Advanced Hydraulic Fracturing Technology For Unconventional Tight Gas Reservoirs

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THE HAROLD VANCE DEPARTMENT OF PETROLEUM ENGINEERING

Outline

- Project Overview
- Experimental Determination of Hydraulic Fracture Conductivity
- Static Yield Stress Study and Gel Displacement Modeling
- Tight Gas Sand (TGS) Advisory System

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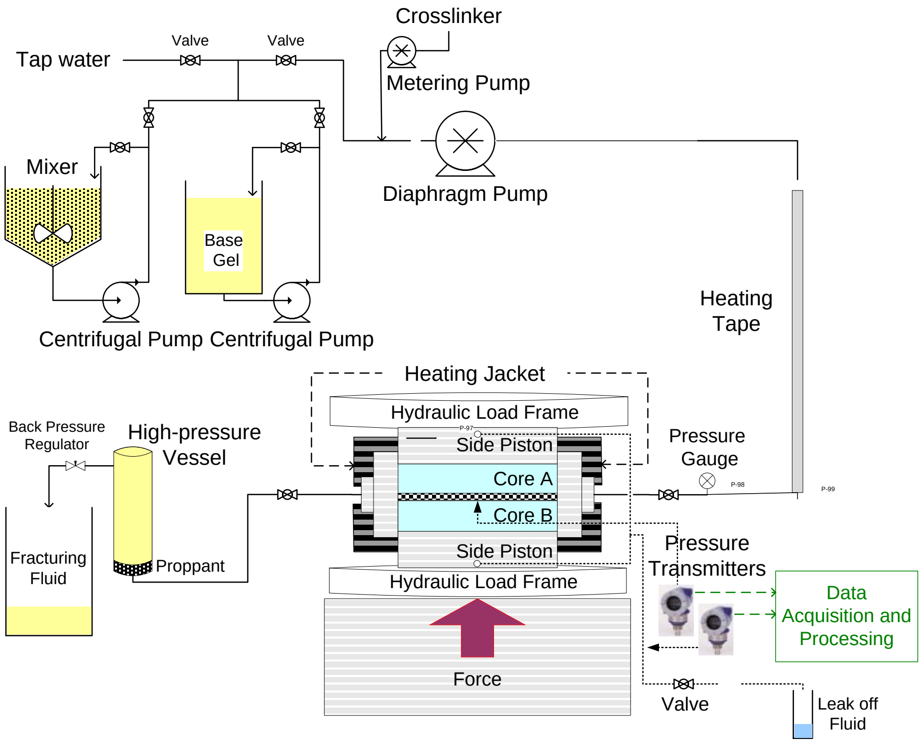
Dynamic Fracture Conductivity Tests
(Task 4)

Introduction

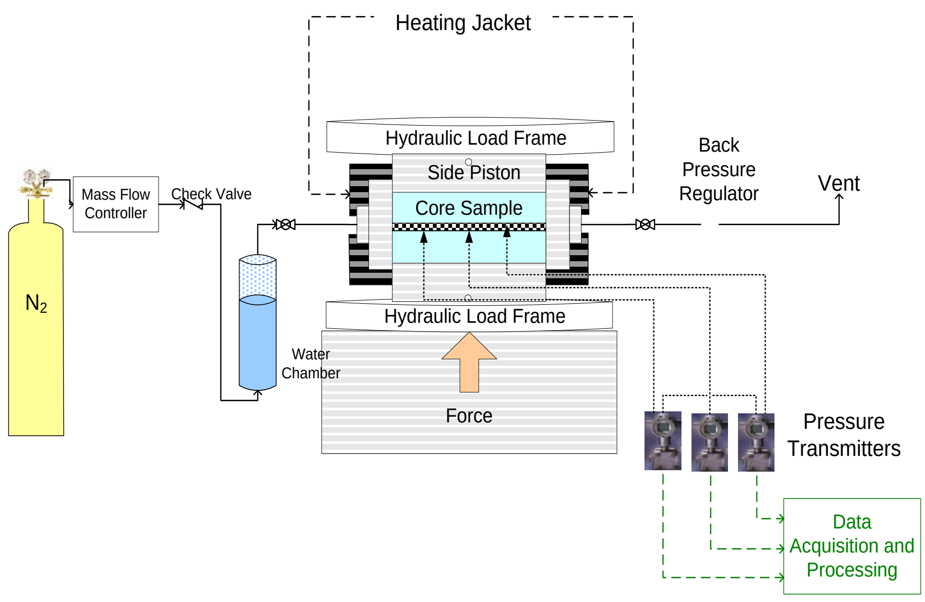
- Polymer damage in the fracture reduces fracture conductivity and effective fracture length
- Static conductivity tests in general overestimate fracture conductivity
- Dynamic conductivity test is designed to simulate filter cake buildup and gel behavior in a condition closer to field conditions

Conductivity Experiments – Schematics

❑ Setup for Slurry Pumping

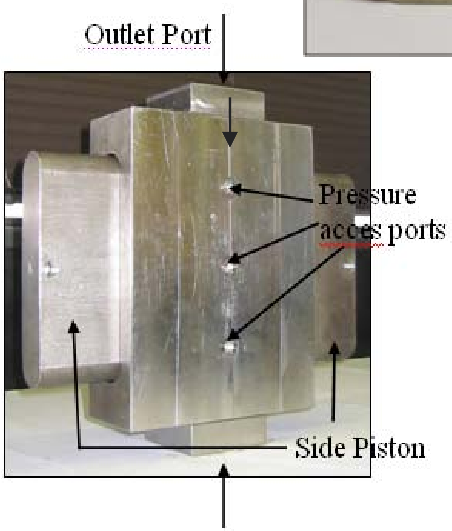


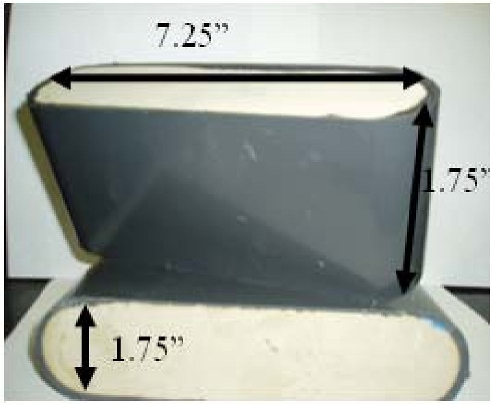
❑ Setup for Fracture Conductivity Measurements



Conductivity Experiments – Core Properties and Dimensions

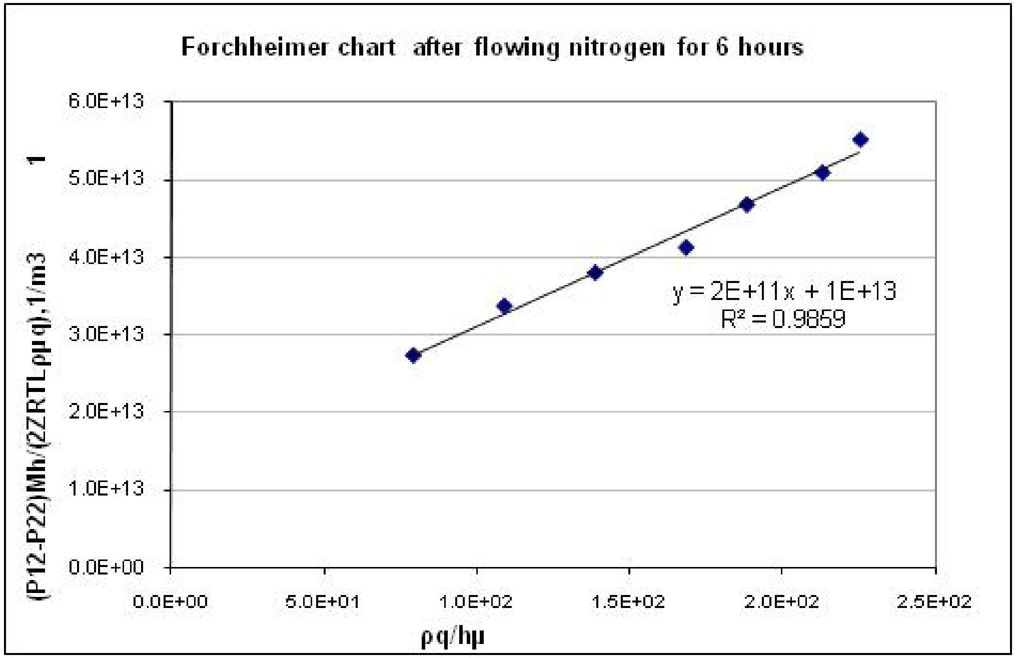
- Length: 7.25 in
- Width: 1.65 in
- Height: 3 in
- Permeability: 0.05-0.1 md





Conductivity Experiments – Conductivity Computation

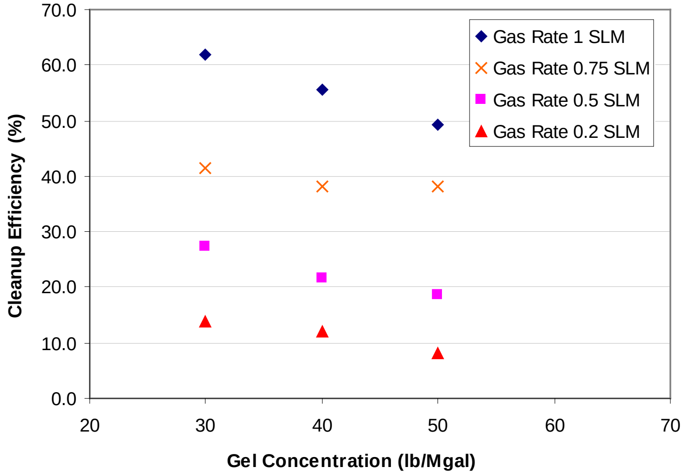
$$\frac{-dp}{dL} = \frac{\mu \upsilon}{k} + \beta \rho \upsilon^2$$



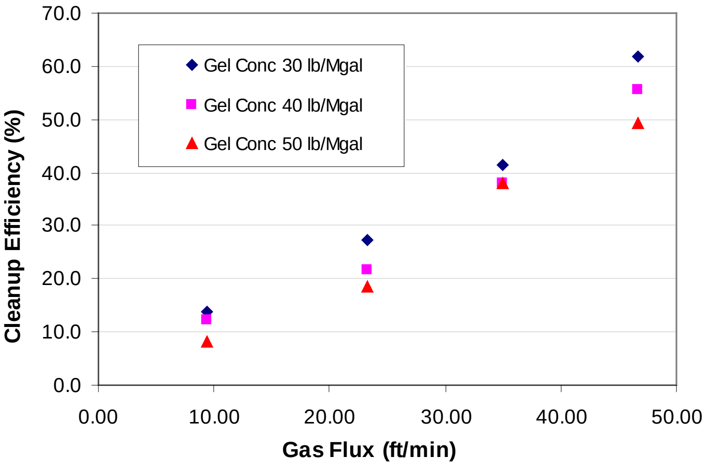
$$\underbrace{\frac{\left(p_1^2 - p_2^2\right)Mh}{2ZRTL\,\mu\rho q}}_{y} = \underbrace{\frac{1}{k_f w}}_{b} + \underbrace{\frac{\beta \rho q}{w^2 \mu h}}_{mx}$$

Conductivity Experiments – Summary of Previous Results

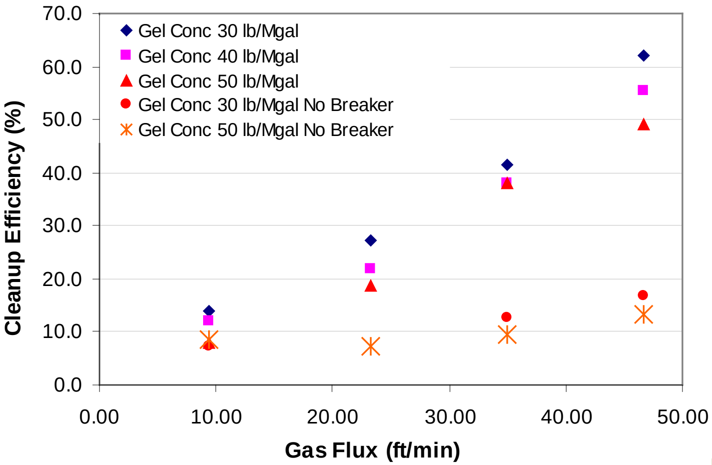
Polymer concentration has a small but clear impact on clean up efficiency



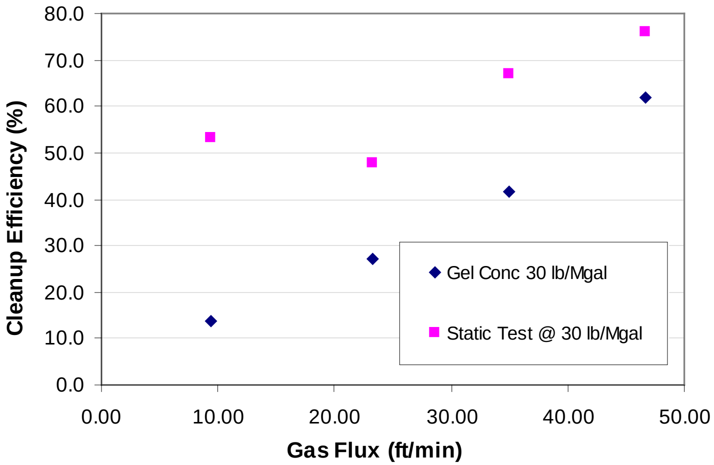
Gas flux has a large effect on clean up efficiency



Presence/absence of breaker has a clear impact on clean up efficiency



Static tests will produce higher clean-up efficiencies compared to dynamic tests



Conductivity Experiments – Current Work

- Addition of new equipment to previous setup
  - Diaphragm pump to handle solid pumping
  - Load frame
    - ✓ Accurate load control
    - ✓ Accurate vertical displacement measurement
    - ✓ Automatic data acquisition

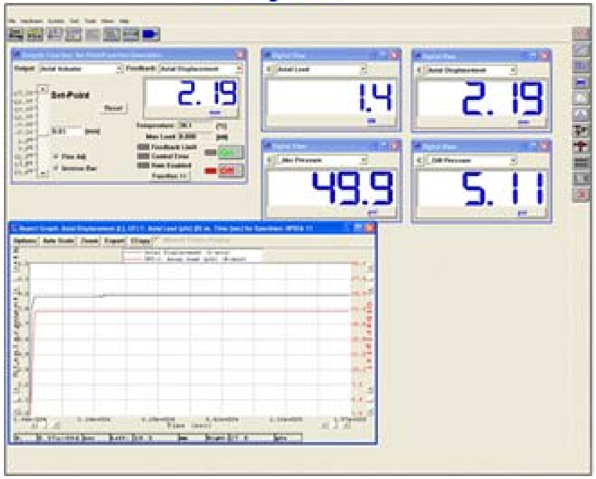
Conductivity Experiments – Apparatus

Load frame and conductivity cell.

Conductivity cell and pressure transducers.

Diaphragm pump.

Real time data recording software template



Conductivity Experiments – Range of Test Variables

1. Nitrogen rate: 0.5-3 standard liter minute
2. Temperature: 150-250 ^{0}F
3. Polymer loading: 10-30 lb/Mgal
4. Breaker: Presence or absence of breaker
5. Closure stress: 2000-6000 psi
6. Proppant concentration: 0.5-2 ppg
7. Fracture fluid pumping rate: 0.7-1.5 gpm

Develop an experimental schedule based on Design of Experiments to identify the most important factors

Conductivity Experiments – Design of Experiments

- Experimental Design allows us to have a more efficiently designed schedule of experiments and determine interaction between multiple and complex system variables.

Screening experiments in order to determine which variables are the most important.

↓

Two-factor / multiple factor experiments to refine information and develop a conductivity model.

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Optimization, to determine which levels of the critical variables result in the best system performance.

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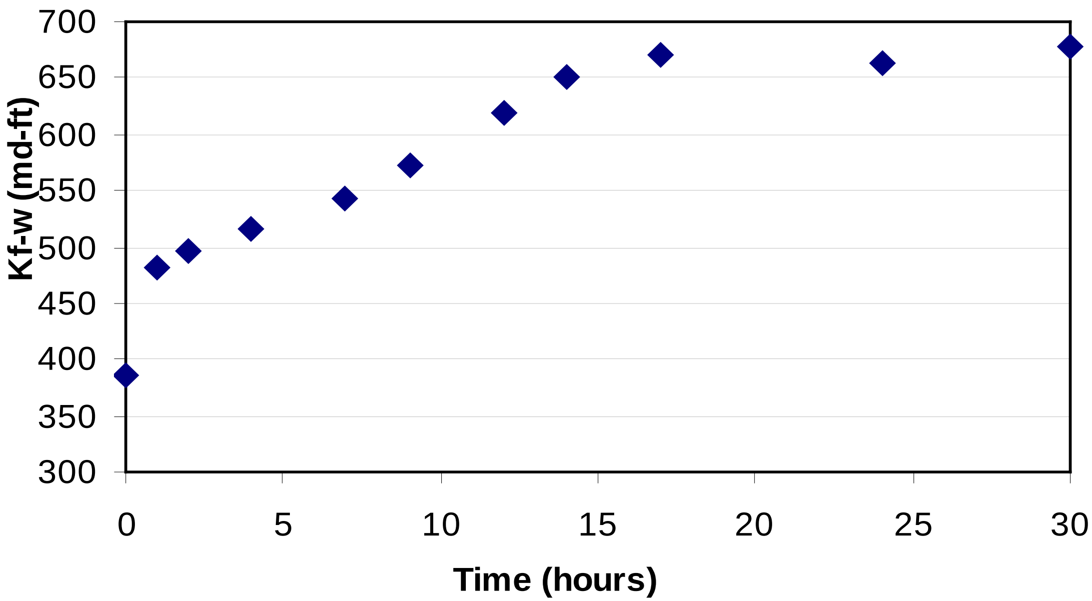
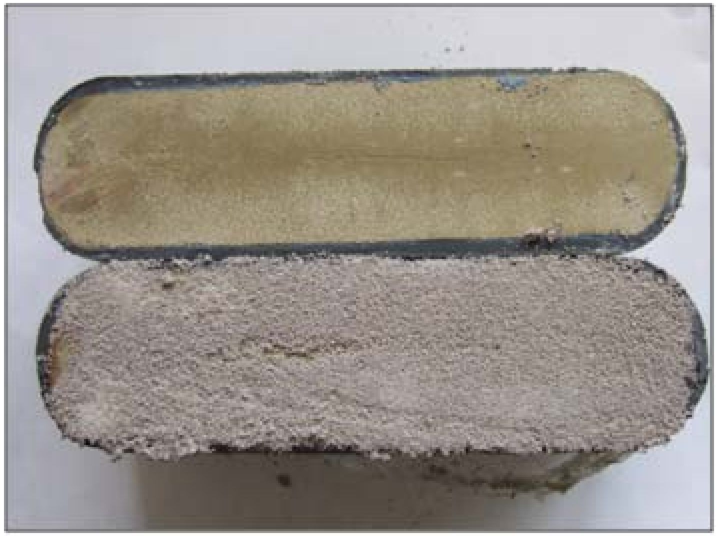
Experimental Schedule based on Design of Experiments

No.	N2 rate (sl/min) X1	T (^{0}F) X2	Polymer loading (lb/1000gal) X3	Breaker X4	Closure Stress (psi) X5	Proppant conc. (ppa) X6	Fluid rate (gpm) X7
1	1.75	200	20	half loading	4000	1.25	1.1
2	0.5	150	30	normal loading	2000	0.5	1.5
3	3	150	30	no breaker	2000	2	0.7
4	0.5	250	10	normal loading	2000	2	0.7
5	0.5	250	30	no breaker	6000	0.5	0.7
6	1.75	200	20	half loading	4000	1.25	1.1
7	3	250	30	normal loading	6000	2	1.5
8	3	250	10	no breaker	2000	0.5	1.5
9	0.5	150	10	no breaker	6000	2	1.5
10	3	150	10	normal loading	6000	0.5	0.7
11	1.75	200	20	half loading	4000	1.25	1.1
12	3	250	10	no breaker	6000	2	0.7
13	3	150	30	no breaker	6000	0.5	1.5
14	0.5	150	10	no breaker	2000	0.5	0.7
15	0.5	250	10	normal loading	6000	0.5	1.5
16	0.5	250	30	no breaker	2000	2	1.5
17	3	250	30	normal loading	2000	0.5	0.7
18	0.5	150	30	normal loading	6000	2	0.7
19	3	150	10	normal loading	2000	2	1.5
20	1.75	200	20	half loading	4000	1.25	1.1

Recent Results



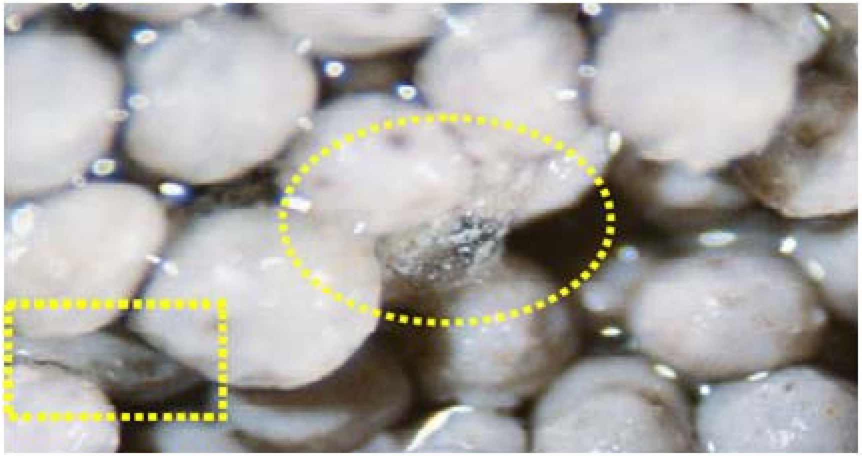


- Polymer concentration: 10 lb/Mgal
- Clean-Up Gas Rate: 0.5 slm
- Cleanup Efficiency: 57.2%

Dynamic Fracture Conductivity Experiments-Future Work

- Continue running experiments based on the experimental schedule
- Identify the most critical factors affecting dynamic fracture conductivity
- Determine the effect of these critical factors on dynamic fracture conductivity
- Develop correlations for predicting dynamic fracture conductivity based on critical variables

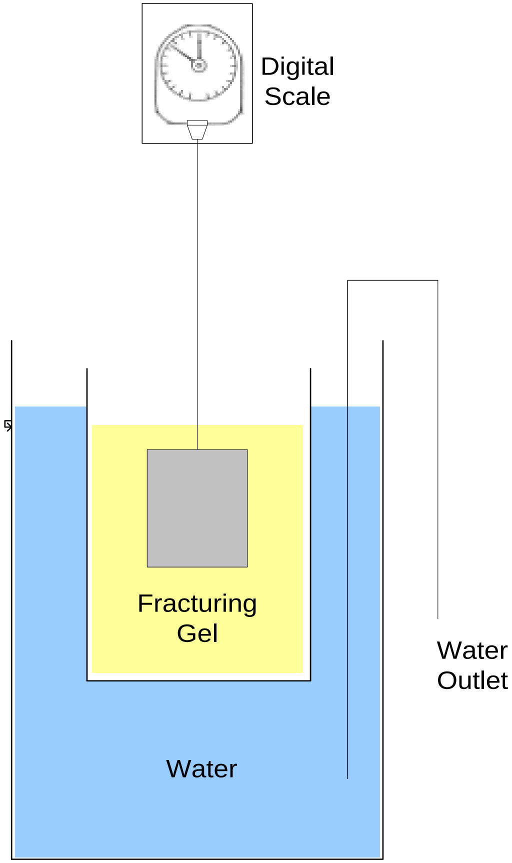
Gel Damage Investigation (Task 5)



Gel Damage Investigation - Objectives

- Yield stress measurement
- Investigating the relationship between yield stress, polymer concentration and breaker concentration
- Modeling of gel movement in proppant pack

Static Yield Stress Measurement



- A range of polymer concentration was tested
- Force change is (static yield stress) measured while water is drained
- Building relationship between the gel concentration and yield stress

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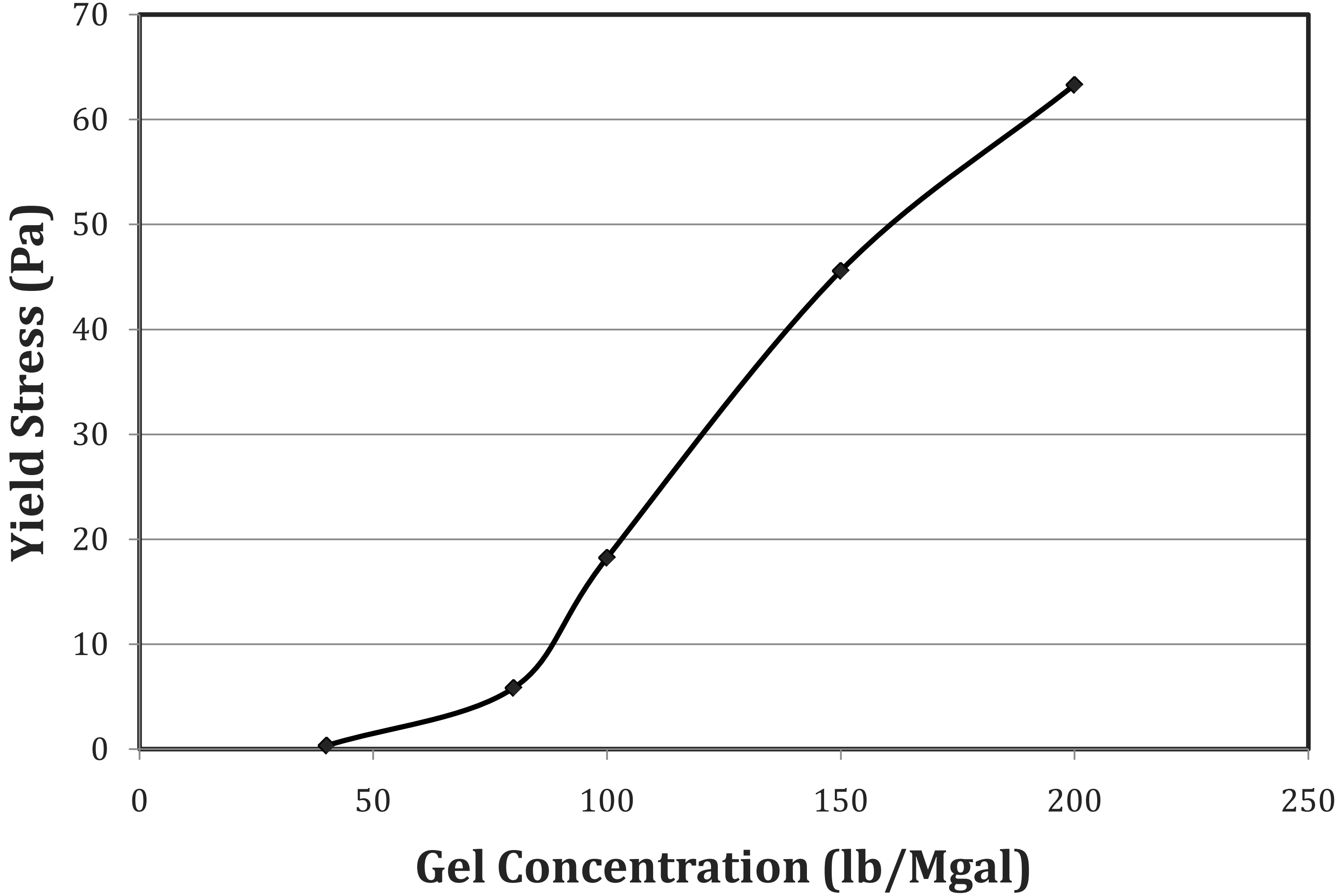
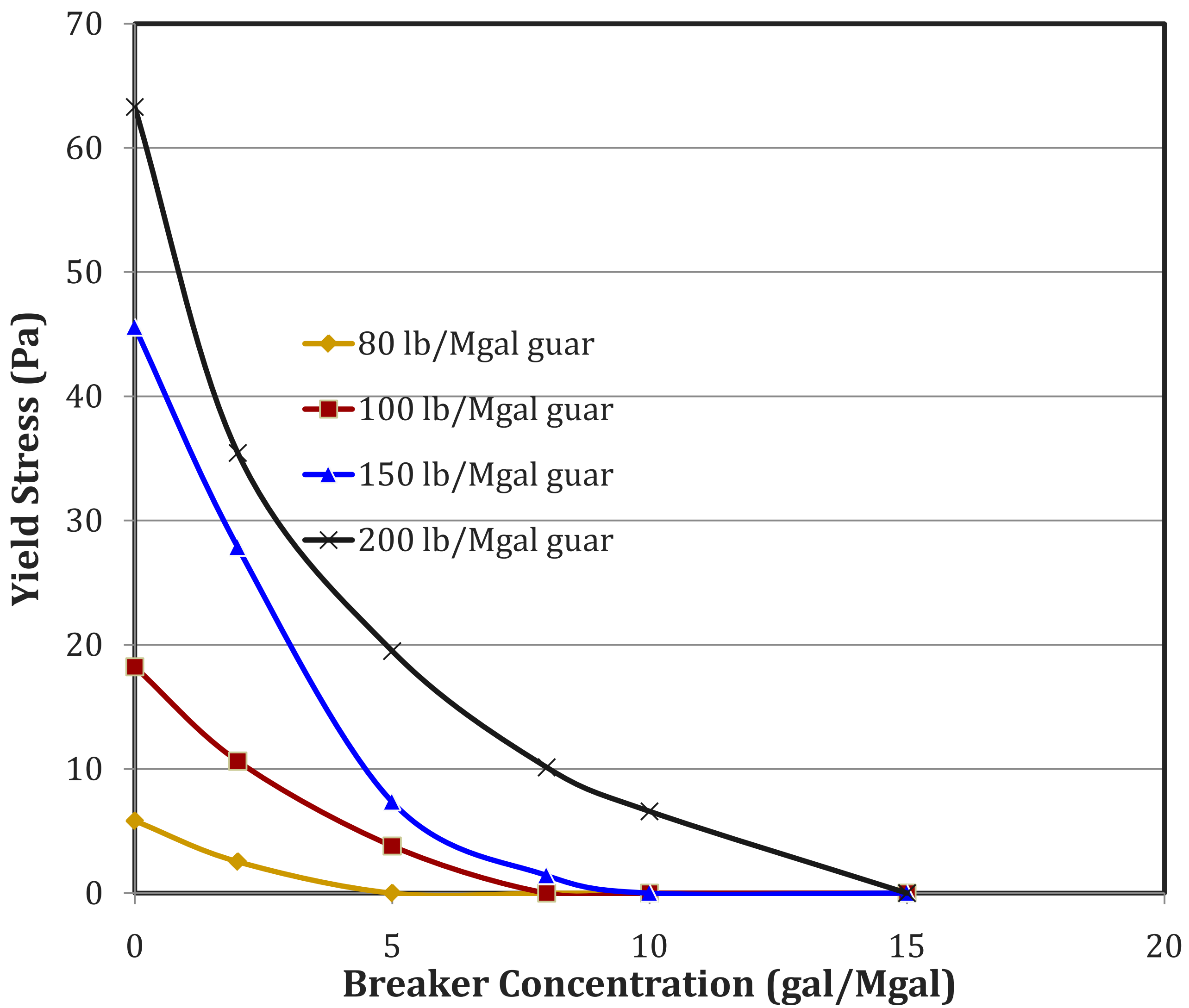
Static Yield Stress of Polymer Gel



Yield Stress of Polymer Gel with Breaker Concentration



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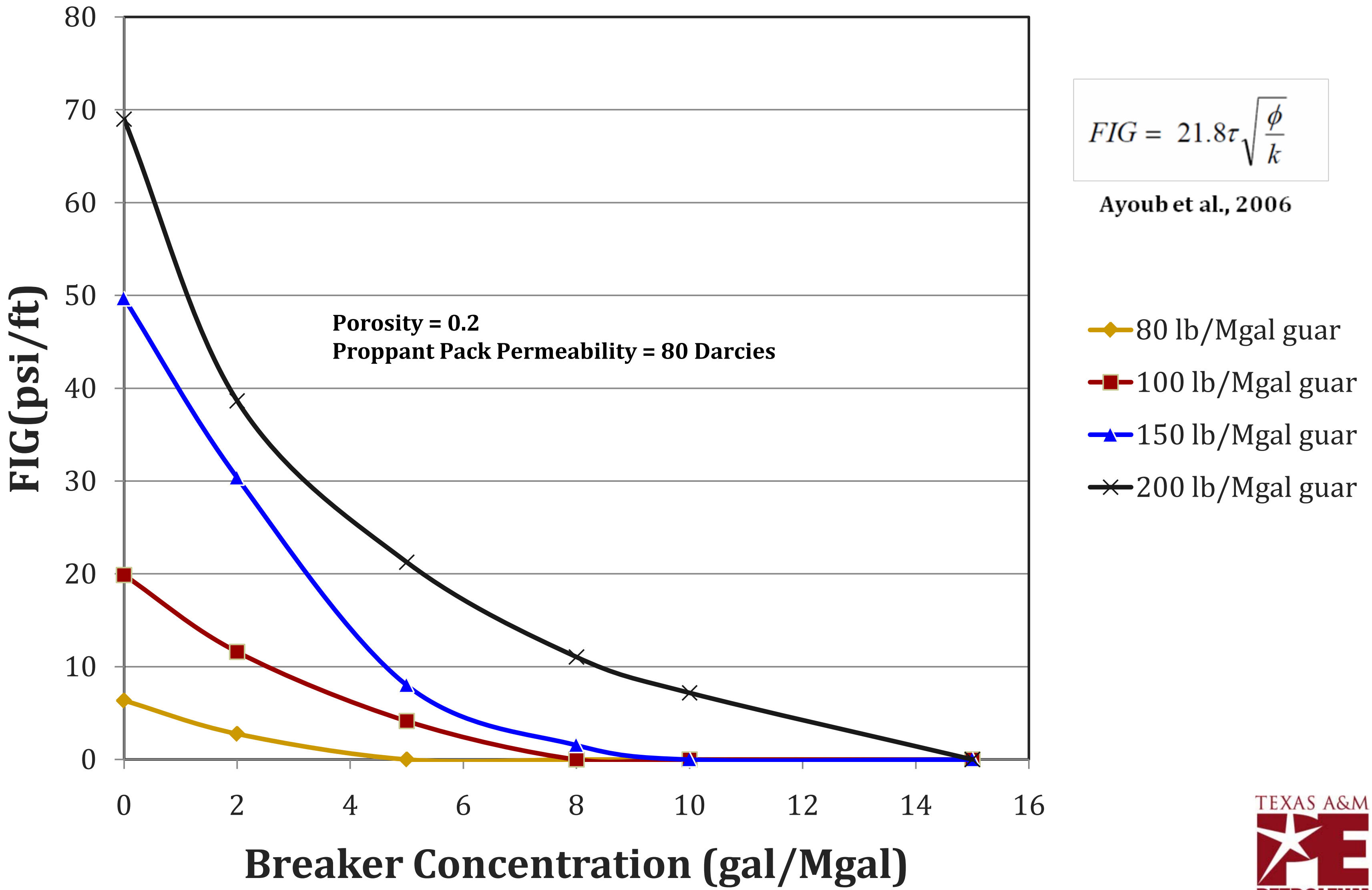
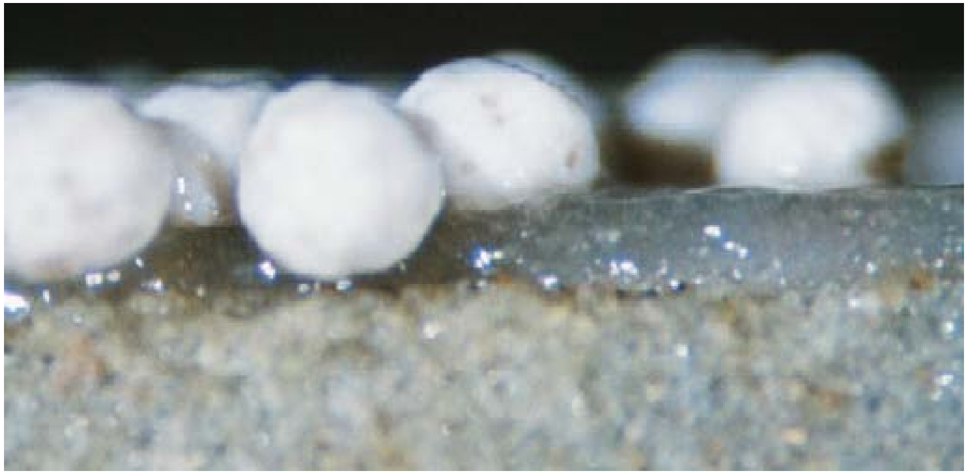
Flow Initiation Gradient (FIG) with Breaker Concentration

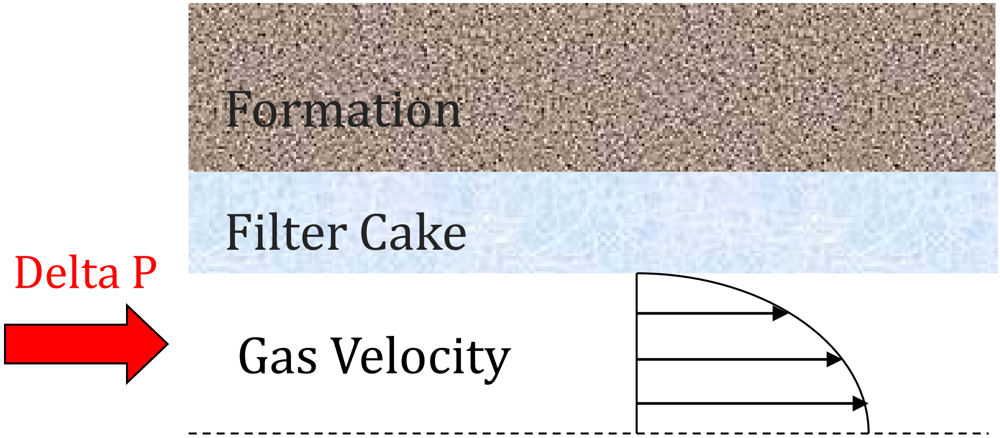


$$FIG = 21.8\tau\sqrt{\frac{\phi}{k}}$$

Ayoub et al., 2006

Gel Movement Modeling





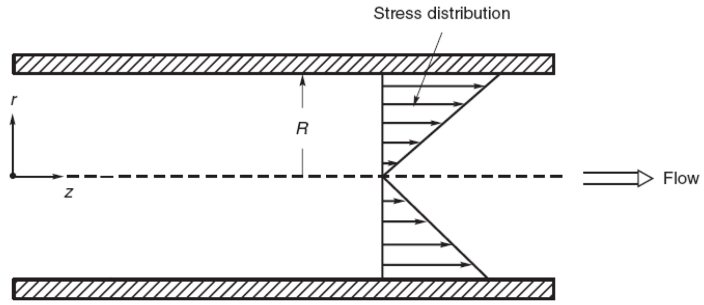
- Flow in cylindrical tube
- Solve equations of motion and momentum with appropriate boundary conditions
- Velocity profile must be continuous
- Stress profile must be continuous
- No slip boundary condition at the walls of the tube

Stress Distribution in Tube

- For a given pressure gradient, the linear shear stress profile is given by

$$\tau = \frac{\Delta p}{L}\frac{r}{2}$$

- This equation is independent of the fluid properties and state of fluid motion (i.e., laminar or turbulent)



Laminar Flow

- Newtonian Flow (Gas)

$$\tau = \mu \cdot \gamma$$

- Yield Pseudo-Plastic Fluid (Gel)

$$\begin{aligned} \gamma &= 0, & |\tau| < \tau_0 \\ \tau &= k\gamma^n + \tau_0 \frac{\gamma}{|\gamma|}, & |\tau| \geq \tau_0 \end{aligned}$$

shear rate $\gamma = \frac{\partial u}{\partial r}$ combined with $\tau = \frac{\Delta p}{L} \frac{r}{2}$

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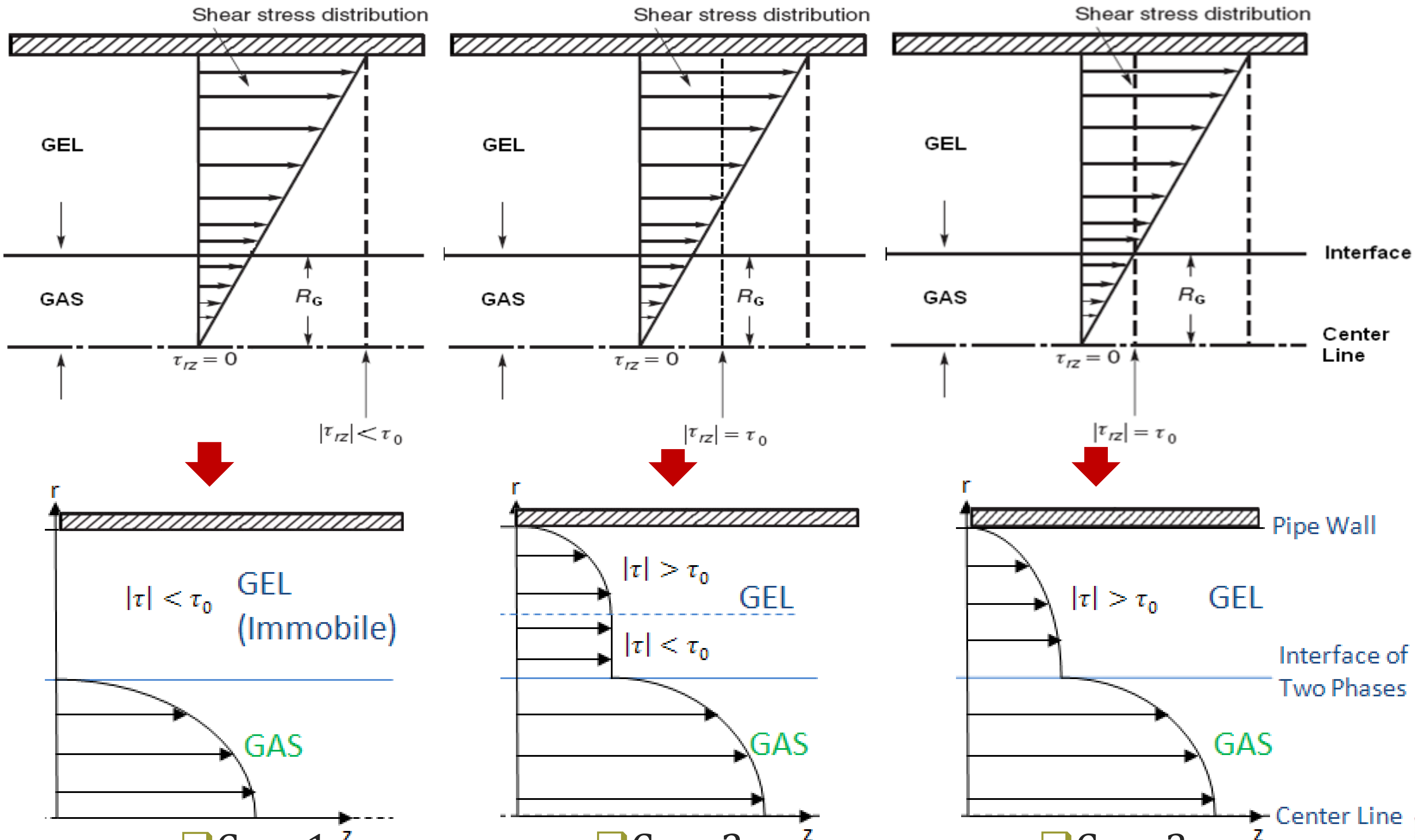
Flow Patterns Identified Under Imposed Pressure Gradients



- Case 1
- Case 2
- Case 3

Future Work- Gel Damage

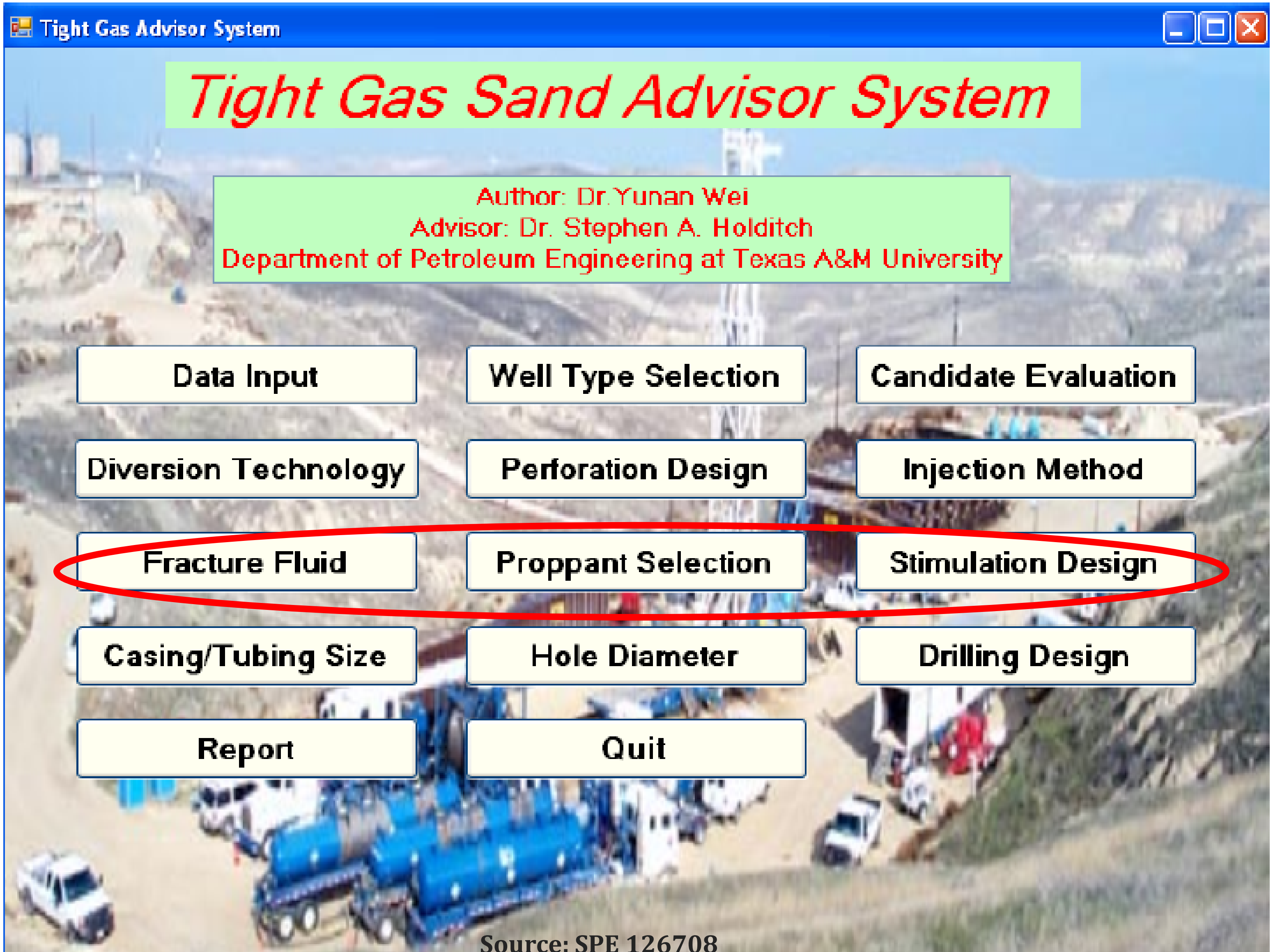
- Identify the critical gas flow rate for gel clean up for tube geometry

- Derive equations for 2-phase stratified flow in the turbulent flow regime

- Extend the results to flow in porous proppant pack

Tight Gas Sand Advisory System (Task 6)

Tight Gas Sand Advisory System – Previous Work



Source: SPE 126708

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TGS – Current and Future Work

- Communication with Newfield Exploration Company for data to support current studies
- A rigorous field study of the Tight Gas Sand Advisory System
- Application of the TGS Advisory System in fracture treatment design

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Tentative Field Study Plan

- Receive stimulation and production data for the Cromwell formation in the Arkoma Basin from Newfield Exploration Company
- Compare the stimulation treatment designs and well performances to the suggestions made by the Advisory System
- Review micro-seismic and pressure data from fracture treatments
- Optimize the stimulation design for the Cromwell formation using the results of the field study

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TGS – Advanced Treatment Design

- Combine information from….
  - TGS Advisory System
  - Dynamic Fracture Conductivity Experiments
  - Gel Damage Studies
- ….To develop an optimized fracturing design methodology.

Advanced Hydraulic Fracturing Technology For Unconventional Tight Gas Reservoirs

Thank you

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