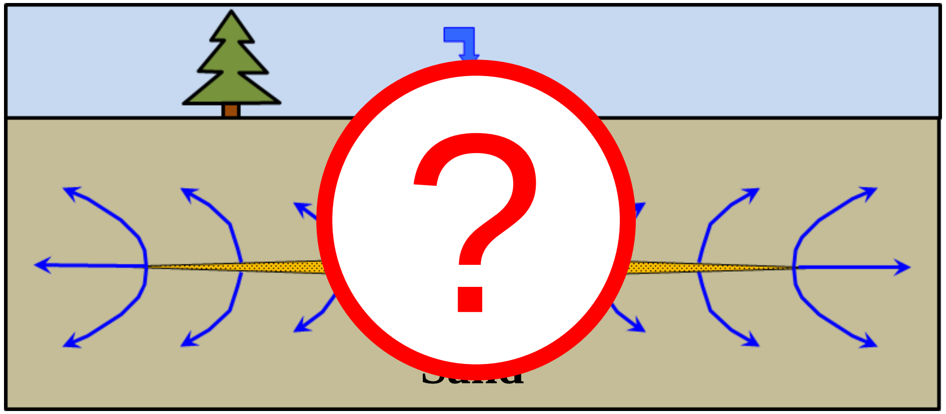
Soluble Remedial Solids



Flow-Through Remedial Solids

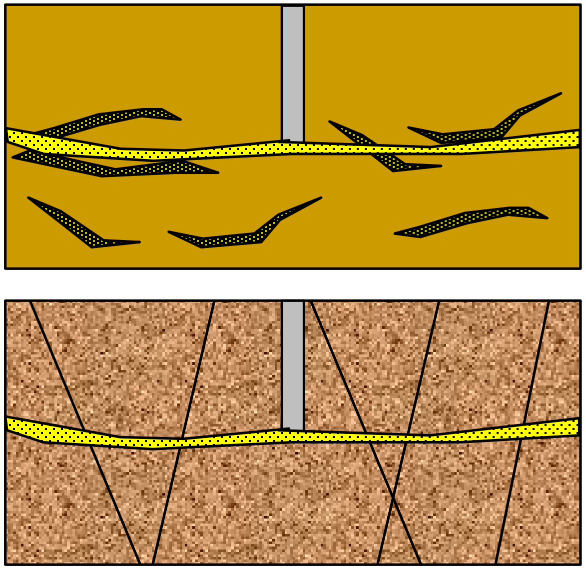


Enhanced Flow:

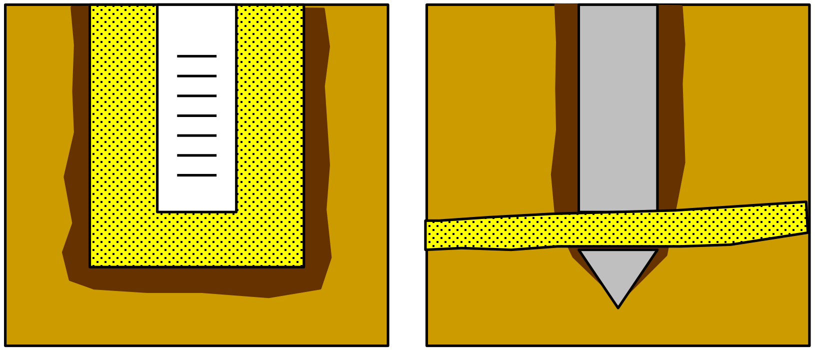


How do Hydraulic Fractures Enhance Flow?

Intersection High k Features:

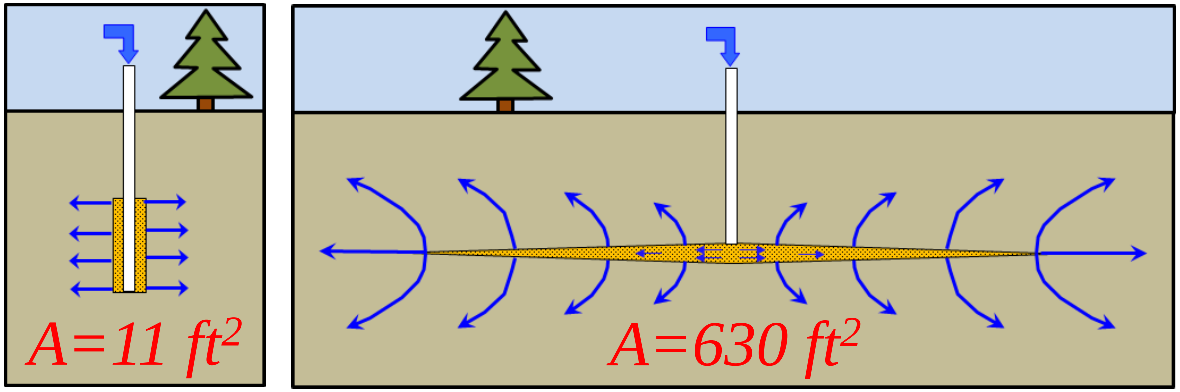


Alleviation of Well Skin Effects:

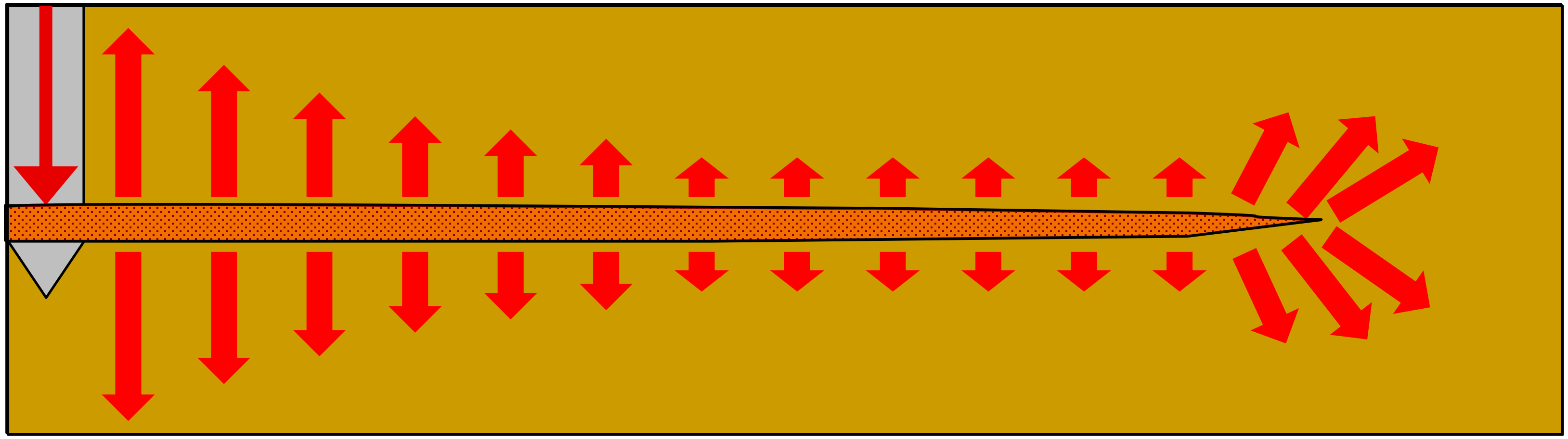


Increased Interfacial Area:

$$Q = -KA\frac{dh}{dl}$$



Controlling Factors on Distribution



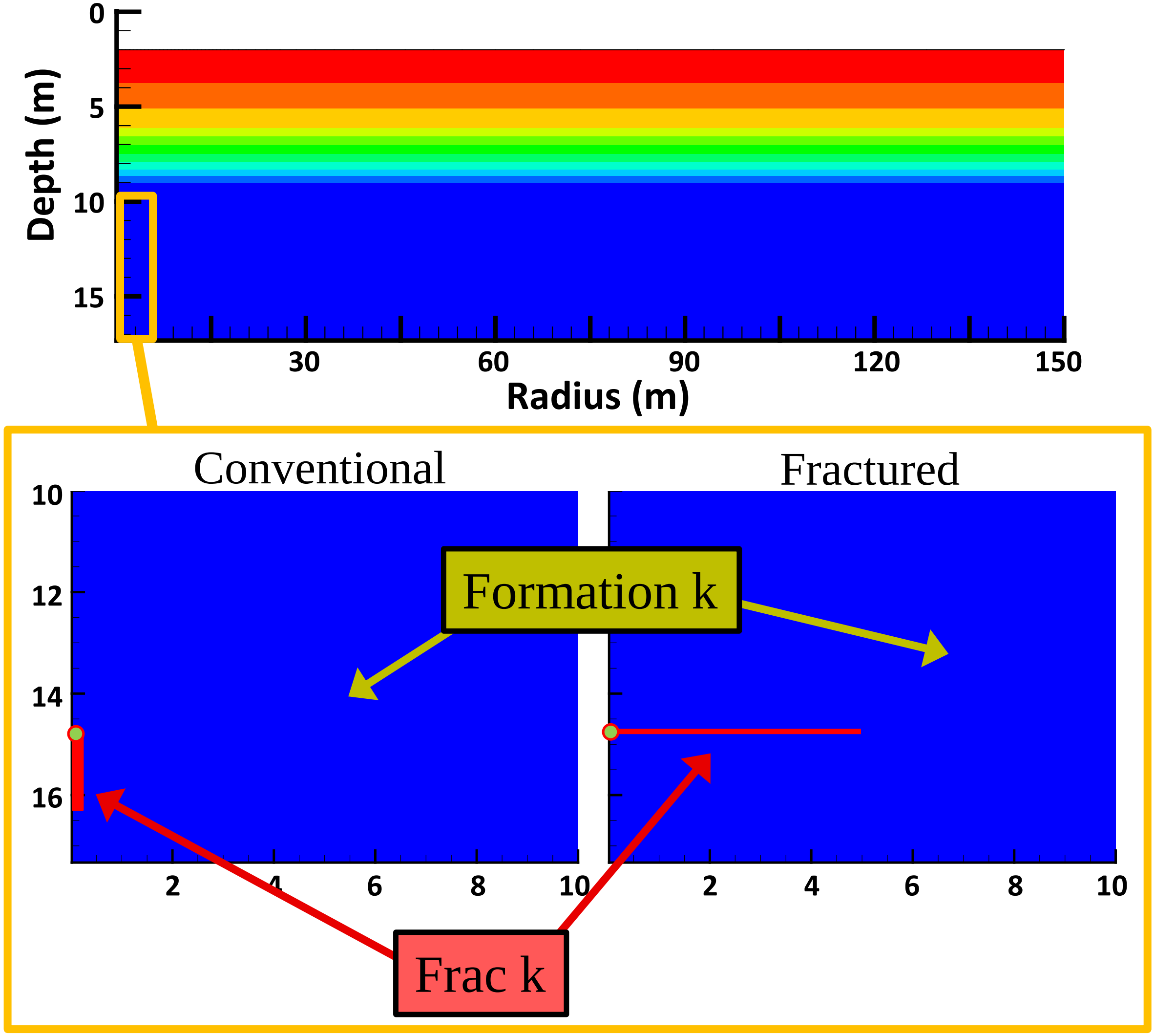
-Fracture to Formation Permeability Ratio

-Fluid Properties

-Tip Effects

Can we make predictions about final distribution patterns?

Model Description



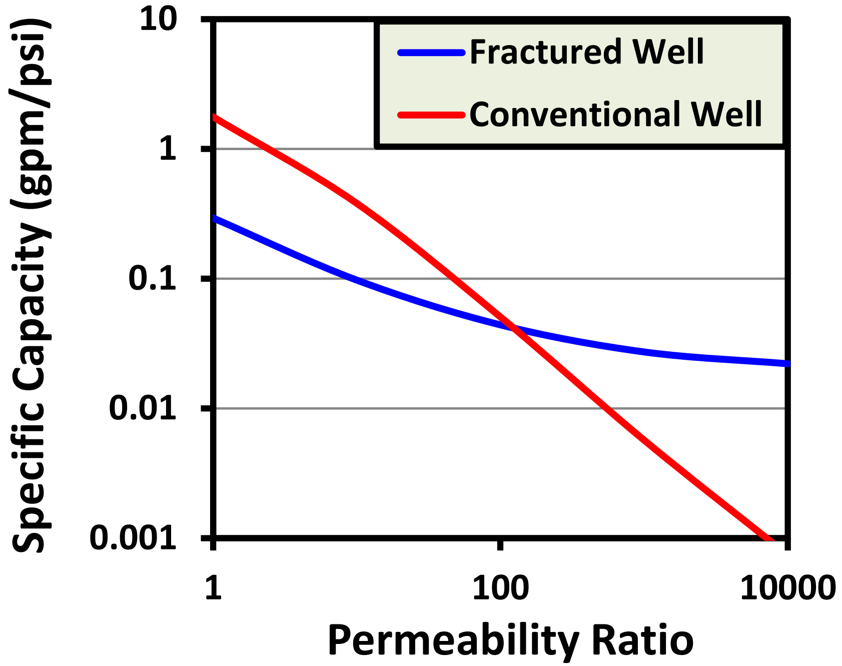
Inner Radius: 3 cm

Fracture Aperture: 1 cm

Conventional Sandpack
Length: 1.5 m (5 ft)
Radius: 10 cm (4 inch)

$\frac{\text{Frac k}}{\text{Form k}}$ (kRat): 1, 10, 100, 1K, 10K

Well Performance Comparison



Silty Sand → Clay

Saprolite

Glacial Till

Frac Sand

Permeability ≈ 10^{-12} m^2

Hydraulic Conductivity ≈ 10^{-3} cm/s

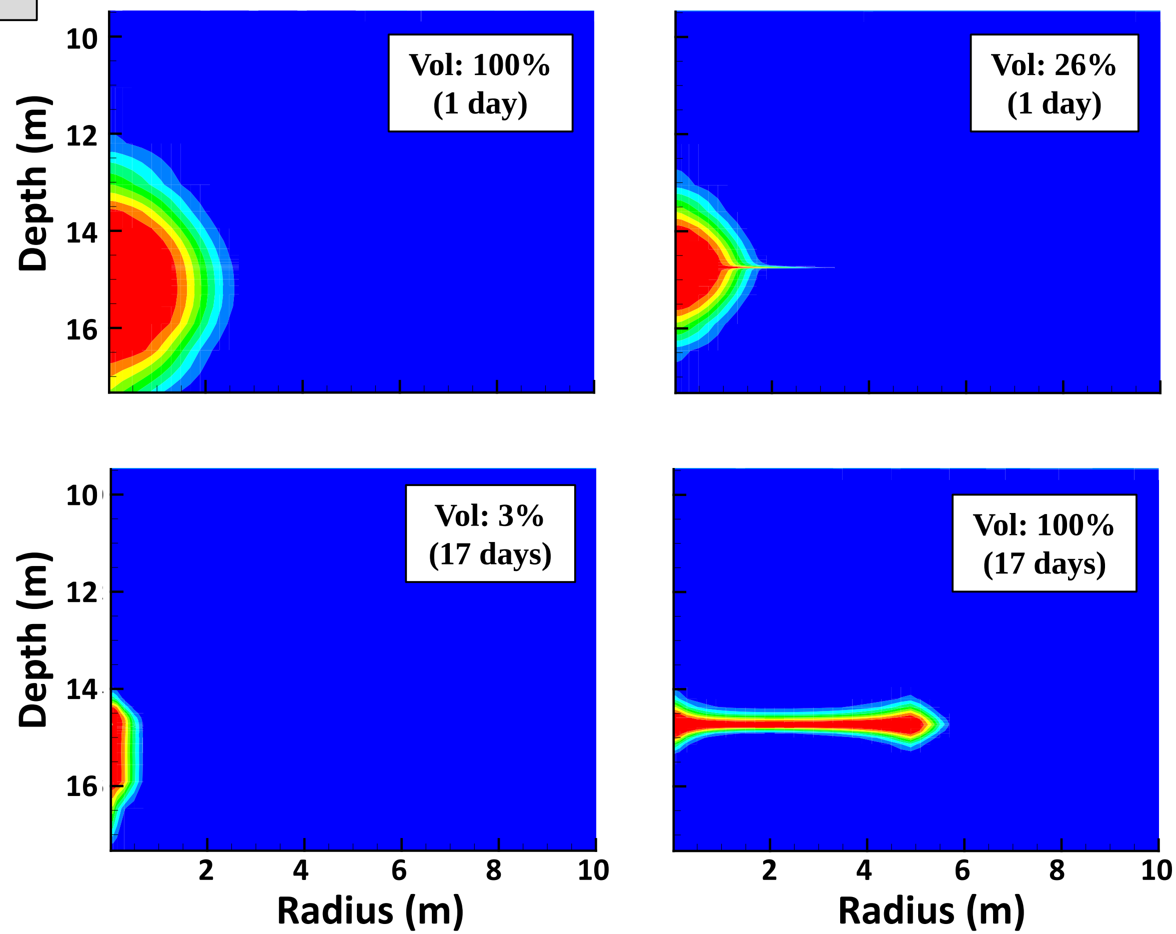
Distribution Patterns

Inject Aqueous Solution at 20 psi

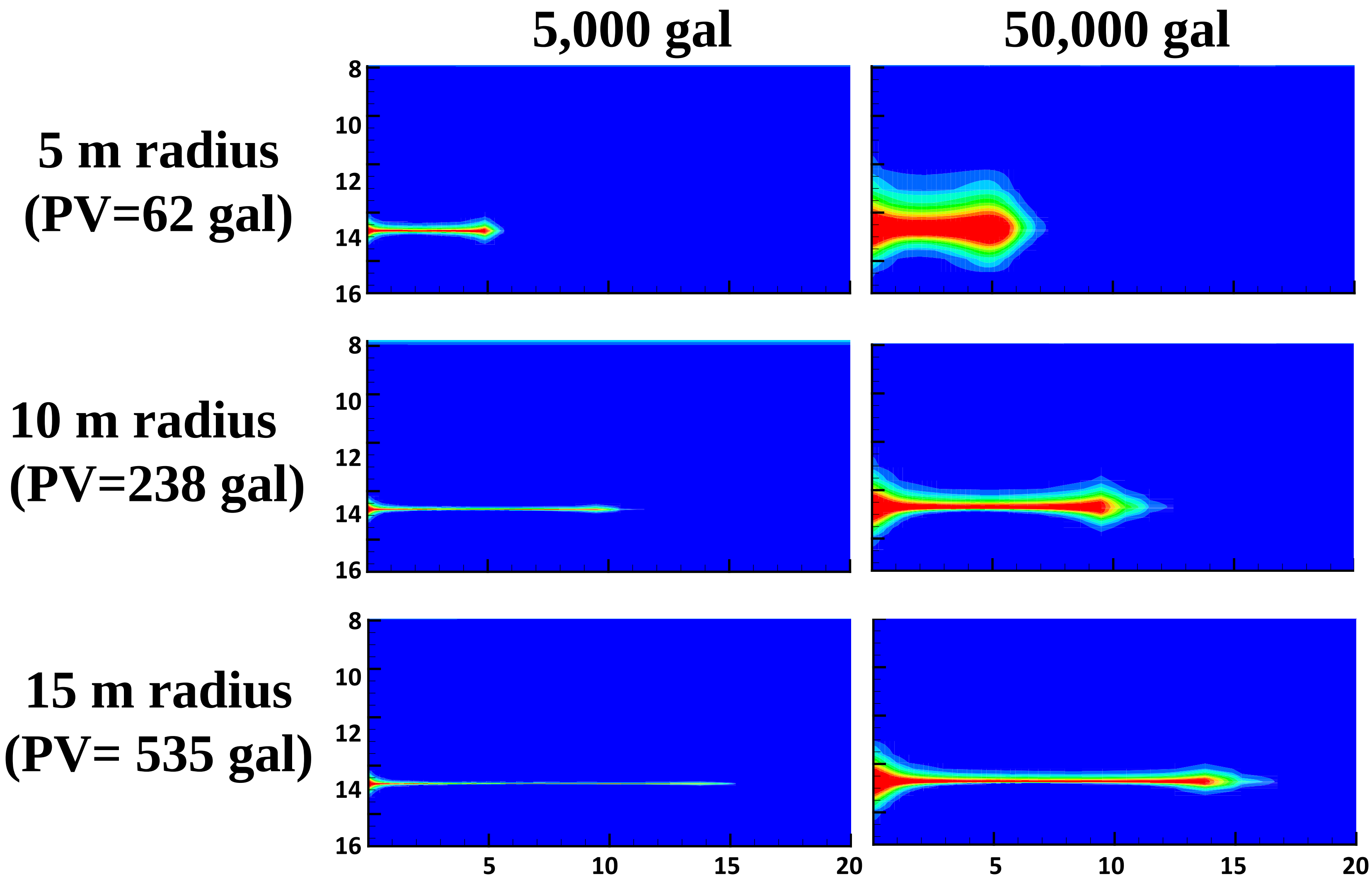
Conventional | Fractured

K Rat = 10

K Rat = 10,000



Frac Radii- Bigger Always Better?

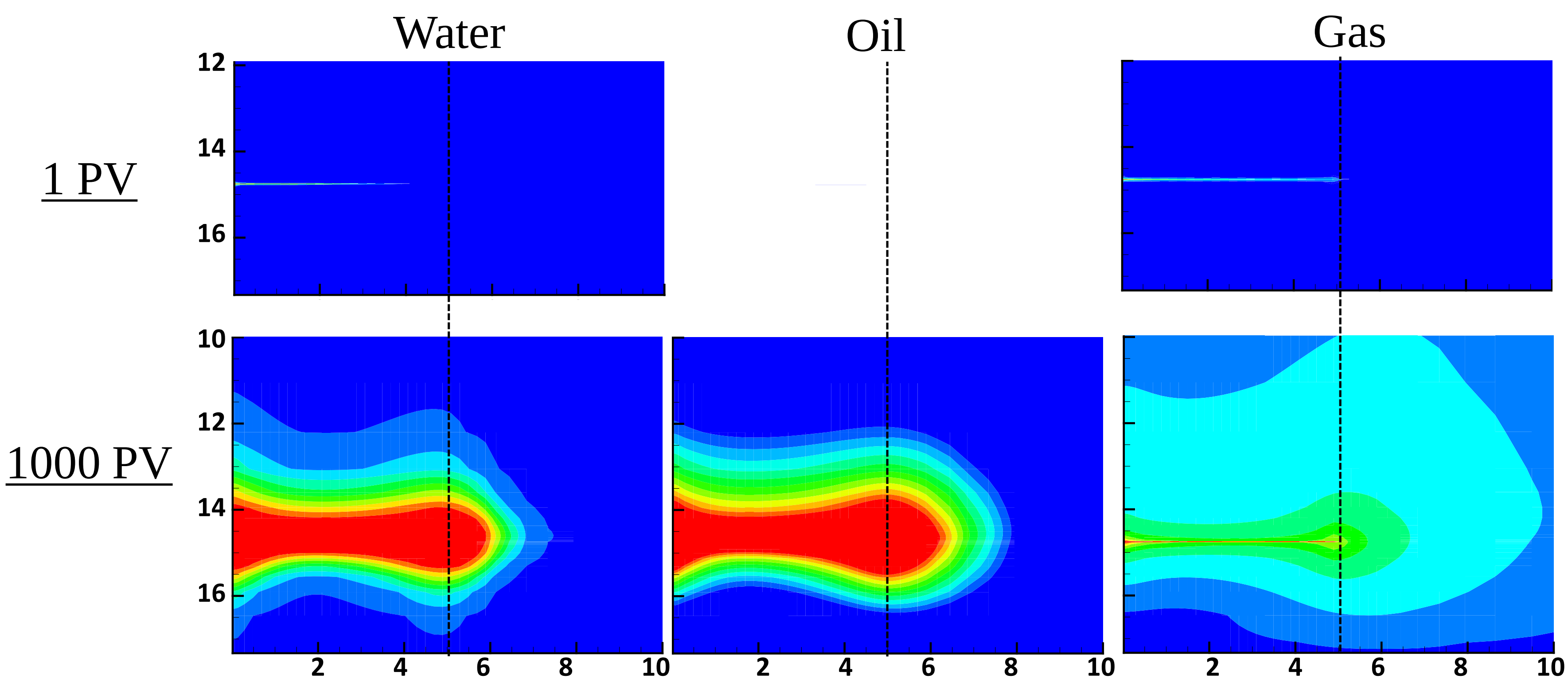


Differences Based on Fluid

Pore volumes to reach tip of 5 m radius fracture

kRat=	1	10	100	1000	10000
Gas	NA	NA	NA	1	1
Oil	NA	NA	~100	7	2
Water	NA	NA	~100	8	3.5

kRat = 10K



In Situ Access to Contaminants

Summary

- Emplacement of sand-filled hydraulic fractures can significantly increase the injection rates and ROI of injection wells installed in low permeability formations.

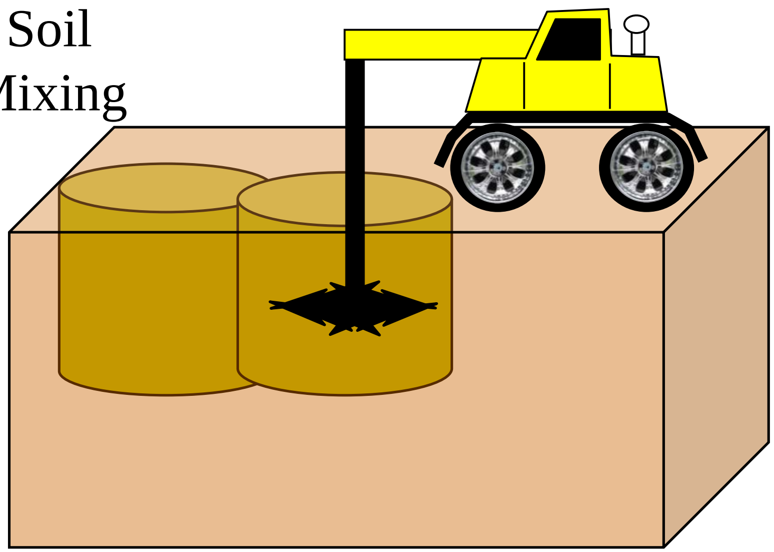
- The total volume to be injected into each fracture along with desired vertical thickness affected must be considered when selecting fracture size.

- Fracture tip effects can result in more ideal distributions, exploitation of this effect is dependent upon kRat, volume injected, and fracture radius.

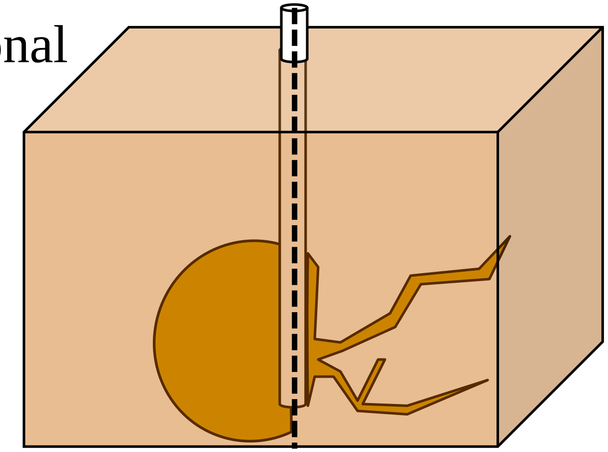
Emplacement Options

Examples: Oxidant Solutions, Nutrient/Donor/Microbe Solutions, Neat/Emulsified Oils, Etc.

Soil Mixing



Conventional Well



Hydraulic Fracturing