Increased Well Productivity from Energized Fluid Fracing, in Tight Unconventional Formations*

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Abstract

The oil industry today is expanding its hydrocarbon resource and reserve base by exploiting very tight (unconventional) formations. The numbers of plays has expanded quickly, with production coming from formations consisting of true siliciclastic shales to carbonate-dominated mudstones. Each of these formations has very low matrix permeability and thus the production is dependent on hydraulically fracturing the rock. Since the well productivity is highly dependent on hydraulically fracturing, the type of stimulation applied is a key parameter to the relative success of a well.

To unlock the hydrocarbons from unconventional formations there are several parts to the completion process such as long reach laterals, well direction, multiple stages, and stage spacing, combined with hydraulic fracturing technique itself. All aspects influence a well's productivity along with the damage associated with the fracturing process. This damage has a strong influence on productivity. Damage comes from the interaction of the frac fluids in both the induced fractures and from leakoff into the rock matrix. Within natural and induced fractures, polymer residue can result in damage. In the formation, damage can occur as fine's migration, clay swelling, and as capillary and relative permeability water blockage. This fracture and formation damage can be reduced by applying energized fluids such as CO_2 and N_2 in the hydraulic fracturing process.

Energized Fluid fracing can increase a well's productivity while using less water. Fracture simulations studies of energized fluid fracing take into account both the geomechanical as well as the petrophysical rock properties. Petrophysical properties include capillary pressure and relative permeability. Including these petrophysical properties models damage associated with injecting water into the rock. By accounting for these fluid –rock interactions the productivity index of well fractured with energized fluids is greater than straight water fracs.

Selected References

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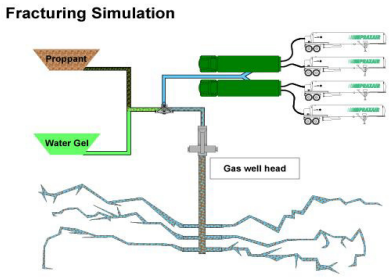


Outline

- Overview
- Energized Fluid Effects By Stage
- Fracture Damage
- Well Productivity
- Summary

Well Fracing

- **Reasons for Hydraulic Fracturing**
  - Near wellbore damage mitigation
  - Production enhancement
  - Increases effective wellbore radius
- **Hydraulic Fracing is a 3 Stage Process**
  1. Pad stage, initiates and propagates fracture
  2. The slurry stage, moving proppant into fracture
  3. Flush stage, cleaning up frac fluid

Controls On Well Fracturing

- **The Magnitude and Direction of Formation Principal Stresses**
- **Perforation Alignment with Principal Stresses**
  - **Misalignment results in higher treating pressures**
  - **Poor wellbore-fracture communication**
- **Design of Hydraulic Fracing Process**
  - **Fluids, pressures, proppants**

Fracturing Fluid Systems

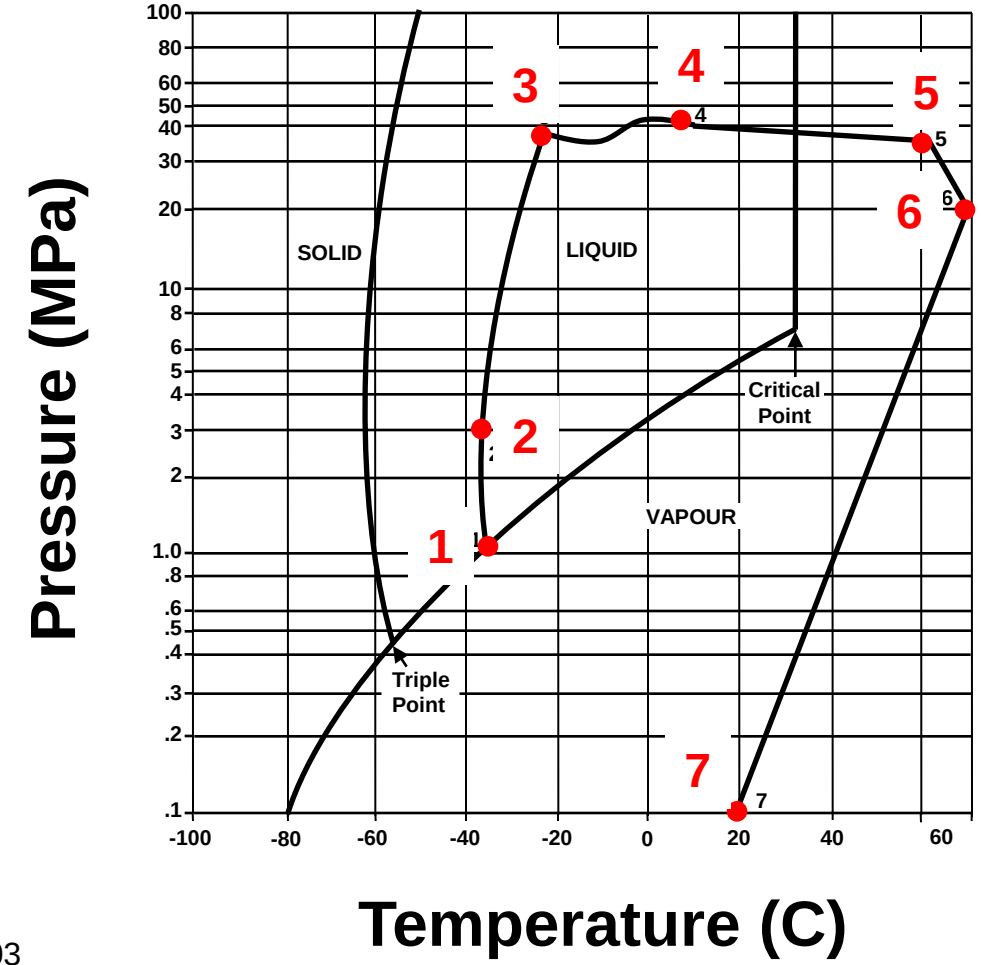
- **Purpose:**
  - **Initiate and propagate fractures**
  - **Transport proppant**
  - **Aid in cleanup**

- **Selection Criteria Includes:**
  - **Safety and environmental compatibility**
  - **Compatibility with formation and additives**
  - **Simple preparation and quality control**
  - **Low pumping pressure**
  - **Appropriate viscosity**
  - **Low fluid loss (leakoff)**
  - **Flowback and Cleanup (for higher fracture conductivity)**
  - **Economics**

(Modified from Jones and Britt, 2009

CO_2 Phases During Fracing

Pressure – Temperature of CO_2 Thru Frac Process



1. Storage
2. Booster pump
3. High pressure pump
4. Mixed with proppant
5. Injection Bottom hole
6. Completed bottom hole
7. Flow to surface

From Gupta, 2003

Pad Stage CO_2 and N_2 Effects

- **Due to less Interfacial Tension and Fluid Density CO_2 Foam Fracturing Results in:**
  - **Greater effective frac length**
  - **Increase in pressure connected or drainable area**
  - **Increase of pressure support available at the formation face**
- **Hydrostatic Head Increase Due to CO_2 Fluid Density**
- **Generates Two Phase Fluid with Excellent Foaming Ability and Excellent Surface Tension Reduction**

Effects of High Fluid Density

- **Less Horsepower for Fracing is Required thus Reducing Costs**
- **Allows Use of Normal Fracturing Equipment**
- **Size of jobs are Only Limited by:**
  - **Storage equipment, fluid supply, transport**
  - **Size of location**
- **Excellent Proppant Transporter**
  - **CO_2 properties remain relatively constant**
  - **Foam is viscous**

Flush Stage
Energized Fluids Assistance

- Increased Fluid Recoveries Cause by Gas Expansion
- CO_2 Dissolves or Mixes with Hydrocarbon Fluids
  - Solution causes hydrocarbon swelling decreasing viscosity and increasing fluid mobility on flow back
- CO_2 Solubility Reduces Interfacial Tension
  - Results in less force in the capillaries causing increased fluid recovery
  - This type of interfacial tension is not seen in a water based frac, without the use of surfactants
- Faster Wellbore Cleanup to Start Producing Sooner

Hydraulic Formation Damage

- **To Achieve a Conductive Fracture all Fracturing Fluids Must be Removed From:**
  - **The formation**
  - **The induced and natural fractures**
- **It Is Essential To Prevent Polymer From :**
  - **Invading the formation**
  - **Invading natural fractures (natural fractures can be plugged by polymer)**

Categories of Fracturing Damage

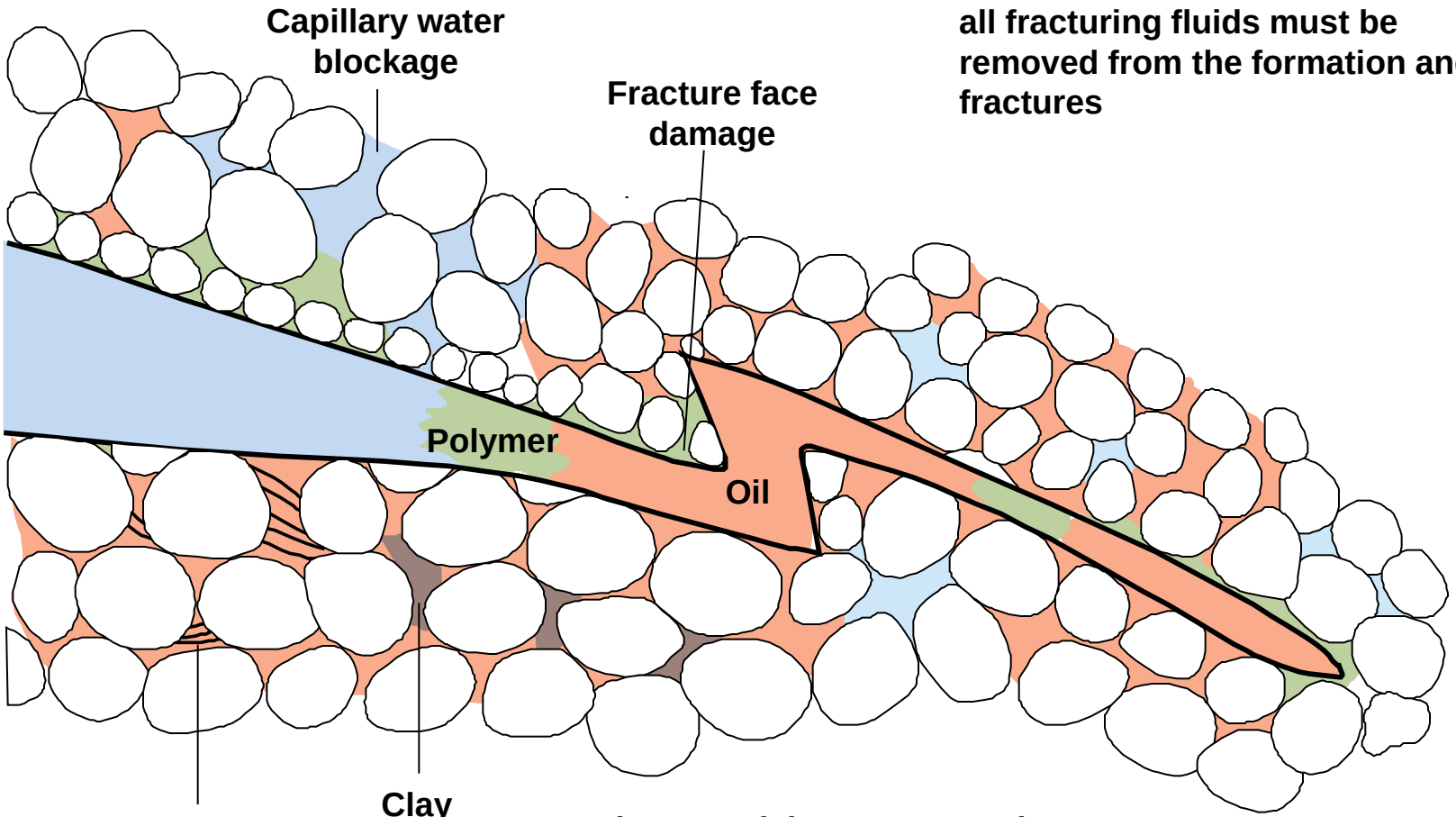
1. **Within the Fracture**
    1. **Proppant crushing**
    2. **Proppant embedment**

2. **Fracture Face Damage**
    1. **Chemical and polymer fracture plugging (polymer residue)**

3. **Within the Formation**
    1. **Excessive fluid leakoff**
    2. **Clay swelling**
    3. **Relative permeability damage**
    4. **Capillary effects**

Fracture Damage

- To achieve a conductive fracture all fracturing fluids must be removed from the formation and fractures



- It is essential to prevent polymer form invading the formation and natural fractures (natural fractures can be plugged by polymer)

- Sand Grains

Hydraulic Formation Damage

- **Fracture Face Permeability Damage of 90% or Higher can Cause:**
  - **A major increase in water production**
  - **Reduction in gas production (Gdanski et al. 2005)**
- **CO_2 is Relatively Soluble in Water**
  - **Solution forms relatively noncorrosive carbolic acid (ph 3.1- 4)**
- **CO_2 Reduces or Eliminates Clay Swelling**
  - **Swelling reduction due to extra hydrogen ion**
  - **Critical in many shaly formations**

Water Based Hydraulic Fracing

- **Hydraulically Fractured Gas Wells Can Experience Water Blocking Due To:**
  - **Capillary pressure character**
  - **Capillary pressure hysteresis**
  - **Relative permeability**
- **Gel Damage**

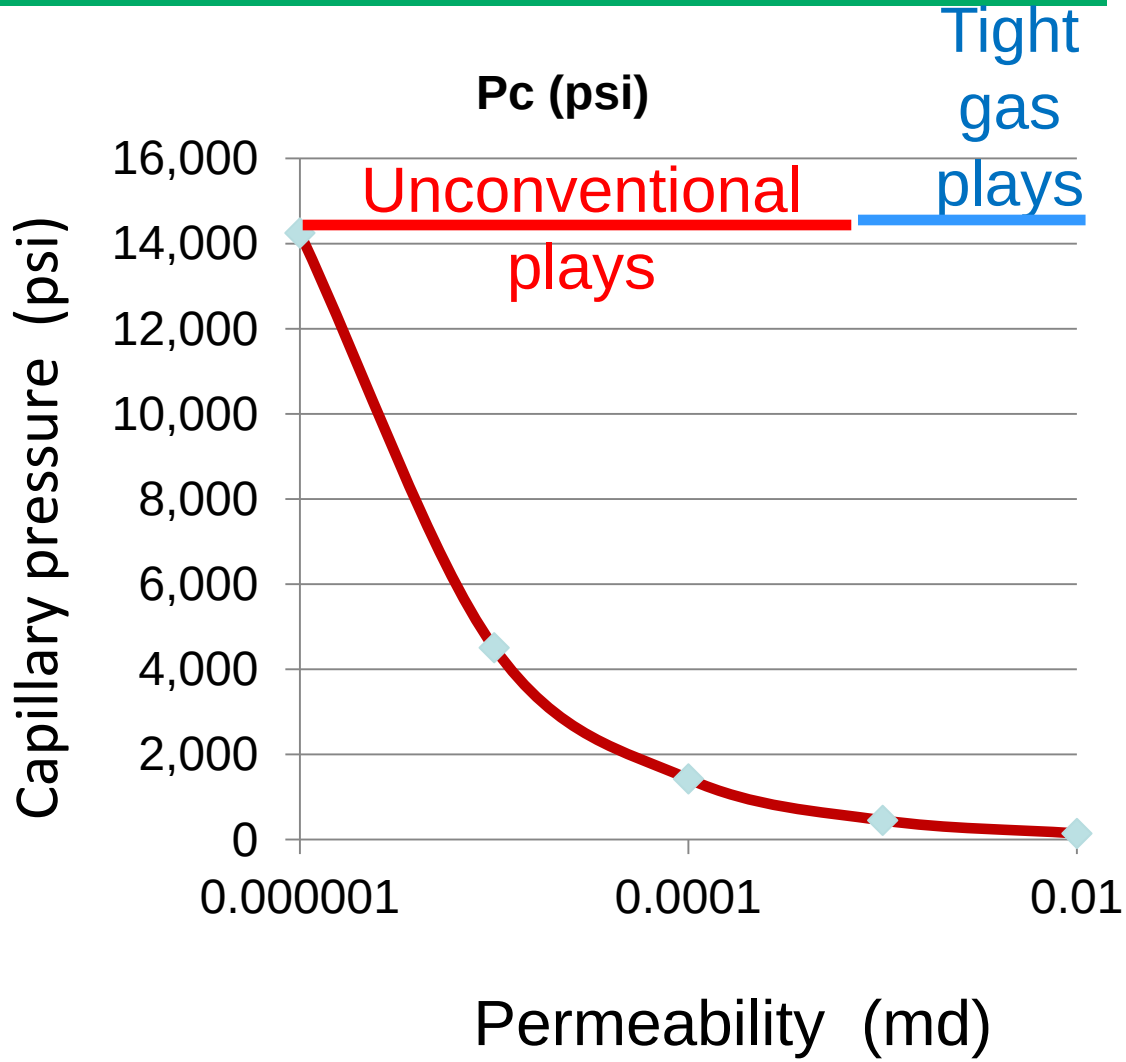
"The most important factor that reduces fracture fluid cleanup and gas recovery is the gel strength of the fluid that remains in the fracture at the end of the treatment." **Wang, Holditch and McVay, 2009 SPE # 119624**

Energized Fluid Fracing Reduces Gel Usage

Leverett Capillary Pressure Function

$$Pc = 0.42\,\sigma\cos\Theta\sqrt{\frac{\phi}{k}}$$

Pc = Capillary pressure
⍰= Interfacial tension
⍰= Contact angle
⍰= Porosity
k= Permeability



Assumes oil-water, 8% porosity

N_2 and CO_2 Foams, The Surfactant Gel System

- **Logistically Simple**
  - **2 surfactant based system**
  - **Provides exceptional low-shear viscosity and cleanup characteristics**
- **Fluids are not Wall-Building on Fractures**
- **Very Good Retained Permeability Both in the Formation and the Proppant Pack**
- **Foaming Provides:**
  - **Significant increases in viscosity**
  - **Superior leak-off control**
- **Nearly 100% Propped Fracture Clean-up**

Productivity Index

Productivity Index is a tool which helps compare well flow rates.

Definition

$$J = \frac{q}{\Delta P}$$

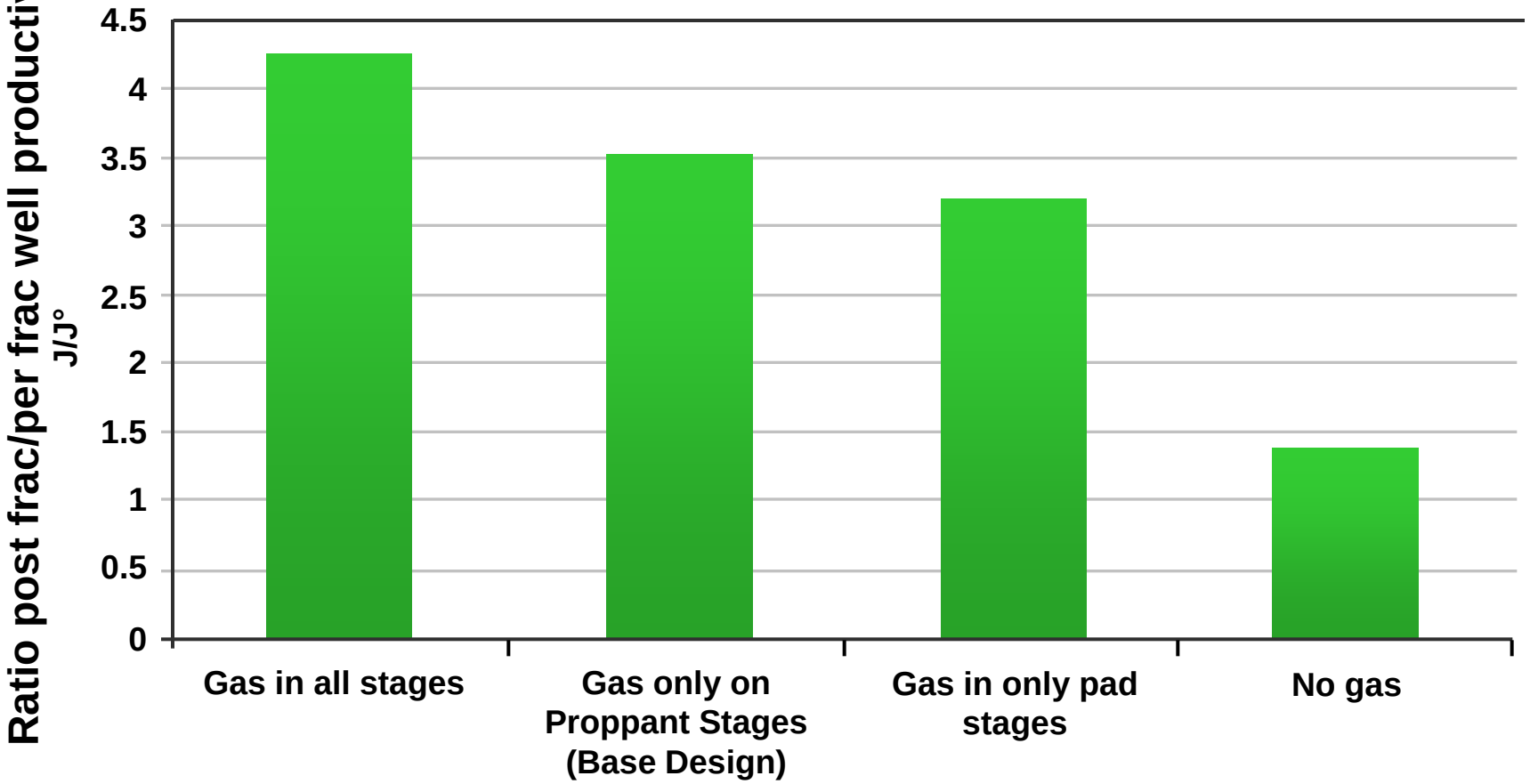
q = hydrocarbon production rate

ΔP= drawdown pressure

drawdown pressure is the difference between the wellbore pressure the reservoir pressure

Benefits of Energized Fluid Fracs

Obtaining Greater Well Productivity



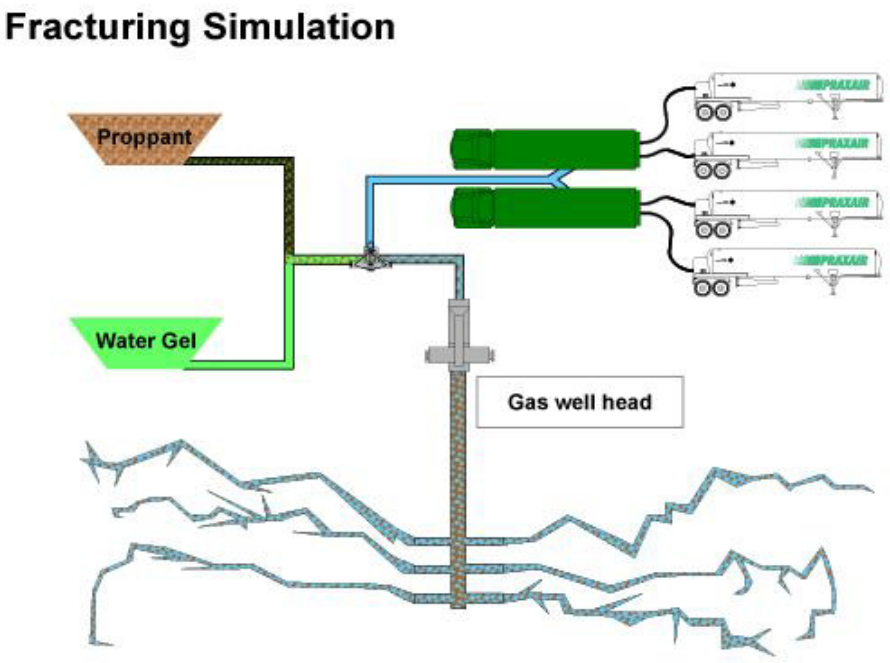
SPE paper # 119265

Summary
Water Fracturing Challenges

- **Damage to Fracture Face, Formation, and Natural Fractures**
- **Undesirable By-Products Reduce Fracture Conductivity**
- **Wasted Fracture Volume**
- **Less Than Optimal Production**
- **Environmental Challenges to Water Usage and Disposal**

Summary Energized Fluid Stimulation

- Solubility and Viscosity of CO_2
- Less Damaging
- Easier Cleanup
- Foaming Ability
- Excellent Surface Tension Reduction
- Greater Effective Frac Length



CO_2 Storage and Booster Pumping

Appendix

- CO_2 Case Histories

Energized Fluid Fracing State of the Art

- **7,500 N_2 and CO_2 Foam Treatments Have Been Successfully Applied**
- **3,500 Visco-elastic Treatments in Canada with N_2 or CO_2 for Energized Flow-Back Assistance**
- **Praxair Participated in 1,600 CO_2 Frac Applications in 2008**

SPE 119626 Cawiezel and Gupta, 2009 ;Gupta et al. 2005

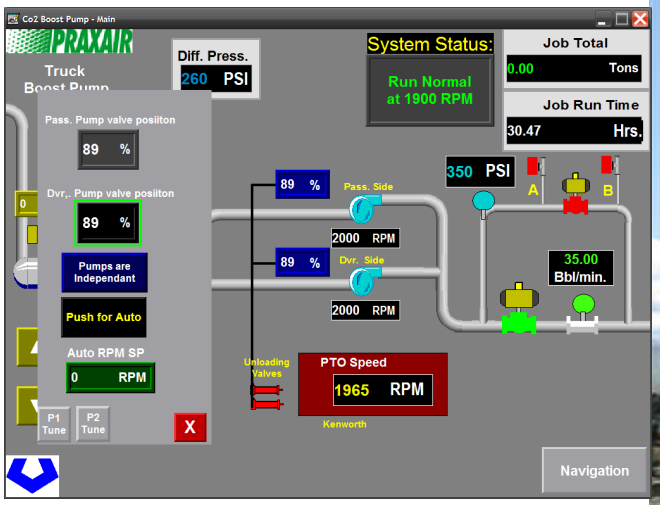
Sinal and Lancaster, JCPT, Sept-Oct, 1987

- "Liquid CO2 Fracturing: Advantages and Limitations"
  - 1 year of lab work before field implementation
  - Over 450 Liquid CO2 Frac treatments done
    - 95% gas 5% oil wells
    - 95% of well < 2500m deep, up to 22 tons of sand
    - 400 to 600 kg/M^3 pump concentrations
    - Rates up to 7.5 M^3/min
    - Treating pressures up to 70 Mpa (10,152 psi)
  - Major advantage is elimination of fracture damage.
  - Major advantage rapid cleanup

- Disadvantages
- High leakoff thus rate dependent
- Sand concentration must be lower
- Sand size may need to be smaller
- Friction pressures are higher
  - therefore larger tubing is needed in deep wells (>2200m)
- Fracture conductivity in oil reservoirs may be an issue.

Praxair Capabilities

- **Remote Booster Pump Control for Added Safety**
- **Automatically Records Suction Pressure, Discharge Pressure, and CO_2 Flow Rate**



Main Control System

Praxair Capabilities

- Supply liquid CO_2 and N_2 to Site
- Portable CO_2 Storage Containers
  - (33 Ton, 50, 60 and 80 Ton)
- Boost Pumps
  - Takes the product from the storage tanks (275 psig) and boosts the pressure to a constant 350 psig
- CO_2 Expansion Skids
- Ensure that the Customer gets a Consistent Flow of Pressurized Product

Well Stimulation Services

Gas Supply and Service Provider