WaterLess Fracturing Technology
“Making the Most of Your Reservoir”

Robert Lestz - GasFrac Chief Technology Officer
Calgary SPE Chapter - Back to Basics Special Interest Group Luncheon
15 Feb 2012
Technology – Creating a “Game Changer” & Providing a “Competitive Advantage”
Technology – Creating a “Game Changer” & Providing a “Competitive Advantage”

Is There Such a Technology For Fracturing?
Agenda

- Need for an Alternative Fracturing Fluid
- Technical & Game Changing Benefits of LPG Fracturing
- Safety/Operations
- Applications
- Case Histories
- Environmental Benefits of LPG Fracturing
- Q&A
Why an Alternative Stimulation Fluid?

- Lower Reservoir Quality of Today’s Reservoirs
  - Lower Permeability/High Capillary Pressure (Imbibition, Water Blocks)
  - Easily Damaged Reservoirs (Clay Rich)
- Dealing with Lower Pressured or Partially Depleted Reservoirs
- Known Reserves but Not Economically Recoverable w/Current Fluids
- Reservoir Certainty Post Stimulation
  - Where’s the Water Coming from? (Frac or Formation)
- Consistently Observe Shorter Fracture Lengths and Lower Rates than Designed
  - Where is all that Water we Pumped?
  - Where did all that Sand Go?
- Desire to Achieve Better Economics
  - Reach Peak Production Immediately
  - Higher Initial Rates
  - Higher Economic Ultimate Recoveries
  - Reduce $/BOE Cost
- Minimizing Environmental Impact
  - Water Usage
  - Venting/Flaring
  - Reducing Truck Traffic
The Challenges of Water Based Fracturing – Infill Drilling

12 Months of Fluid Clean Up!
The Challenges of Water Based Fracturing – Re-Fracing

Incremental Reserves but were they Economical?

3 Years of Fluid Clean Up!
What is The Perfect Fracturing Fluid?

- **Ultimate Reservoir Performance & Certainty**
  - Create the Required Fracture Geometry
  - Effective Proppant Transport
  - Non-Damaging (Water Blocks, Polymer Residue, Clay Swelling)
  - All Created Fracture Volume Contributes to Production
  - 100% Fluid Recovery
  - Only Proppant Remains in the Frac

- **Economic & Environmental Performance**
  - Readily Available
  - All Frac Fluids Recovered are Marketable or Recyclable
  - Reduces Swabbing, Coiled Tubing Jetting, or Extended Flowbacks
  - Eliminates Water Usage, Disposal Needs, & CO₂ Venting

- **Operationally Safe**
  - Jobs can be Conducted Incident Free
The Answer is Cross-Linked LPG

- LPG can be Handled as a Liquid on the Surface
- Easily X-Linked to Create Desired Frac Geometry and Achieve Ideal Proppant Transport
  - Similar Rheology Properties as a Visco-Elastic Fluid
  - Achievable and “Adjustable” Break Times (.5 to > 4 hrs.)
  - Industry LPG Standards Ensures Fluid Consistency
- Post Job, it Disappears → ~90+% Fluid Recovery
  - LPG is soluble w/natural gas
  - 1st contact miscible w/crude oil
  - Very low viscosity, surface tension, & density ½ of water
- Recovered Frac Fluid is Marketable
  - No Waste Streams Created
- Sustainable, Recyclable, and Environmental
  - No Water Use in the Fracturing Operation
  - Inert to Salts and Other Reservoir Minerals
  - Reduced Truck Traffic to and from Location
- Readily Available and Widely Used by the Public
- Numerous Best Practices & Procedures Exist to Provide for Safe LPG Operations

Photo courtesy of Stacey Walker – Chevron Energy Technology Company
“Laboratory experiments have demonstrated that complete removal of oil from a porous medium can readily be obtained by displacing it with the liquefied petroleum gases, propane, and butanes, which generally are completely miscible with crude oils. And incidental confirmation has been obtained from field observations of stimulated oil recovery when liquefied petroleum gas (LPG) has been injected into partially depleted oil-producing formations for storage purposes.”

Morris Muskat, Industrial and Engineering Chemistry, July 1953
Comparison of Liquid LPG and Water Properties

- **Liquid Propane**
  - Viscosity = 0.08 cps (@105F)
  - Specific Gravity = 0.51
  - Surface Tension = 7.6 dynes/cm
  - Non Damaging – Inert with the Formation Clays and Salts
  - First Contact Miscible with Crude Oil

- **Water**
  - Viscosity = 0.66 cps (@105F)
  - Specific Gravity = 1.02
  - Surface Tension = 72 dynes/cm
  - Potentially Damaging – Reactive with Formation Clays and Salts
  - Immiscible with Crude Oil
Gelling LPG – Creating a Perfect Transport Fluid

8 Seconds

15 Seconds
LPG Regain Permeabilities

- Regain Permeabilities for LPG Commonly Approach 100%
- Leakoff Fluid is a Light Hydrocarbon
- Soluble with Natural Gas
  - Recovered as a Vapor
- Miscible with Crude Oils
  - Viscosity Reduction
  - Reduces Oil Saturation
- Inert with Formation Clays (and Salts)
- Lack of Imbibition in Water Wet Reservoirs

Source: Montney Fracturing - Fluid Considerations
Petroleum Society – Canadian Institute of Mining Metallurgy
and Petroleum Paper 2009-154
Water Based Fracturing Fluids

- Damage Occurs in the Near Fracture Area due to Imbibition from the Water Leakoff

![Diagram showing gas flow and fluid block]

- Effective Fracture Length
- Propped Fracture Length
LPG as a Fracturing Fluid

- Two Areas of Stimulation are Achieved – the Fracture and the Near Fracture Area due to the LPG Miscibility
Comparison of Frac Fluid Recoveries

- Impact of LPG’s Lower Viscosity, Lower Surface Tension, Solubility/Miscibility, Lower Density (Higher Drawdowns) Leading to Higher % and Quicker Load Recovery

Source: Don LeBlanc, Eastex Petroleum Consultants Inc.
Comparison of Effective Fracture Lengths

- Effective Fracture Half Length, $X_f$, Determined from Pressure Transient Analysis
- Effective $X_f$ for the Propane Fractures were Measurably Longer than Equivalently Sized Water Based Jobs

Source: Don LeBlanc, Eastex Petroleum Consultants Inc.
Impact of Fracture Length and Number of Stages

Top View

5 - 200’ Created Frac Length

5 - 100’ Effective Frac Length
Impact of Fracture Length and Number of Stages

Top View

5 - 200’ Effective Frac Length w/LPG

10 - 100’ Effective Frac Length w/Water

Area of Incremental Recovery Due to Larger Effective Length
Impact of Fracture Length and Number of Stages

Production From Fractured Horizontal Wellbores

\[ q = \frac{hL_f (P_i - P_{wf})}{ \mu t} \]

\[ 4.064B_o \left( \frac{\mu t}{k \phi c_t} \right)^{1/2} \]

\[ t = 948 \phi \mu c_t r_i^2 / k \]

Source: Schubarth Inc.
Proppant Settling – Water Frac vs. LPG Frac

Slickwater Frac Scenarios

Viscous (LPG) Frac Scenarios

Pay Zone Height

Pumping
Long Term

Pumping
Long Term
Total Cost Advantage of LPG Fracturing

- Unit Cost or Total Cost?
- A Key Drilling Metric is Cost per Foot ($/ft)
  - Flex-Rigs, PDC Bit, and Oil Based Mud Systems all Cost More on a Per Unit Basis - But all Result in a Lower Total Drilling Costs on a Per Foot Basis

- Key Completion Metric that Creates Value is $/Effective Frac Length (Not the Created Length)
  - Conventional Frac ~ 2500 $/ft
  - LPG Frac ~ 1500 $/ft

- LPG Fracturing is More Expensive than Water Fracturing BUT just as Horizontal Wells are More Expensive than Vertical Wells; Economic Results Have Justified Horizontal Wells as a Better Investment than Vertical Wells

- Achieving 3 - 5 Times Longer Effective Fracs will Offset the Incremental Cost by Delivering
  - Lower $ / BOE Development Cost
  - Higher Production and EUR’s / Well
Total Cost Advantage of LPG Fracturing

- Additional Costs Savings for LPG Fracs
  - No Water Wells/Ponds, Handling Facilities, Logistics, or Frac Tanks
  - No Disposal Cost – One Way Hauling
  - Less Truck Traffic to Location
  - Reduced Flowback Costs Due to Quick Cleanup
  - No Well Intervention to Kick Off Well

- Additional Cost Benefit of LPG Fracs
  - Minimal Gas Lost Due to Flaring During Cleanup
  - Frac Fluid can be Recovered and with the Proper Equipment/Infrastructure it can be Sold with the Gas Stream or as Natural Gas Liquids or Used on a Future Job
Value Through Greater Recovery

Assumptions:
- Base Case Reserves 100,000 BOEG
- 50-50 Oil / Gas
- 20% RI
- 90 $/BO
- 2 $/MCF
- No Uplift for LPG Recover

Profitability Index (Multiples) vs. Incremental Cost for Various Reserve Uplifts

Profitability Index (Multiples) vs. Incremental Cost (\$'s)
How Common is LPG/Propane?

- U.S. Home Propane Market is 9.5 Billion Gallons/Year

Source: PERC 2010 Propane Market Outlook
Propane dates back to 1911 and the industry has develop substantial “best practices” for propane to be used by the general public. Even in the worst case when propane vehicles are involved in accidents, the standards are such that the propane is still safe. It is these practices and standards that GasFrac uses and incorporates into all our equipment and procedures.
How are Large Volumes of LPG Pumped Safely?

- Incorporate Existing Industry Recommended Practices (IRP)
  - IRP 4 – Well Testing and Fluid Handling
  - IRP 8 – Pumping of Flammable Fluids
  - IRP 9 - Basic Safety Awareness
  - IRP 16 – Recommend Safety Practices
  - IRP 18 – Flammable Fluid Handling

- Utilize the Broader LPG/Propane Industry
  - Propane Education & Research Council
  - Petroleum Service Association of Canada
  - Canadian Association of Petroleum Producers
  - Propane Gas Association of Canada Inc.

- Conducted a 3\textsuperscript{rd} Party HAZOP Evaluation of the Equipment Design, Operating Procedures, and Inspection Schedules with Suggested Modifications Incorporated

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GasFrac Experience

As of Jan 1, 2012: 1155 Fracs on 398 Location

- **42.6 Million Gallons** of Propane and **68 Million Pounds** of Proppant
- Largest job to date: 1 Million Pounds on a 10 stage (3900’ horizontal)
- Highest pressure treatment to 13,050 psi
- Treating rates to 50 BPM & Proppant Concentrations to 8 lb/gal

**Treatments placed into over 45 different reservoirs**

- Oil, Gas, Condensate, and Gas Storage Reservoirs
- Deepest Treatment to 13150’ TVD
- Formation Temperatures from 59°F to 300 °F

**Have worked with over 50 clients including**

- Chevron, Shell, Husky, Devon, Quicksilver, Union Gas Operating, Murchison, Approach Resources, …
LPG Fracturing Process

Note: Because lines are flushed after the job with Nitrogen, the location is as dry as it was when GasFrac arrived.
Suction Manifold Pressure Monitoring

- Low Pressure Suction Manifold Pressure Monitoring to Identify Premature Pump Failure
“State of the Art” Monitoring

- 20+ Lower Explosive Limit (LEL) Monitoring Array Used for Leak Detection on Location
- Monitors are Set Below the LEL For Propane (2.1%)
Two Close Circuit Cameras are Used to Inspect Entire Location
One Infrared Camera is Used to Monitored Pumps and Manifold
“State of the Art” Monitoring – Thermal Imaging

- Propane is a Natural Refrigerant Due to it’s Low Boiling Point (-44 F at 1 ATM)
- Infrared Imaging Easily Identifies Leaks Too Small for Humans to Detect and Much Sooner than LEL’s
- Infrared Imaging Has Greatly Improved Our Ability to Identify Minuscule Leaks During Low Pressure Testing with Nitrogen/Propane

Sample End Cap Leaks Identified w/Low Pressure Nitrogen Testing
“State of the Art” Monitoring - Dedicated Monitoring

- Electronic Display of the LEL Monitors as Located on the Well Site Shown in the Frac Van
- One Full Time Employ is Dedicated to Monitor the LEL’s, Close Circuit Cameras, and Thermal Imaging Cameras
“The safety of the job was the best I have ever been on; the firefighting equipment could pump up 750 gpm they had water, foam and chemical on site for any fire. 1 of the 3 fire fighters was an EMT they were dressed in fire fighting clothes during the entire job stationed outside hot work zone. Nobody can enter the hot zone during the treating of the well. Each piece of GasFrac’s equipment had a minimum of 1LEL device on the downwind side. The infrared camera stood on a pedestal around 20’ tall was able to look in a 360 arc and brought live stream video into the Command and Control Center.

I know the question was brought up about could this be done in a safe and successful manner. In my opinion yes it can be and could also be beneficial to companies that would like to do a work over on an existing well that the formation has the possible chance of swelling due to clay found in the zone that needs to be frac’d.”

Gayland Darity
Oklahoma Corporation Commission
District Manager - District III
Office: (580)-255-0103
Successful Applications – Reservoir

Common Parameters
- All Reservoir Fluids (Oil, Gas, Condensate, & Waxy)
- All Pressures (imbibition not as damaging in highly overpressured reservoirs)
- All Lithologies
- Temps < 60F to 306F
- Horizontal Wells – Liquid Loading Concerns

Best Parameters
- $S_w$ at or Below Irreducible Saturation
- Water Sensitive Formations
- Formations with Clay Issues
- Fine Grain Reservoirs
- Effective Frac Length is Critical
- Matrix Permeability
- Low Pressure / Depleted Reservoirs
Gas - Very Low Pressure LPG Fracturing

Low Pressure Application (7,061 ft @ BHP 362 psi):

- **Initial Rate:** 60 Mscf/day
- **Post Frac Rate:** 520 Mscf/day & 15.8 bbl condensate/day @ 112 psi
- **Cumulative Production:** 2-09 to 7-11, 133.2 MMCF

- **Frac:** 46,200 # proppant in 620 bbl Down 2 7/8” tubing
- **Build-up Test:** 362 psi at 7,061 ft
- **Cleanup to Sales Line**
- **Plunger Lift Installed**
Doe Creek Oil
Incremental Reserves from LPG Fracture Treatment

23 Years
Perforate & Produce

(14 Months)

Remaining P1 Pre Job = 18K BOE
Remaining P1 Post Job = 125K BOE
Incremental Res = 107K BOE
Remaining Reserves Added = 595%
14 Months → 50K Produced = $3.0MM
Value Added 107K BOE X $60 = $6.4MM

Rate (BOE/Op Day)
Cumulative Production (BOE)
Wilcox Formation - East Texas
12,250' - 289F - 2 mD Formation

Natural Completion

Condensate Banking Suspected

LPG Stimulation
100,000 # VersaProp

Gas (MSCFD), Oil (BOPD)

BOPD
MSCFD

Feb-09
Mar-09
Apr-09
May-09
Jun-09
Jul-09
Aug-09
Sep-09
Oct-09
Nov-09
Dec-09
Jan-10
Feb-10
Mar-10
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
LPG vs. Non-LPG Frac Comparison – Viking Formation

Cumulative Production (BOE)

- LPG Frac 1
- LPG Frac 2
- LPG Frac 3
- LPG Frac 4
- Non- LPG Frac

Months on Production

Technology

*Data acquired from GeoScout™; wells terminating in the Viking formation

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### LPG Fracturing - A Superior Alternative.

- Wapiti Field - Cardium Formation in Alberta, Canada

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<th>Well</th>
<th>Loc.</th>
<th>Fluid Type</th>
<th>Proppant</th>
<th>Stages</th>
<th>IP BOE/D</th>
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<tr>
<td>1</td>
<td>1-9</td>
<td>CO2 – Frac Oil</td>
<td>495,000</td>
<td>15</td>
<td>133</td>
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<td>2</td>
<td>4-17</td>
<td>Frac Oil</td>
<td>484,000</td>
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<td>260</td>
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<td>3</td>
<td>4-22</td>
<td>CO2 – Frac Oil</td>
<td>495,000</td>
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<td>215</td>
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<td>4</td>
<td>12-14</td>
<td>CO2 – Frac Oil</td>
<td>704,000</td>
<td>16</td>
<td>280</td>
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<td>5</td>
<td>14-28</td>
<td>LPG</td>
<td>333,000</td>
<td>10</td>
<td>1,138</td>
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</table>

These results highlight the effectiveness and benefits of LPG fracturing. A well with half the amount of sand and a third less stages produces FOUR times the production! With LPG Fracturing, Less can Yield more!

Wapiti Cardium - Hz Wells - GasFrac Vs. Offsets

1 Year Cumulative Production
25 MBOEG vs. 70 MBOEG
2.5 to 3 Times Greater Recovery!
Shale Gas Comparison
LPG Vertical Wells vs. Water Horizontal Wells

- Frederick Brook Shale Same Age as Barnett and Fayetteville
- Corridor’s Success Results in an Operator “A” Buying into the Play & Bringing their “Best Practices”

<table>
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<th>Operator Well</th>
<th>Frac Job Type</th>
<th>Job Size</th>
<th>Post Frac Production</th>
<th>Comments</th>
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<tr>
<td>Corridor G-41</td>
<td>Vertical Well (w/2 stages)</td>
<td>0.25 Million lbs. GasFrac (Waterless)</td>
<td>4.1 MMCFPD @ 2083 psi 57 hours after frac</td>
<td>Average 5.5 MMCFPD the 1st week</td>
</tr>
<tr>
<td>Operator “A” B-41</td>
<td>Horizontal Well (w/5 stages)</td>
<td>2.50 Million lbs. 4.7 Million gals of Water</td>
<td>Recovered 10% Load &amp; No Gas</td>
<td>Well is 2000’ offset to the G-41</td>
</tr>
<tr>
<td>Operator “A” G-59</td>
<td>Horizontal Well (w/5 stages)</td>
<td>2.50 Million lbs. 4.7 Million gals of Water</td>
<td>Recovered 4% Load &amp; Negligible Gas</td>
<td>Water rates have fallen</td>
</tr>
</tbody>
</table>

- 947 Truck Loads of Water vs. 30 Truck Loads of LPG
- Is the Reservoir Failing Us or Are We Failing the Reservoir?

Source: Corridor Public Release dated Dec 6, 2010 “Corridor Updates Elgin Shale Appraisal Program” www.corridor.ca
LPG Fracturing - Environmental Benefits

- **Environmental Impact of LPG Based Frac Fluids can be Minimal**
  - No Potable Water is Used in the Fracturing Process
  - No Biocides Used
  - No Waste Stream Created
  - No Reservoir Minerals, Nuclides, or Salts are Recovered with the LPG
  - Minimal Flaring, Everything Pumped Can be Sold!
  - Smaller Quantities can be Used to Achieve Equivalent Effective Frac Length
  - Less Road Traffic – Less Fluids and No Return Trip for Disposal!
  - LPG can be Recovered with the Natural Gas to the Pipeline or Recovered by Gas Processing where it can be Recycled for Fracturing or Sale.

- **LPG Comes from our Reservoirs and Can be Used to Produce More Oil and Gas from our Reservoirs – Sustainability!**

LPG Fracturing Achieves a Closed Looped Process
Water – Both a Supply and a Disposal Challenge

Texas Drought Conditions as of July 26, 2011

Source: USA TODAY March 3, 2011

Ark. commission votes to shut down wells

Posted on July 27, 2011 at 11:14 am by Associated Press in Drilling Natural Gas

The commission met Wednesday in El Dorado. The Arkansas Democrat-Gazette reports that the commission decided 6-0 to close a well run by Deep-Six Water Disposal Services between Greenbrier and Enola. It then voted 7-0 to ban any future wells in a 1,150-square-mile area around Greenbrier and Guy.

The commission staff says four wells in the area were contributing to the earthquakes. Companies operating three of the wells have shut them down — but the Democrat-Gazette reports that Deep-Six says its well between Greenbrier and Enola isn’t causing the earthquakes.

Source: http://drought.unl.edu/dm/monitor.html
"Alternatives to Hydraulic Fracturing. One of the most effective methods of reducing exposure to contaminated wastewater is to implement processes that do not generate wastewater. GASFRAC Energy Services is testing the use of liquefied petroleum gas (LPG), a fracturing agent that also transports the proppants into the fractures. First introduced in Marcellus Shale drilling in September 2009, LPG is derived from natural gas processing and consists mainly of propane in gel form (24). The process generates no wastewater since all of the LPG is recaptured back up the well."
LPG Fracturing Technology – Game Changing and Creating a “Competitive Advantage”

- Enhanced Well Performance and Project ROR’s, ROI’s, NPV’s, and Development Cost/Bbl
- Minimizing Environmental Issues/Impact
- Providing a Sustainable Stimulation Fluid for Oil and Gas Development!

Example of how Horizontal Drilling was the Game Changer in the 90’s in the Pearsall Field taking production from 4000 BOPD to 90,000 BOPD!
LPG Fracturing Technology
“Putting the Technology Back Into Fracturing”

Thank You!