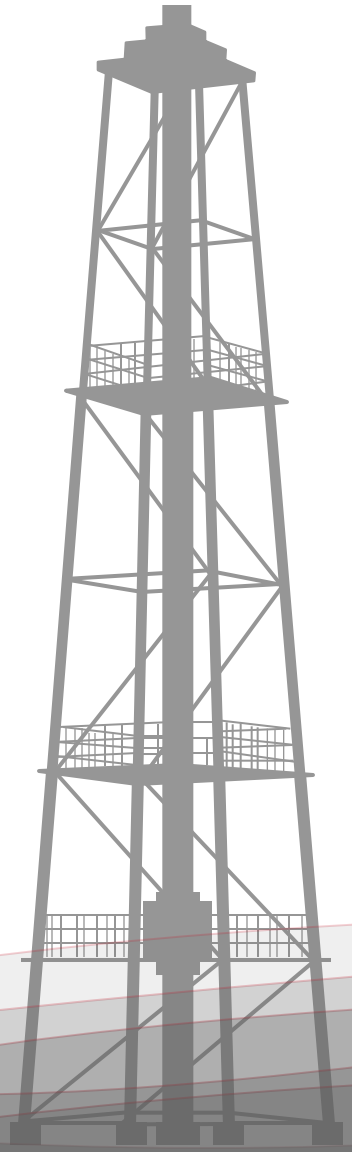

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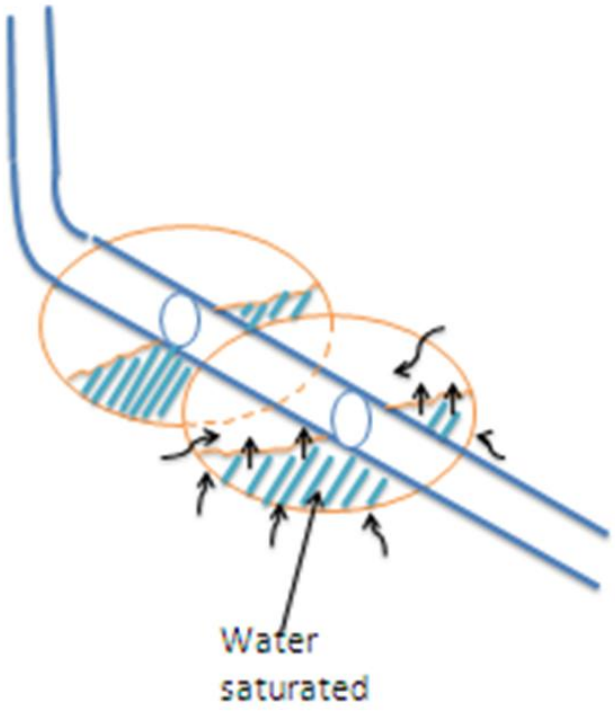
# The Use of Complex Nanofluid technology and $CO_2$ To Stimulate Shale Reservoirs

Glenn S. Penny, Ph.D.

September 29, 2010

- A Flotek Industries, Inc. company
- Corporate HQ in Houston, TX
- New York Stock Exchange: FTK
- www.flotekind.com

# New Research: Horizontal Shale Well Cleanup




- Horizontal Shale Column tests with gas

| | % rec | Sw | kg | Factor kg improve |
|---|---|---|---|---|
| ME2 | 57.5 | 42.5 | 0.30 | 2.00 |
| ME | 52.7 | 47.3 | 0.25 | 1.50 |
| B | 48.2 | 51.8 | 0.20 | 1.00 |
| A | 43.5 | 56.5 | 0.15 | 0.50 |
| Baseline | 37.5 | 62.5 | 0.10 | 0.00 |

Evaluating the combination of new FR, Biocide and ME formula tailored for shale

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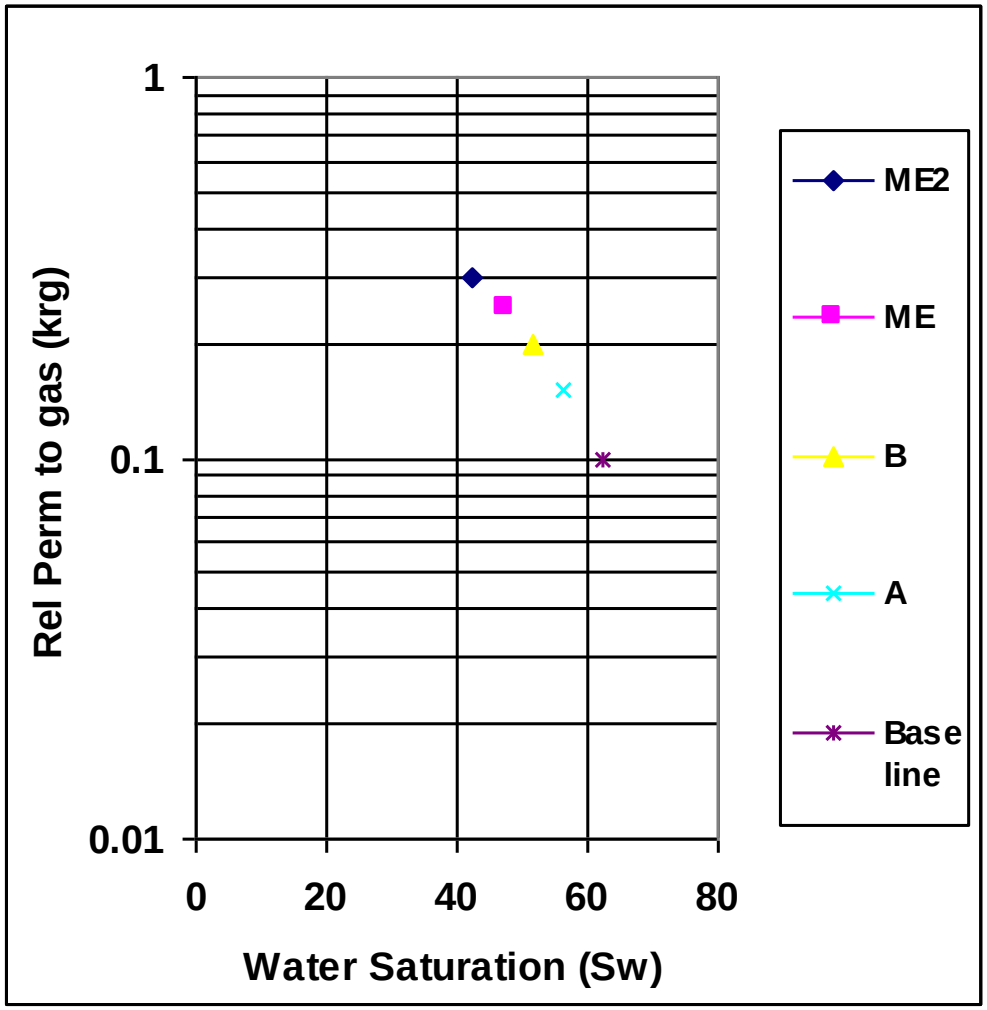
# Rel perm vs water saturation for various ME products SPE

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# Shale Split Core

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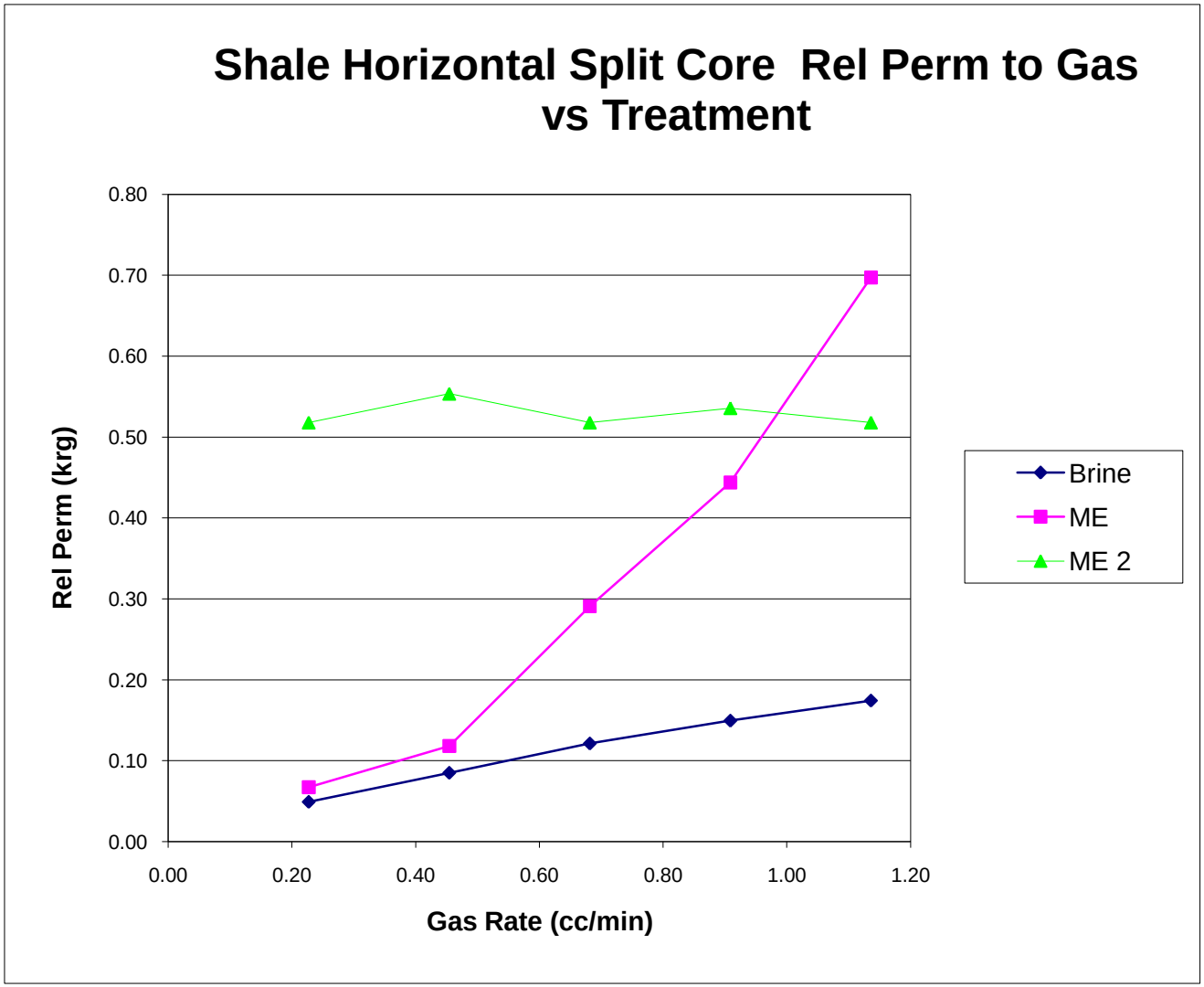
# Split Core Procedure


- Mount in the core holder in the horizontal orientation with the crack vertical
- Heat to 250 F, 1000 psi confining and 200 psi back pressure
- Flow brine followed by gas at 0.1 to 1.0 cc/min
- Inject test fluid followed by gas from 0.1 to 1 cc/min

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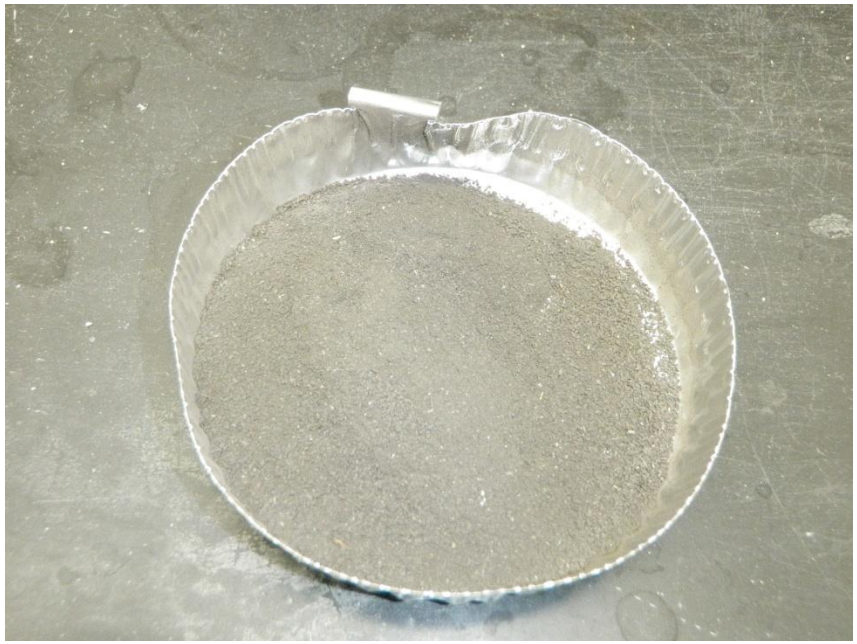
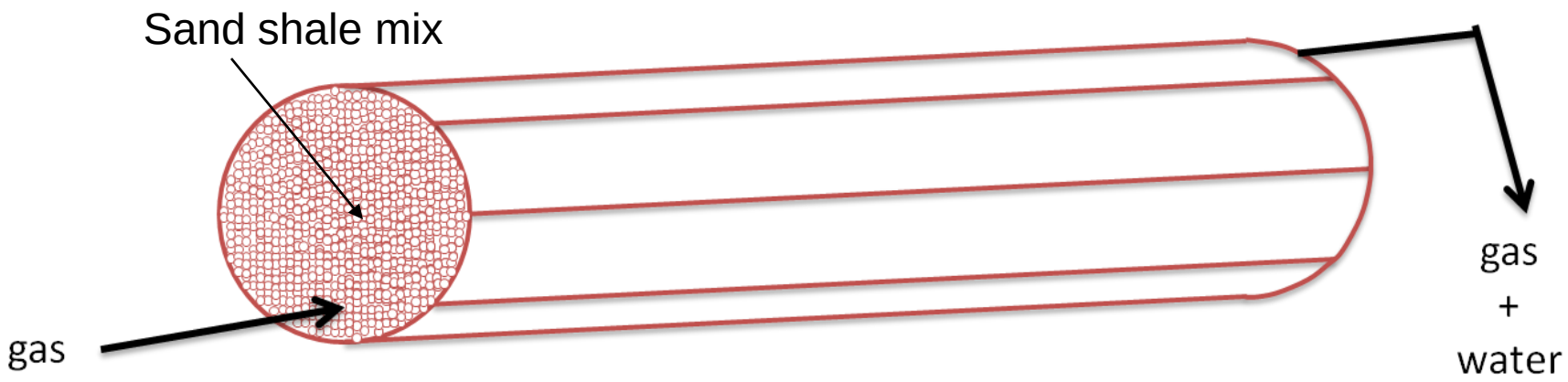
# Shale Cores: after splitting and crushing for sand column test

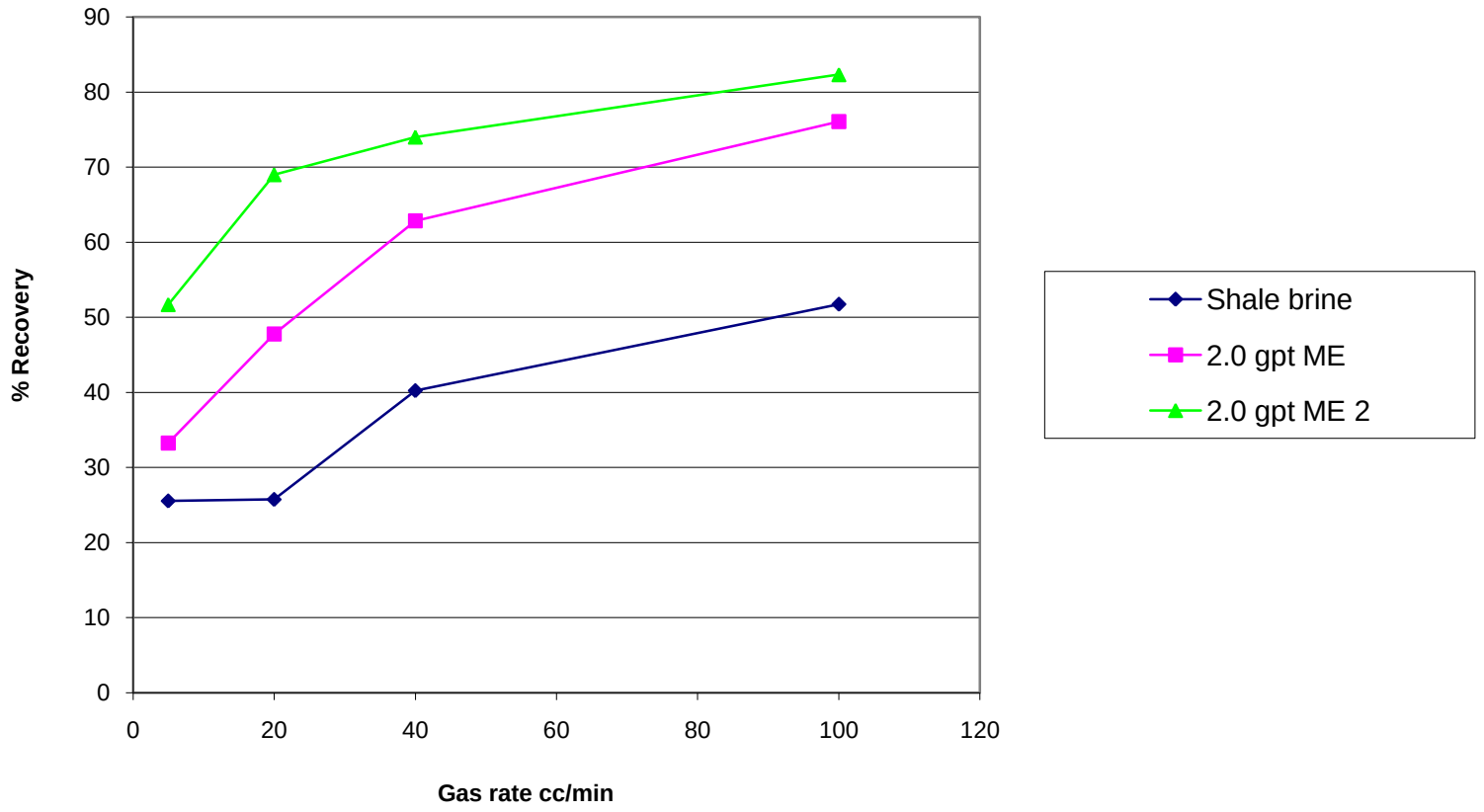


# Sand Column Test




- Standard size = 12 in long by 1 in diameter
- Pack with 30/50 sand or a mix of sand and shale.
- Flow test fluid through and collect effluent for surface tension measurement
- Flow gas at rates of 5 cc/min and up to measure % fluid recovery
- Smaller 4 in long by 0.5 in diameter used for smaller samples (10 ml vol)

# Percent Water Recovery From horizontal 30/50 Sand Column vs Gas Rate

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**% Fluid Recovery on 10 ml horizontal omnifit column**

**Column = 50:50 shale( -10/+40) with sand (30/50)**

Due to limited quantity of shale- samples were only analyzed once

Based upon previous baseline data for this shale the std.dev is appx. ( +/- 5.0)

| Sample | % R at 5cc/min |
|---|---|
| Tap Water | 20 |
| CESI Microemulsion A | 39.3 |
| ME 2 | 48.8 |
| CESI Microemulsion B | 41.5 |

| RECOVERY | % increase over base at 5cc/min |
|---|---|
| Tap Water | Baseline |
| CESI Microemulsion A | 196.5 |
| ME 2 | 244 |
| CESI Microemulsion B | 207.5 |

# Shale Column study with ME + FR

| | | | |
|---|---|---|---|
| ME + FR study in Shale Brine | | | |
| 20/40 Shale- Unimin Utica | | | |
| Flow Rate < 10cc/min | | | |
| Horizontal fluid recovery | | | |
| Samples analyzed in duplicate with average reported | | | |
| Shale Brine Components in mg/L ( $CaCl_2$= 609, $MgCl_2$= 773, | | | |
| NaCl= 22,060 , KCl = 418 , $SrCl_2$=100, $BaCl_2$ = 447 , $NaHCO_3$= 3710, $Na_2SO_4$=12) | | | |
| | | | |
| | | | |
| | | | |
| | | | **RECOVERY** |
| **Sample** | **% Recovery** | | **% INCREASED** |
| | | | **above baseline** |
| | | | |
| **Shale Brine** | **30.6** | | Baseline |
| **1.0 gpt ME 2** | **34.9** | | 14.2 |
| **2.0 gpt ME 2** | **55.8** | | 82.6 |
| **0.25 gpt FR with 2.0 gpt ME 2** | **61.0** | | 99.4 |

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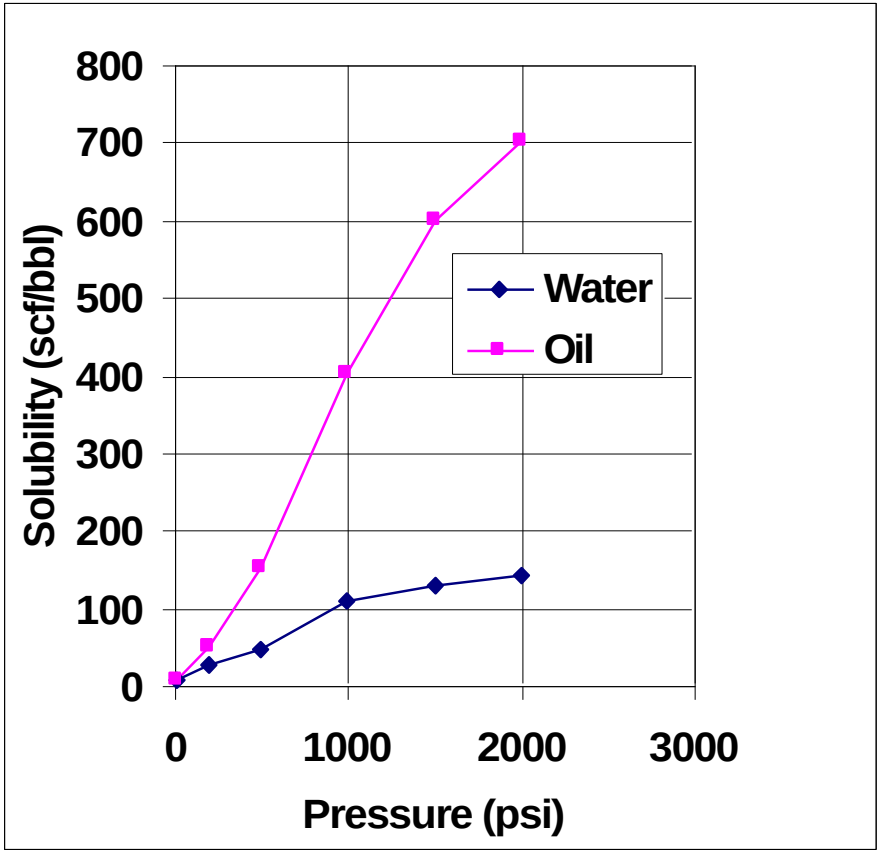
# Conclusions and Observations

- Newly developed ME sample improves rel perm in horizontal split core test to 0.5 at low rates.
- Improves flow in Sand shale column 2 to 5 fold at low rates
- Maintains surface tension reduction upon exposure to 50/50 shale sand pack.
- New ME works well with FR.  In column tests the water recovery and krg was enhanced

# Use of ME with CO2 in Shales Containing Oil

- CO2 has excellent solubility in crude oils as is evidenced in the following slide.
- CESI has developed microemulsion (ME) technology which works well with CO2
- The interfacial tension between crude and CO2 is lowered to near 1 dyne/cm with MA
- In this work ME+CO2 technology has been evaluated for its effectiveness in removing Eagleford crude from cores.

# Solubility of CO2 in Crude

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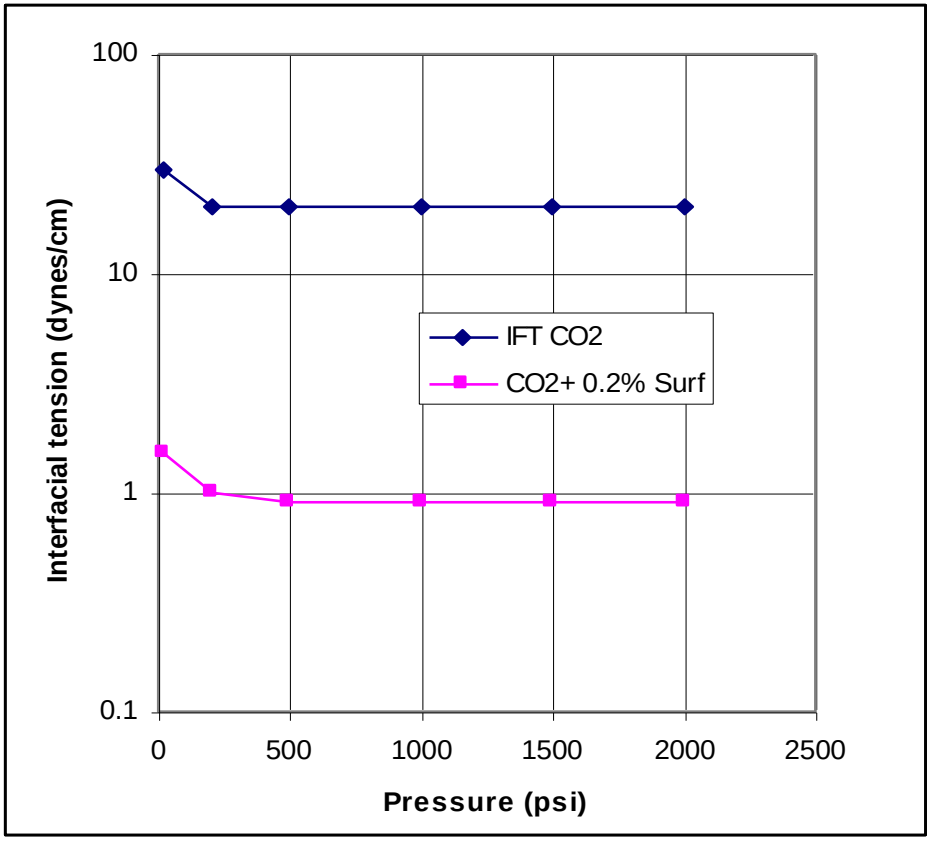
# IFT with CO2 and MA

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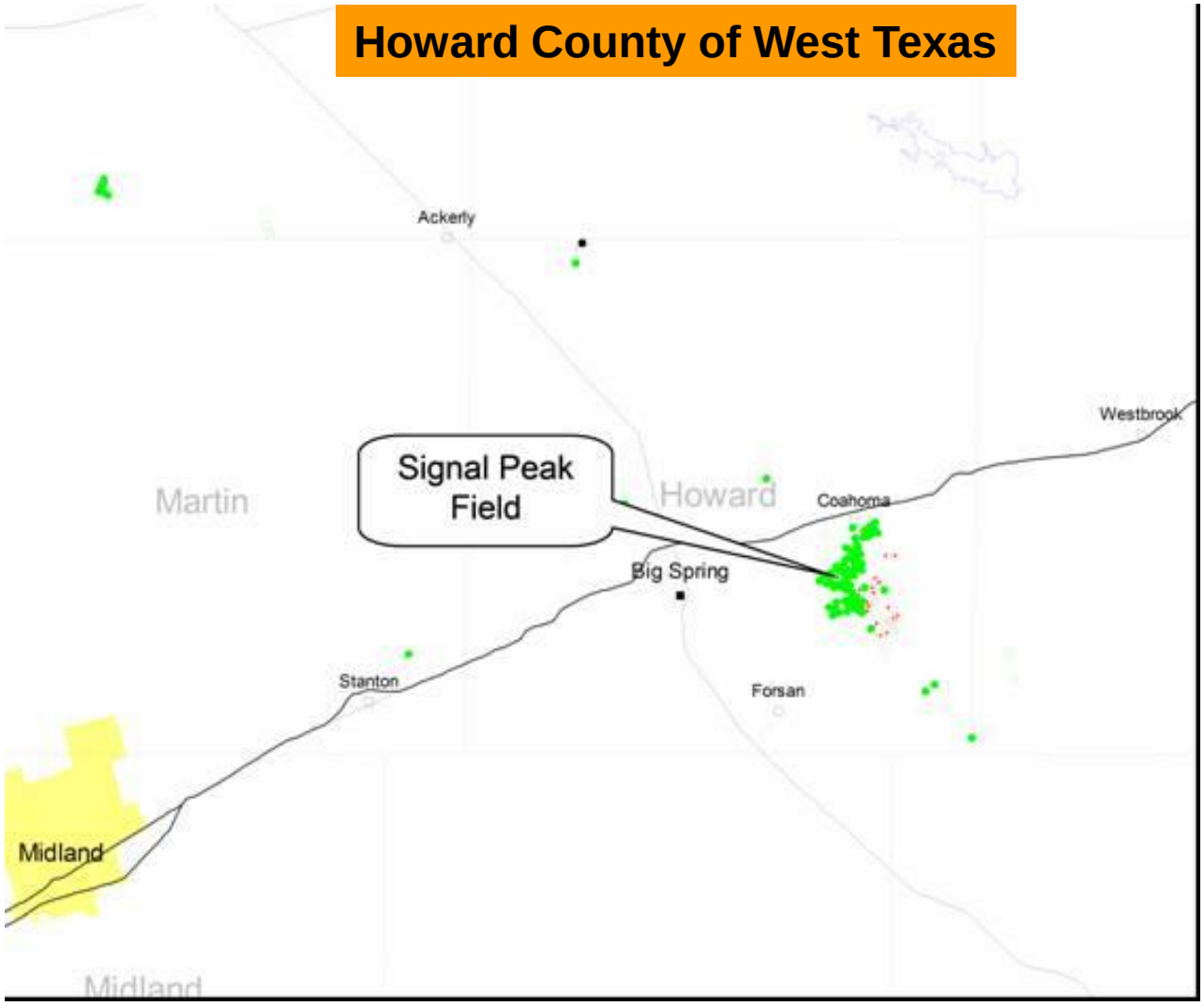
# Field Testing of ME + CO2 Signal Peak Field

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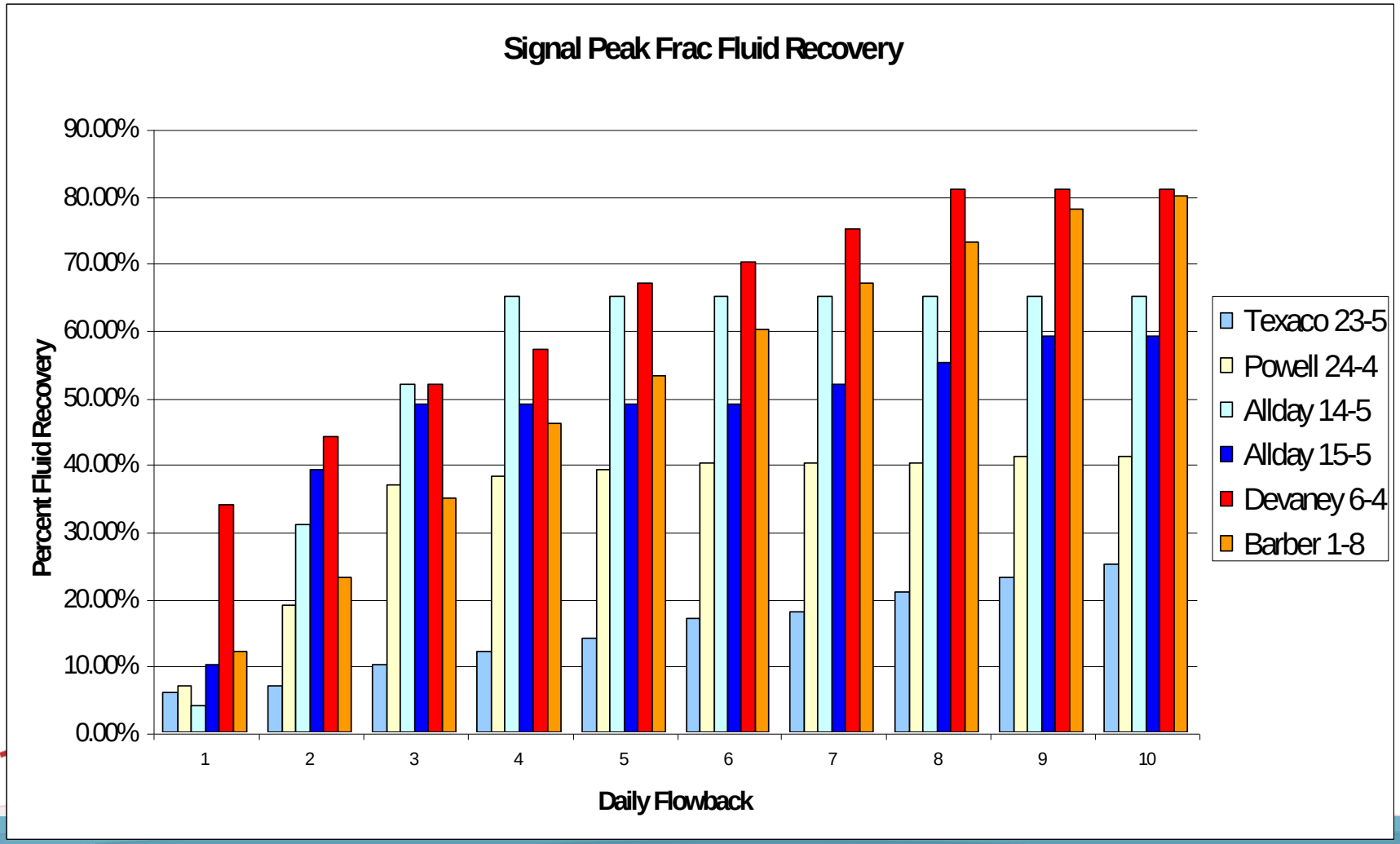
# Signal Peak Well Treatments SPE 107982

- There are a total of six (6) wells in this Signal Peak study .
- One of the wells was completed with a slick water fracture treatment.
- CO2 Foam fluids were used on 5 wells to minimize the fluid volume and energize the return of injected fluids.,
- Two wells were treated with CO2 plus ME
- The average completion depth is 7442 to 7918 ft for an average perforated interval of 185 ft.
- The bottom hole pressures reported range from 636 psi to 2281 psi depending on the reservoir quality and the stage of depletion of the channel.
- The average fluid volume was 97,530 gallons with an average prop volume of 292,705 pounds of 20/40 sand.

# Frac fluid recoveries during the first ten days of fluid flowback after completion

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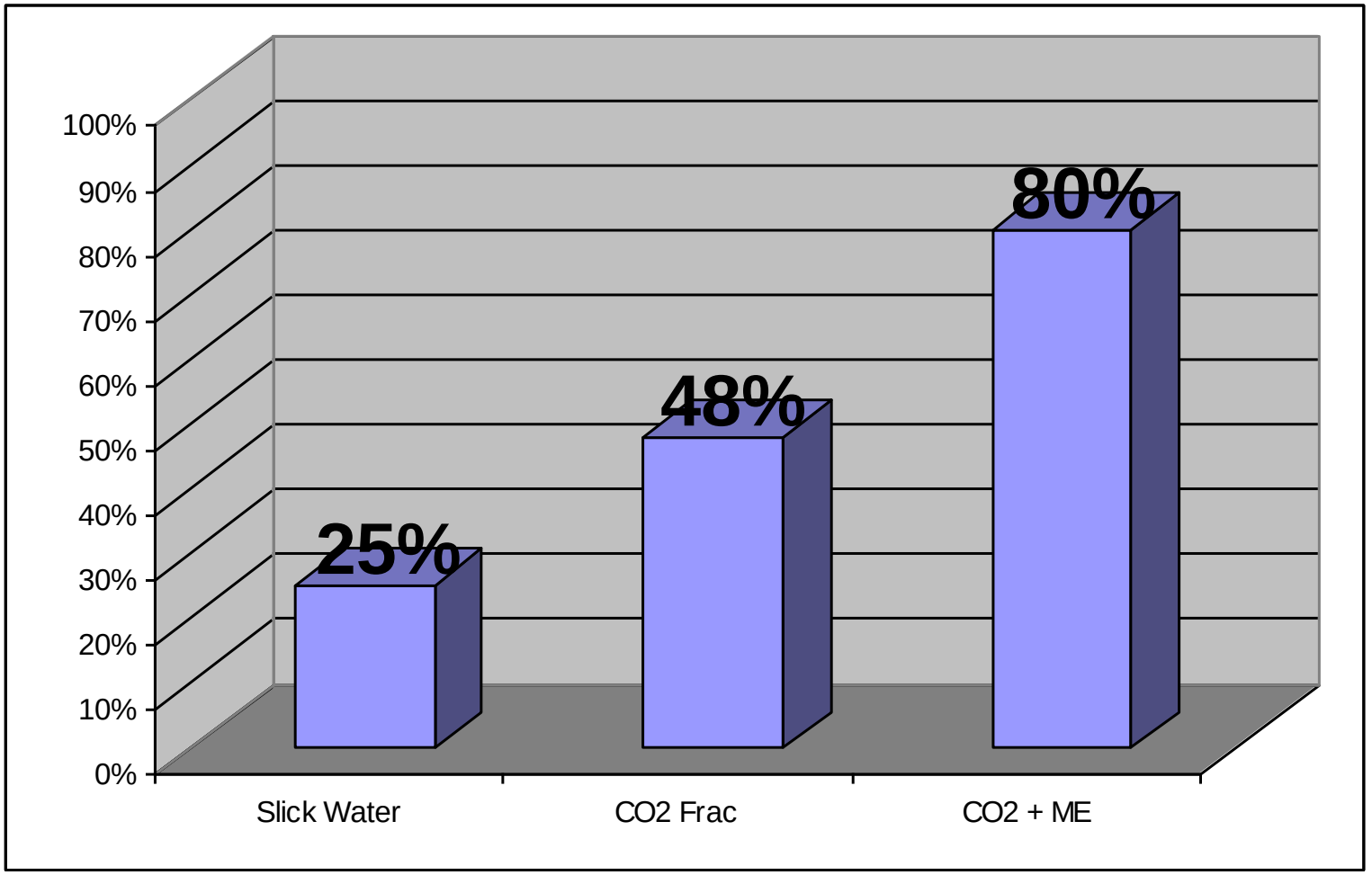
# Signal Peak % Fluid Recovery vs Frac Fluid

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# Conclusions from Signal Peak

- The oil and gas production of wells treated with ME were higher than non-ME offsets. Average was 44 BOPD vs 25
- The wells with ME exhibited over 30% better reservoir conductivity during sustained, long-term production than did the non-ME wells.
- The wells with ME additive exhibited almost 100% longer effective fracture half-lengths than did the non-ME wells.

# Conclusions (cont'd)

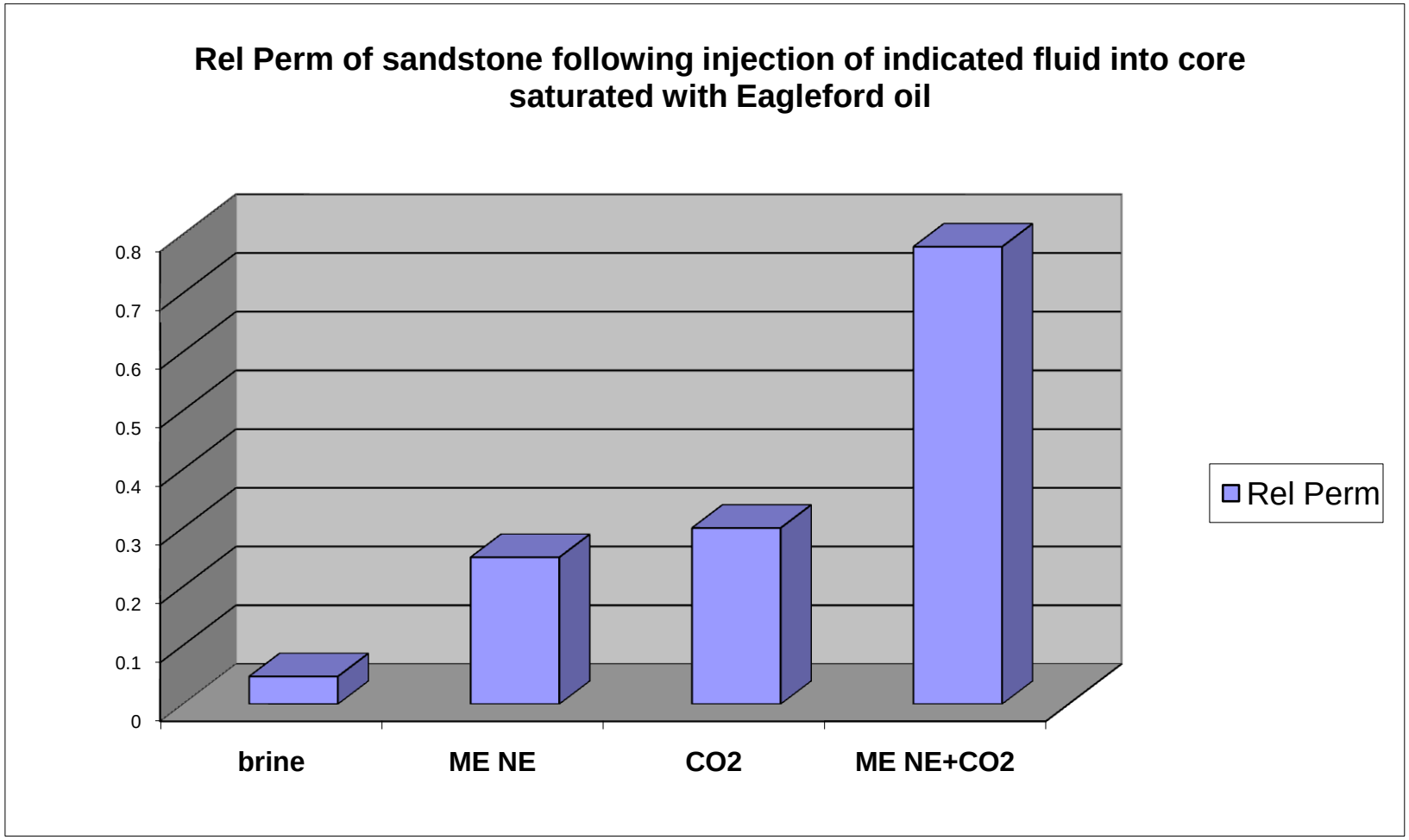
- Even though the shut-in times for the wells with microemulsion additive were very long, these wells experienced significantly less damage than did the non-ME wells.

- The production for the ME wells returned to near pre shut-in rates immediately.

# Procedure to Evaluate ME and CO2 in shale cores with Eagleford Oil at reservoir temperature

- Flow N2 gas to stable perm (0.1 md) Sw = 20%
- Inject Eagleford oil
- Inject treatment at 2 gpt ME NE with and without CO2 at fluid to CO2 ratio of 4:1
- Flow N2 to stable gas perm
- Determine rel perm to gas
- Calculate fractional vol of oil removed

# Rel Perm following various treatments

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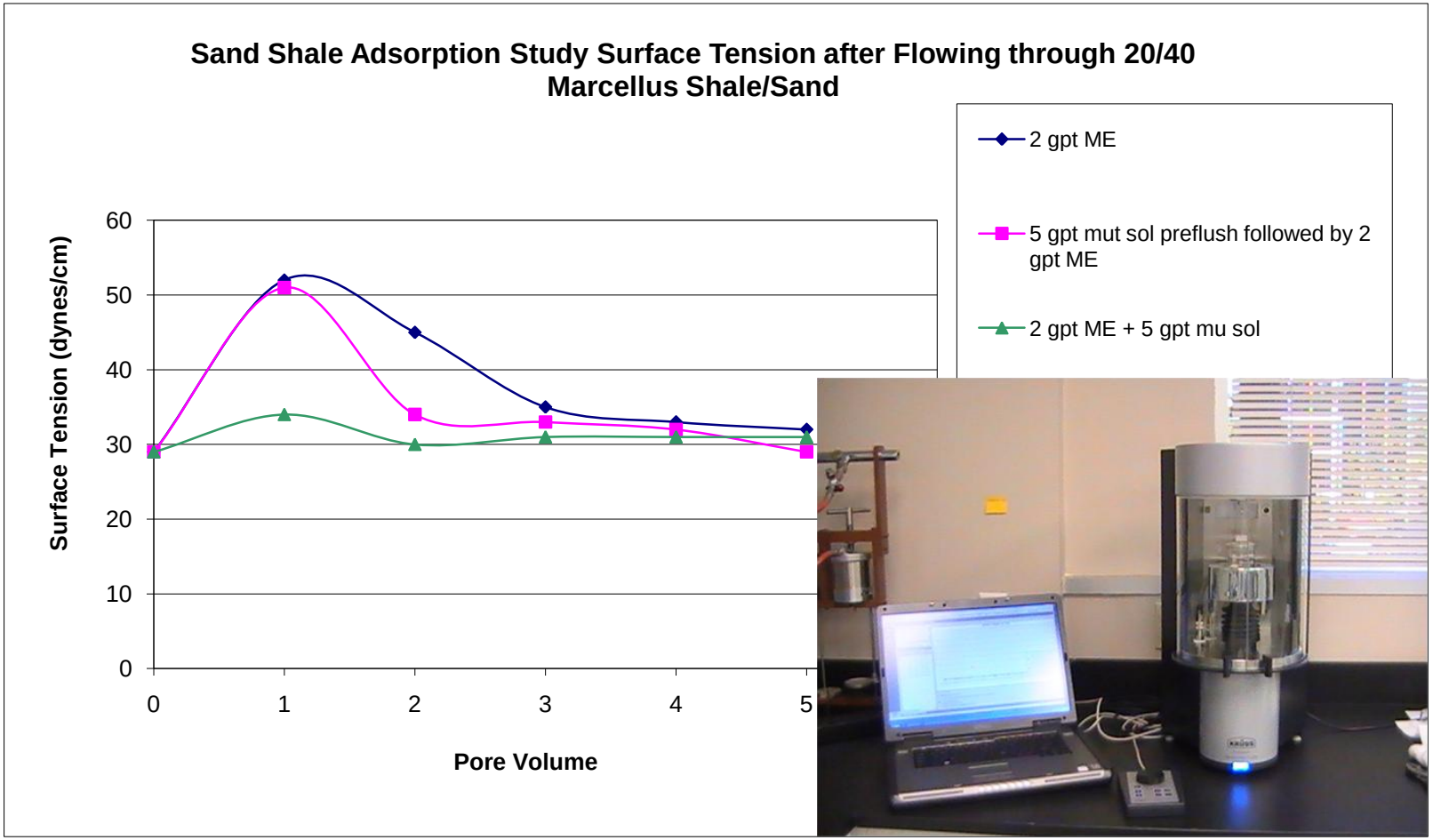
# Calculation of Oil Displaced (ml)

| | Rel Perm | Sw | So | left in core | displaced |
|---|---|---|---|---|---|
| brine | 0.047 | 0.20 | 0.30 | 1.35 | 2.25 |
| ME NE | 0.250 | 0.20 | 0.10 | 0.45 | 3.15 |
| CO2 | 0.300 | 0.20 | 0.10 | 0.45 | 3.15 |
| ME NE+CO2 | 0.779 | 0.20 | 0.01 | 0.05 | 3.56 |

# Adsorption ME and Mutual Solvent




Kruss 100 interfacial Tensiometer

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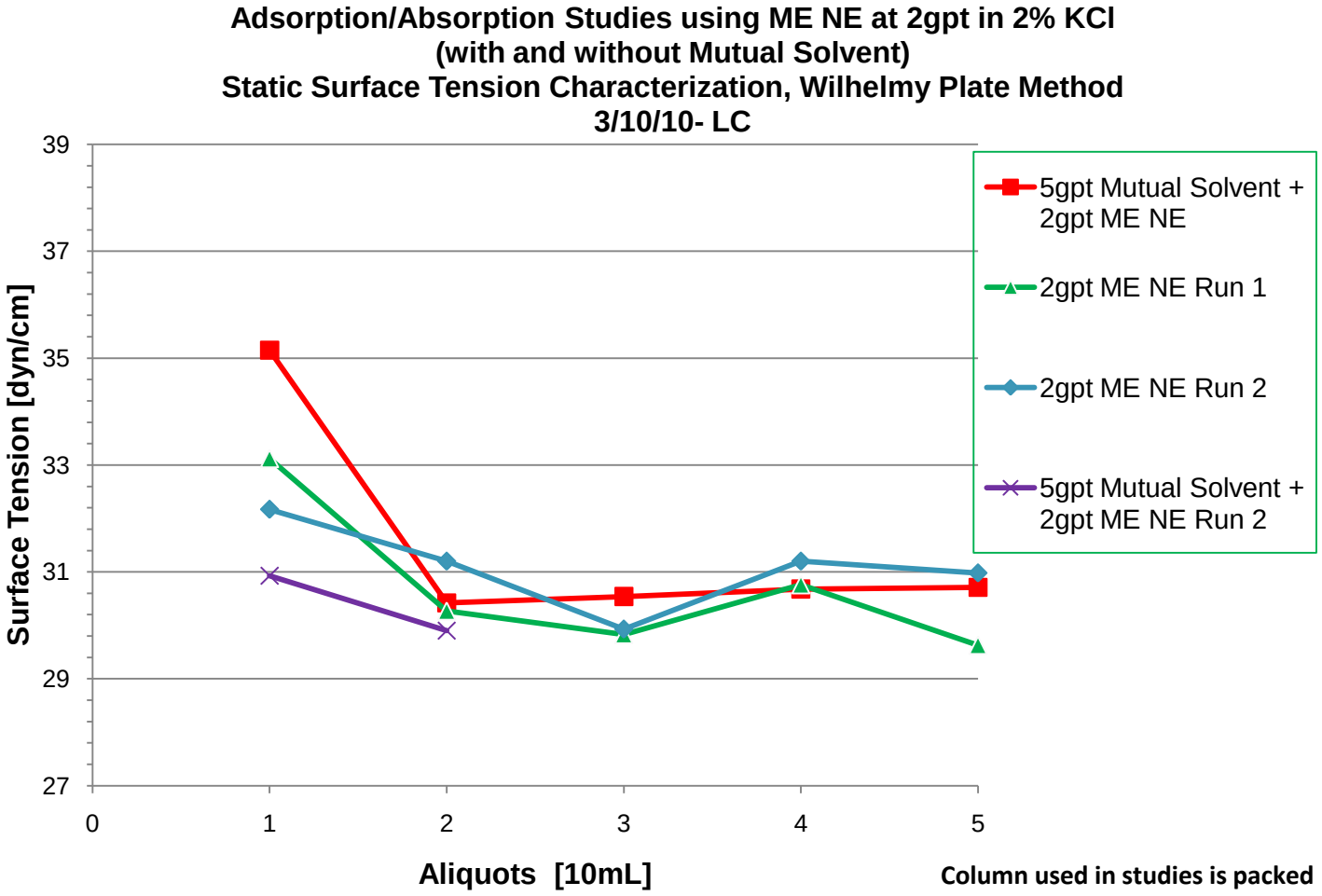
# Adsorption with ME NE with and without mutual solvent




**Column used in studies is packed with a 1:1 ratio of 20/40 mesh Ottawa sand and -10/+40 mesh Marcellus shale**

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# Conclusions

- CESI Microemulsion technology together with CO2 enhances the removal of Eagleford oil from cores.
- Mutual Solvent aids in mitigating the adsorption of MA in shale pack studies
- A specially formulated ME known as ME NE shows decreased adsorption
- Field trials are underway in fracturing and EOR with CO2 and complex nanofluid technology to enhance oil production and recovery