Development and Field Testing Novel Natural Gas (NG) Surface Process Equipment for Replacement of Water as Primary Hydraulic Fracturing Fluid

Project # DE-FE0024314

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U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

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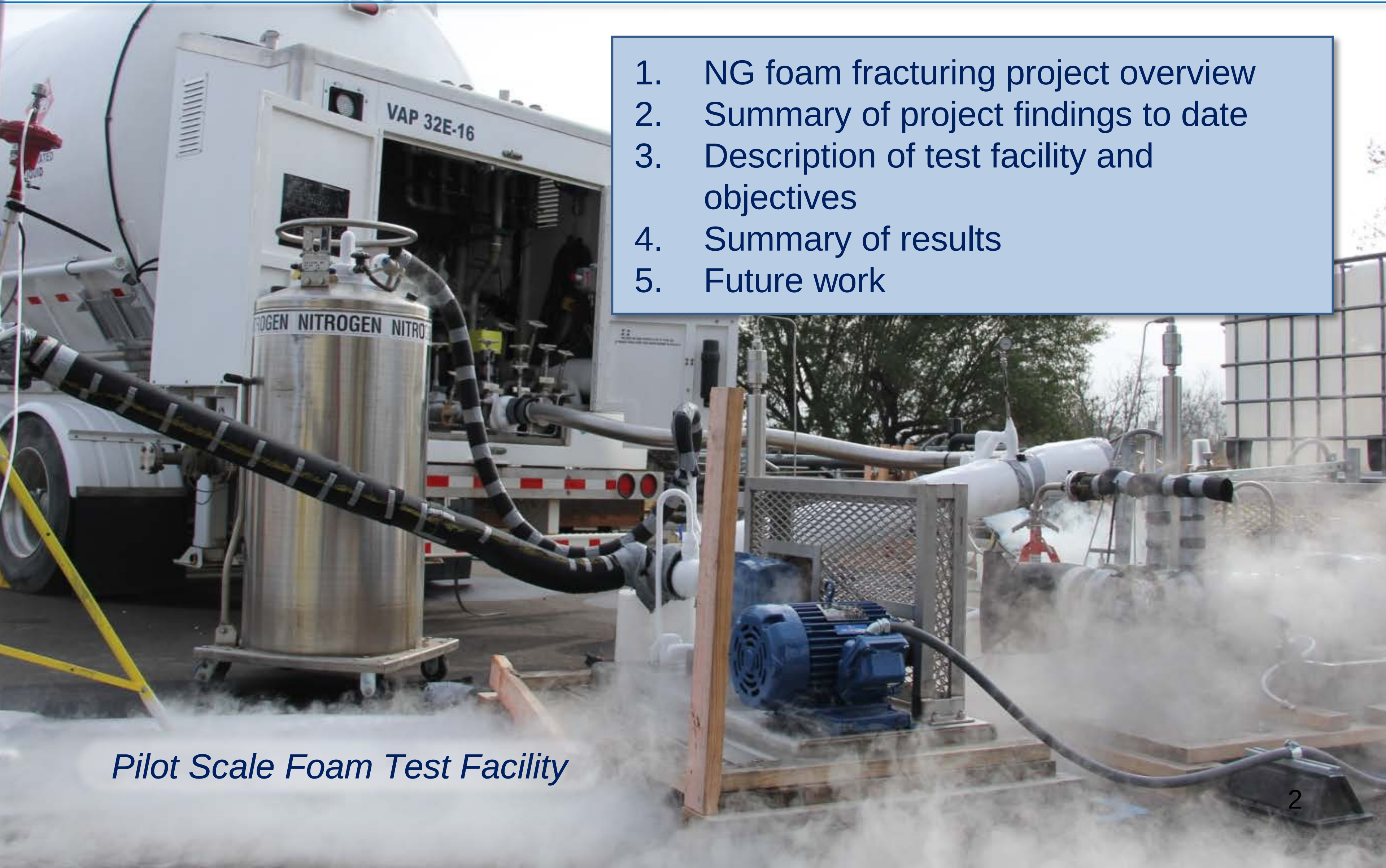
This presentation provides an overview of a recent laboratory investigation of natural-gas based foams

1. NG foam fracturing project overview
2. Summary of project findings to date
3. Description of test facility and objectives
4. Summary of results
5. Future work

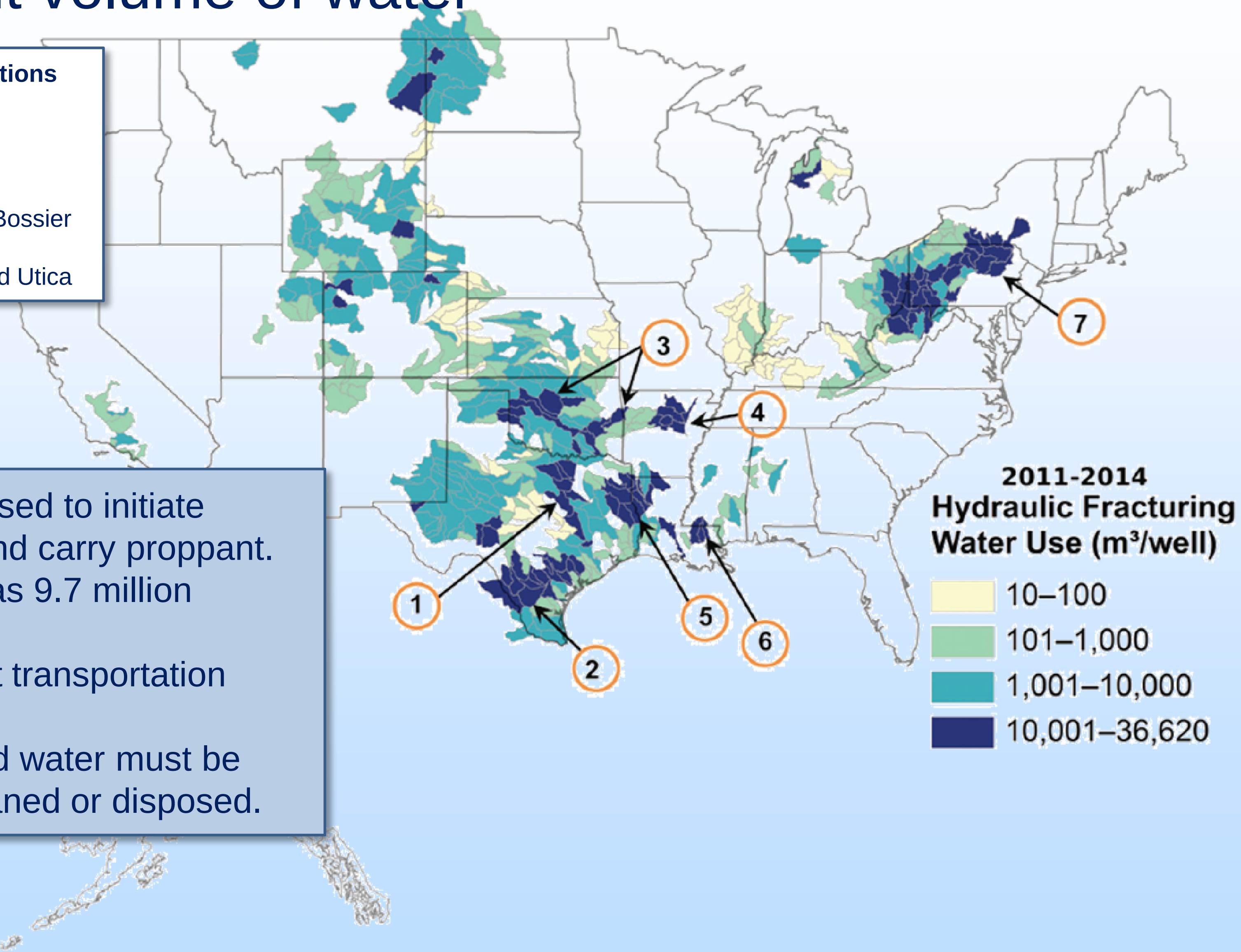


Pilot Scale Foam Test Facility

Typical hydraulic fracture treatments require a significant volume of water

Shale Gas Formations

1. Barnett
2. Eagle Ford
3. Woodford
4. Fayetteville
5. Haynesville-Bossier
6. Tuscaloosa
7. Marcellus and Utica

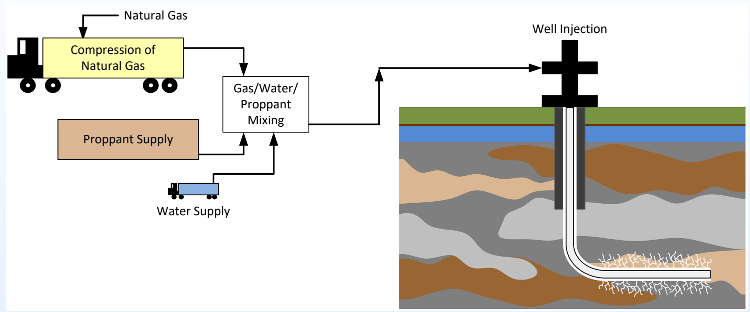


- Water is used to initiate fracture and carry proppant.
- As much as 9.7 million gal/well[1]
- Significant transportation required
- Recovered water must be either cleaned or disposed.

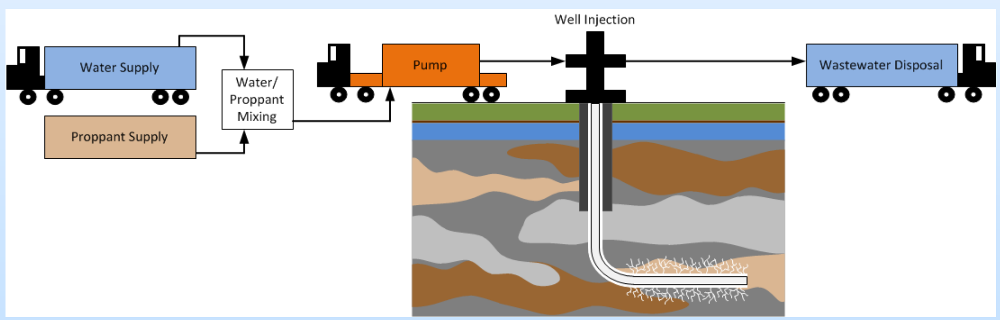
1. **Gallegos, T. J., et al.,** "Hydraulic Fracturing Water Use Variability in the United States and Potential Environmental Implications," *Water Resources Research*, **51** (7) pp. 5839-5845, (July 2015).

SwRI and SLB are developing a novel process that uses of natural gas as the primary fracturing fluid

Proposed Natural Gas Fracturing

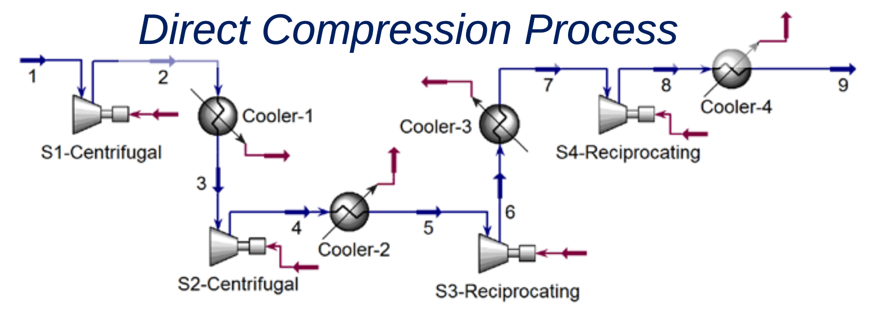


Current Fracturing Process



- The proposed process uses NG foam for hydraulic fracture treatment.
- This could reduce water consumption by as much as 80%.
- Natural gas is readily available at well site.
- The recovered natural gas would be processed.

Initial work identified an appropriate surface process and reviewed foam rheology literature



Key Findings from Process Development[2-4]

- Six processes (including compression and liquefaction cycles) were analyzed.
- The optimal process to produce high pressure NG is through ***direct compression.***
- Equipment needed to compress gas is commercially available.

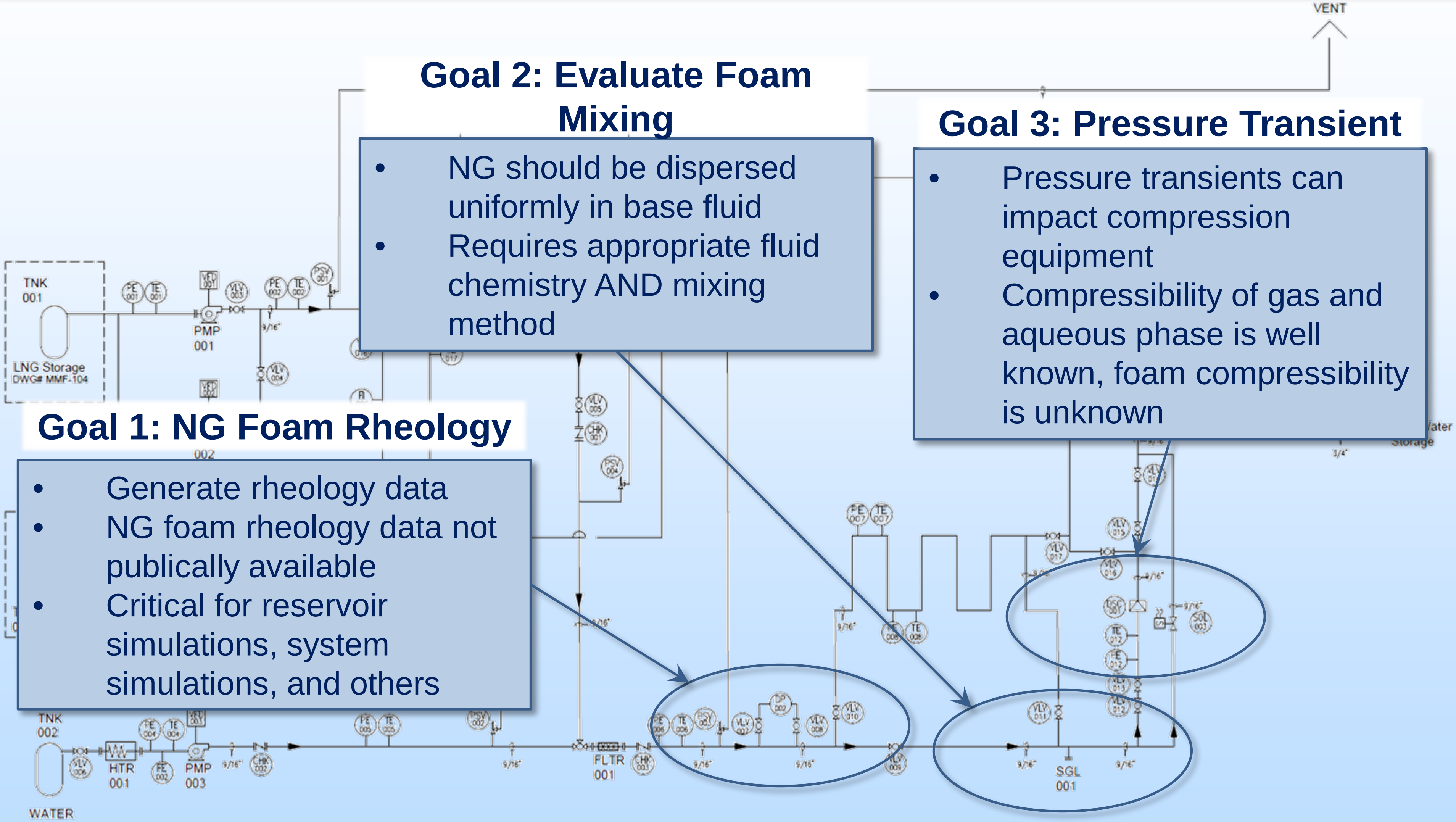
Key Findings from Literature Review[2]

- **No published data for NG foam rheology is available.**
- Summary of CO_2 and N_2 foam trends observed in literature:
  - Fluid viscosity changes with foam quality (x).
  - Temperature impacts viscosity (increasing T decreases μ).
  - Bubble size has minimal impact on foam viscosity.
  - Pressure has a small effect on foam viscosity.
  - ***Foam viscosity is dominated by foam quality and base fluid viscosity.***
- NG foam is expected to follow CO_2 and N_2 foam trends.

$$x(\%) = \frac{\dot{Q}_{gas}}{\dot{Q}_{aqu} + \dot{Q}_{gas}} \times 100$$

2. **Verma, S., et al.,** "Novel Fracturing Process Utilizing Natural Gas," presented at the AIChE Annual Meeting, San Francisco, CA (November 13-18, 2016).
3. **Beck, G. and Verma, S.,** "Development and Field Testing Novel Natural Gas (NG) Surface Process Equipment for Replacement of Water as Primary Hydraulic Fracturing Fluid," presented at the 2016 Carbon Storage and Oil and Natural Gas Technologies Review Meeting, Pittsburgh, PA (August 16-18, 2016).
4. **Beck, G., et. al. "**Development and Evaluation of a Mobile Plant to Prepare Natural Gas for Use in Foam Fracturing Treatments," presented at the 2017 ASME Turbo Expo, Charlotte, NC (June 26-30, 2017).

BP2 work focused on constructing & operating a test facility to generate high pressure NG foam



Goal 2: Evaluate Foam Mixing

- NG should be dispersed uniformly in base fluid
- Requires appropriate fluid chemistry AND mixing method

Goal 3: Pressure Transient

- Pressure transients can impact compression equipment
- Compressibility of gas and aqueous phase is well known, foam compressibility is unknown

Goal 1: NG Foam Rheology

- Generate rheology data
- NG foam rheology data not publically available
- Critical for reservoir simulations, system simulations, and others

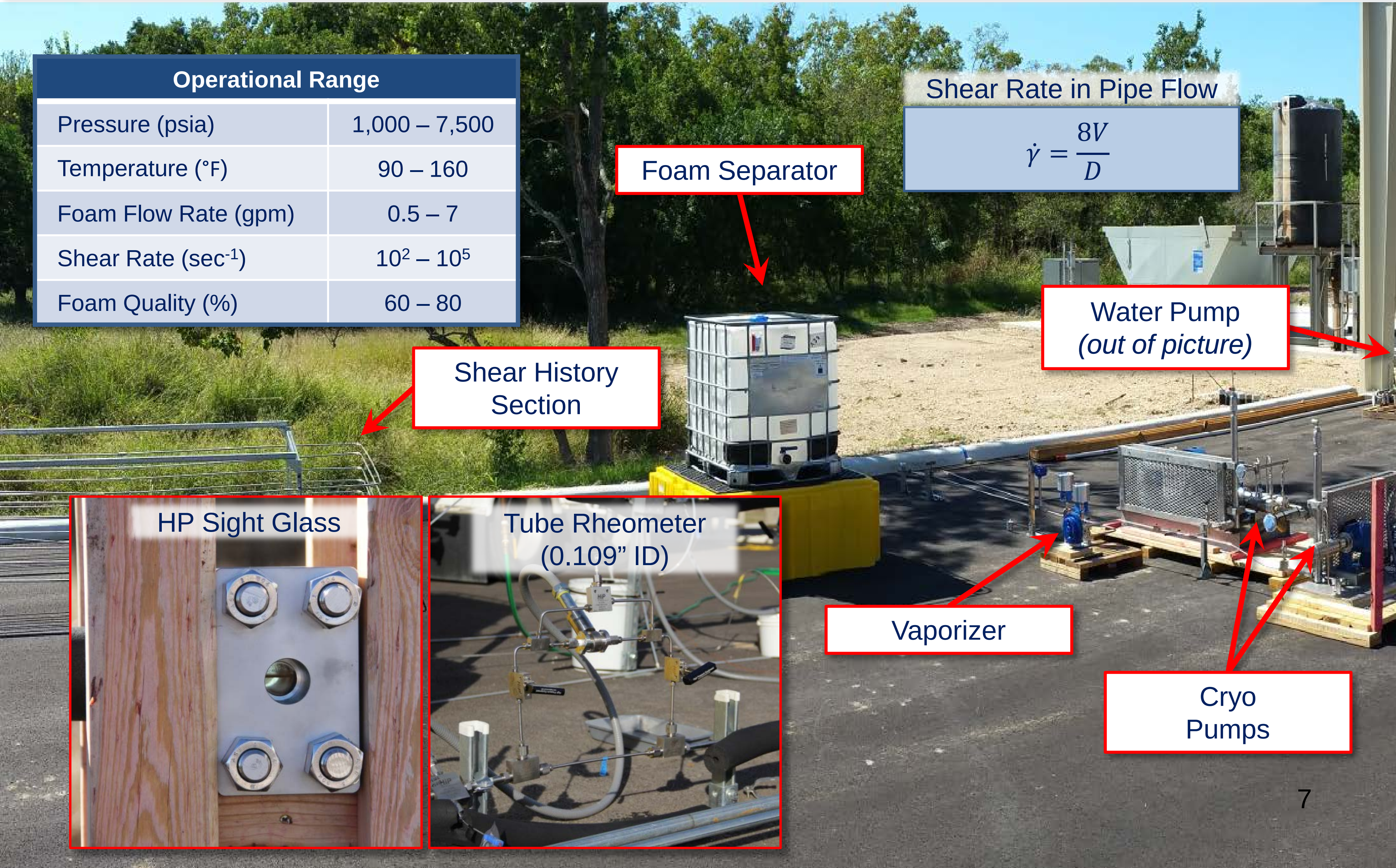
P&ID of BP2 Pilot Scale Test Facility

The pilot scale test loop was constructed at SwRI's facilities in San Antonio

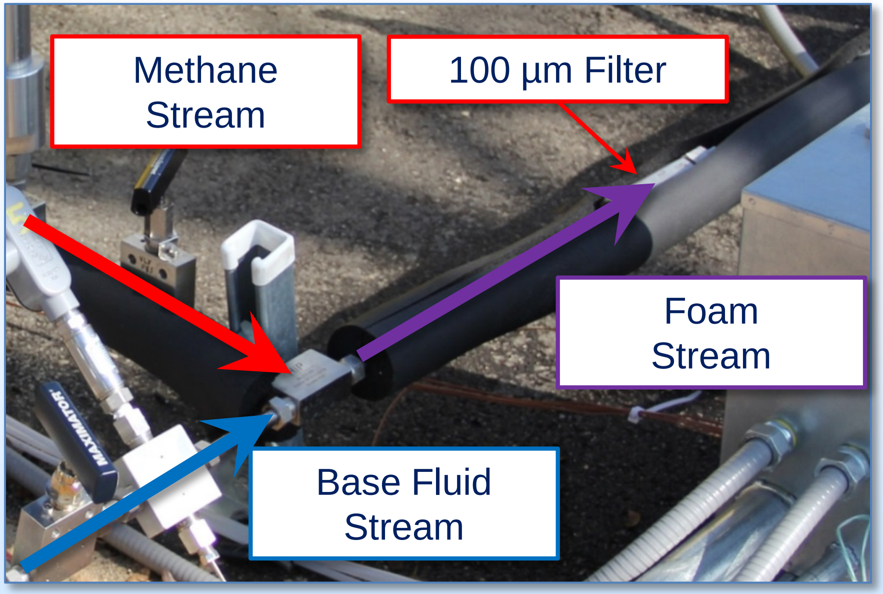
Operational Range	
Pressure (psia)	1,000 – 7,500
Temperature (°F)	90 – 160
Foam Flow Rate (gpm)	0.5 – 7
Shear Rate (sec^{-1})	10^2 – 10^5
Foam Quality (%)	60 – 80

Shear Rate in Pipe Flow

$$\dot{\gamma} = \frac{8V}{D}$$

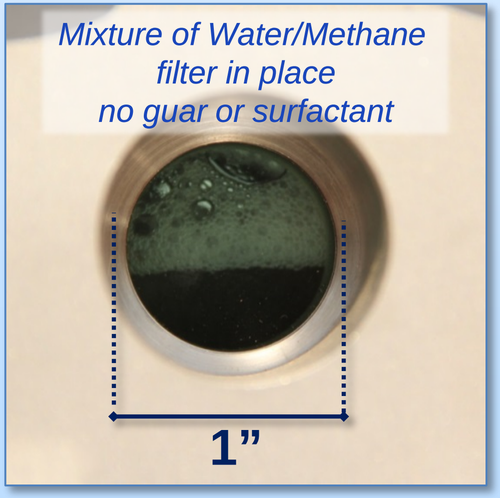


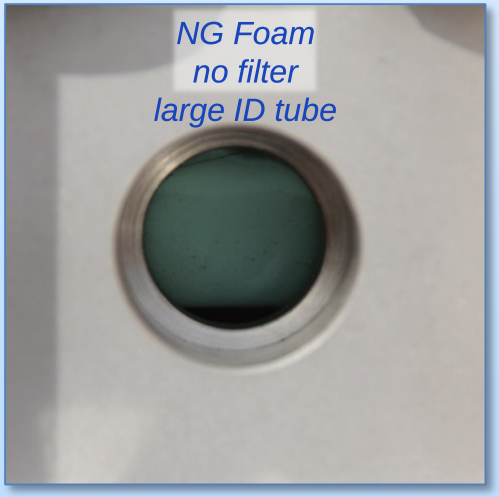
Two mixing methods yield observable differences in mixture quality



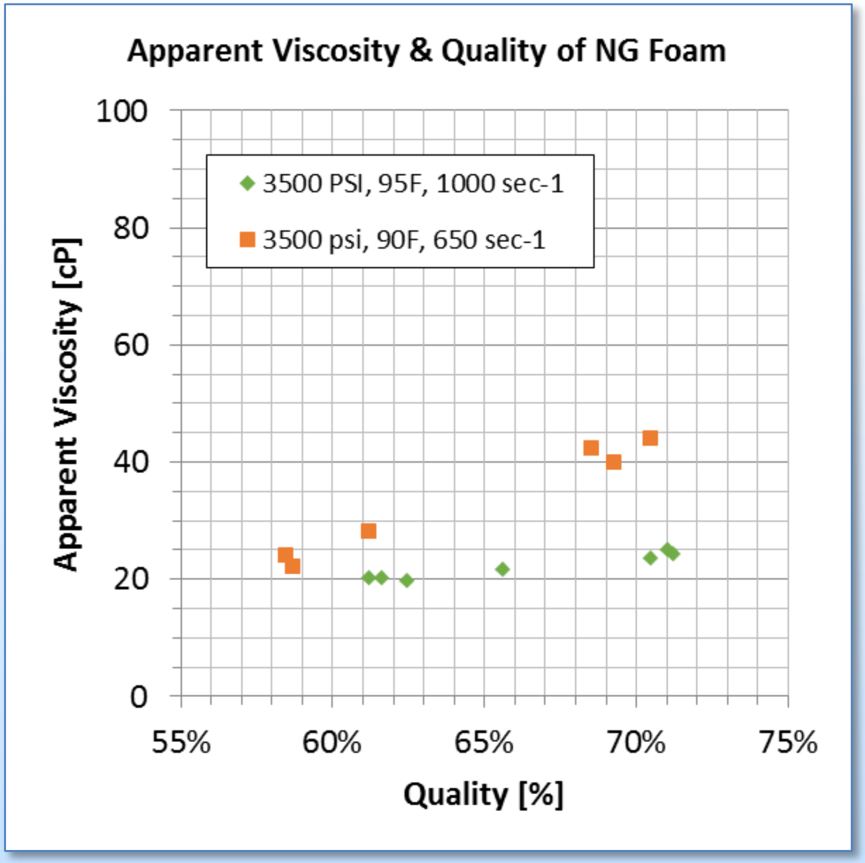
- Two mixing methods:
  - Simple tee
  - 100 µm filter downstream of tee

- Stable foam was generated up to 4750 psia.
- 100 µm filter appears to promote a better mixture.
- More work is needed to investigate foam mixing and stability.





The measured rheology data indicate that NG foam is qualitatively similar to other foams



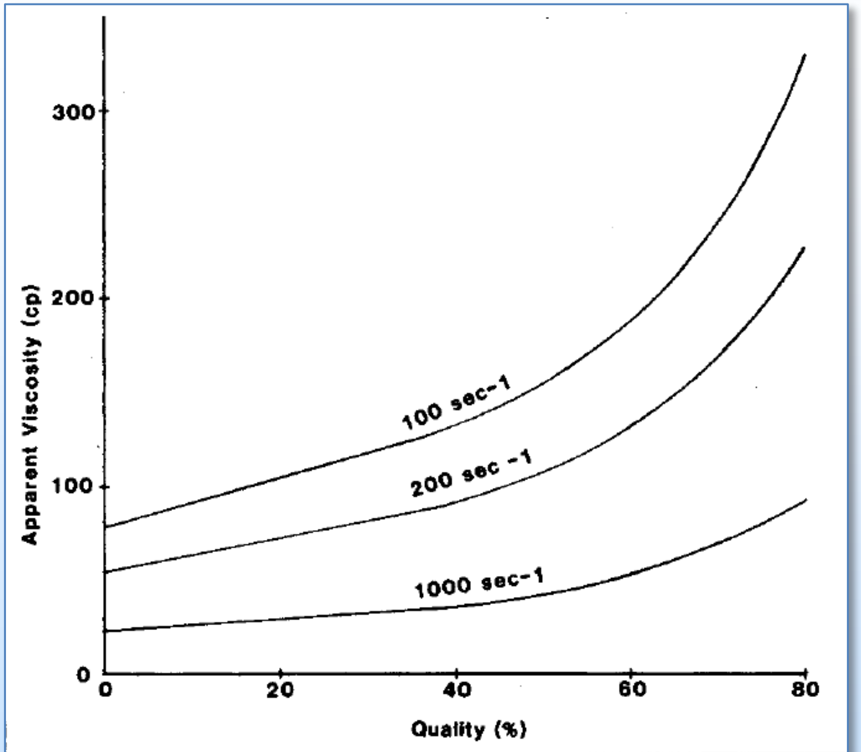
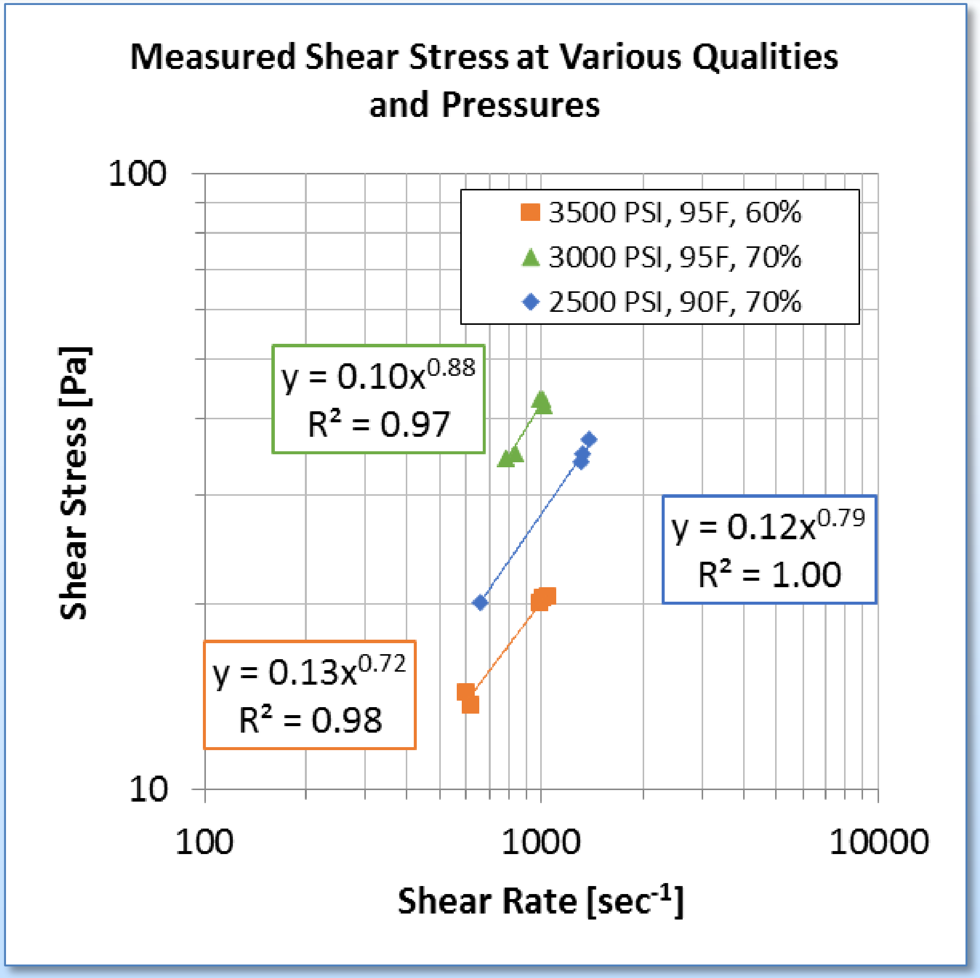


Fig. 9—Apparent viscosity of 40 lbm HPG/1,000 gal water foamed with N_2.

- Values of pressure, temperature, and shear rate on plots represent a range.
- Apparent viscosity increases with foam quality.
- Apparent viscosity decreases with shear rate (shear thinning).

5. **Reidenbach V.G., et al.,** "Rheological Study of Foam Fracturing Fluids Using Nitrogen and Carbon Dioxide," *SPE Production Engineering*, **1** (1) pp. 31-41, (Jan. 1986).

NG foams appear to share other similarities to published data



- Foam rheology in laminar regime often described as either a *Herschel-Bulkley*[5] or a *power law* fluid.[6-8]
- Based on limited data, it seems reasonable to describe NG foam as a power law fluid.
- More definitive models and/or correlations will require a larger experimental data set.

Herschel-Bulkley

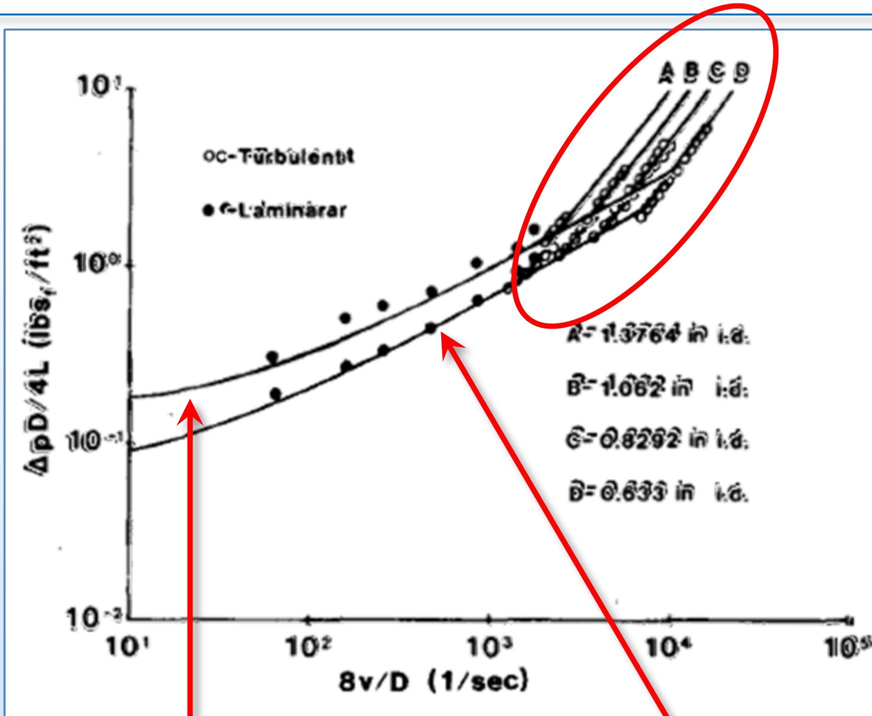
$$\tau = \tau_0 + K\dot{\gamma}^n$$

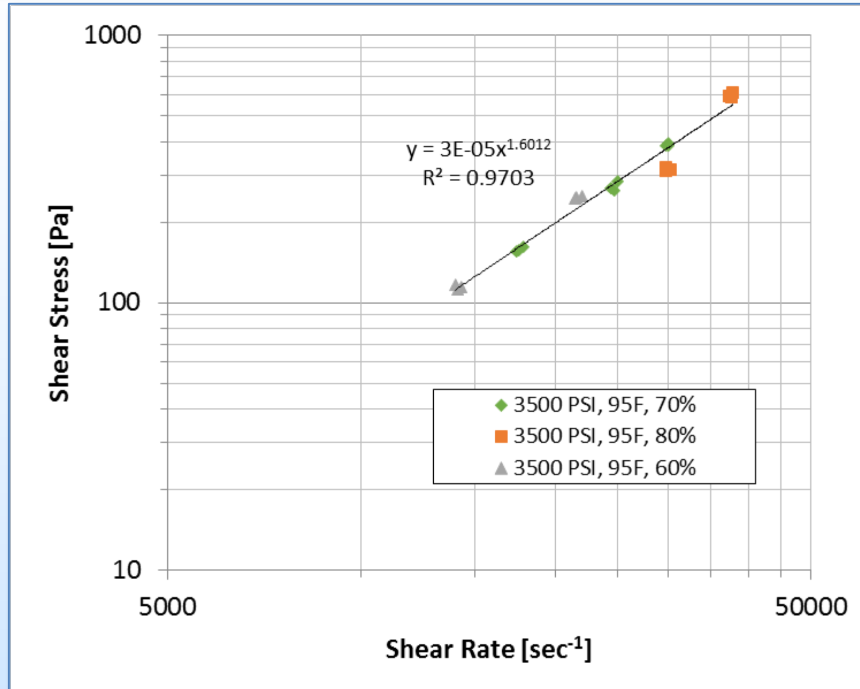
Power Law

$$\tau = K\dot{\gamma}^n$$

5. **Reidenbach V.G., et al.,** "Rheological Study of Foam Fracturing Fluids Using Nitrogen and Carbon Dioxide," *SPE Production Engineering*, **1** (1) pp. 31-41, (Jan. 1986).
6. **Wendorff, C.L. and Earl, R.B.,** "Foam Fracturing Laboratory," presented at the 58th Annual Technical Conference and Exhibition, San Francisco, CA, (Oct. 5-8, 1983)
7. **Cawiezel, K.E. and Niles, T. D.,** "Rheological Properties of Foam Fracturing Fluids Under Downhole Conditions," presented at the SPE Production Operations Symposium, Oklahoma City, OK (Mar. 8-10,1987)
8. **Hutchins, R.D., et al.,** "A Circulating Foam Loop for Evaluating Foam at Conditions of Use," presented at the SPE International Symposium on Oilfield Chemistry, Houston, TX (Feb. 5-7, 2003)

Data collected at higher shear rates appears to be in the turbulent flow regime





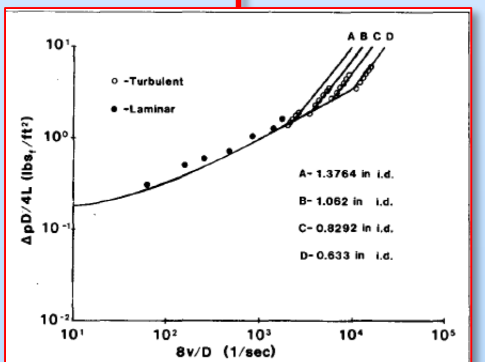


Fig. 14—70-quality 20 lbm-HPG/1,000-gal water foam data with mathematical model.

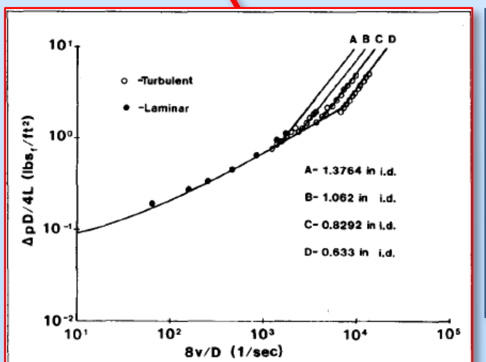
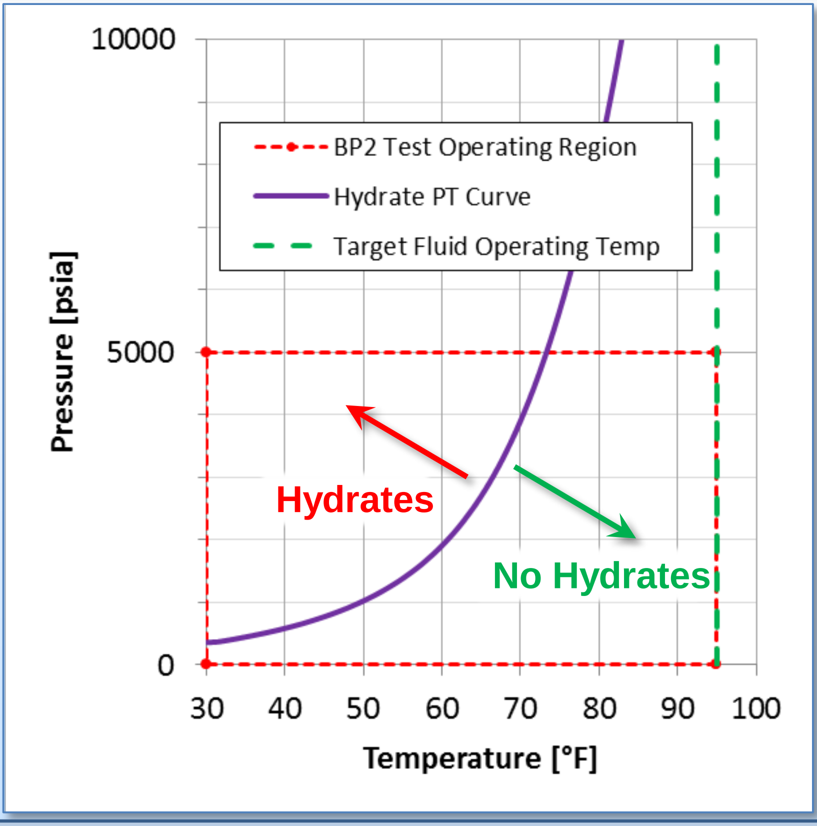


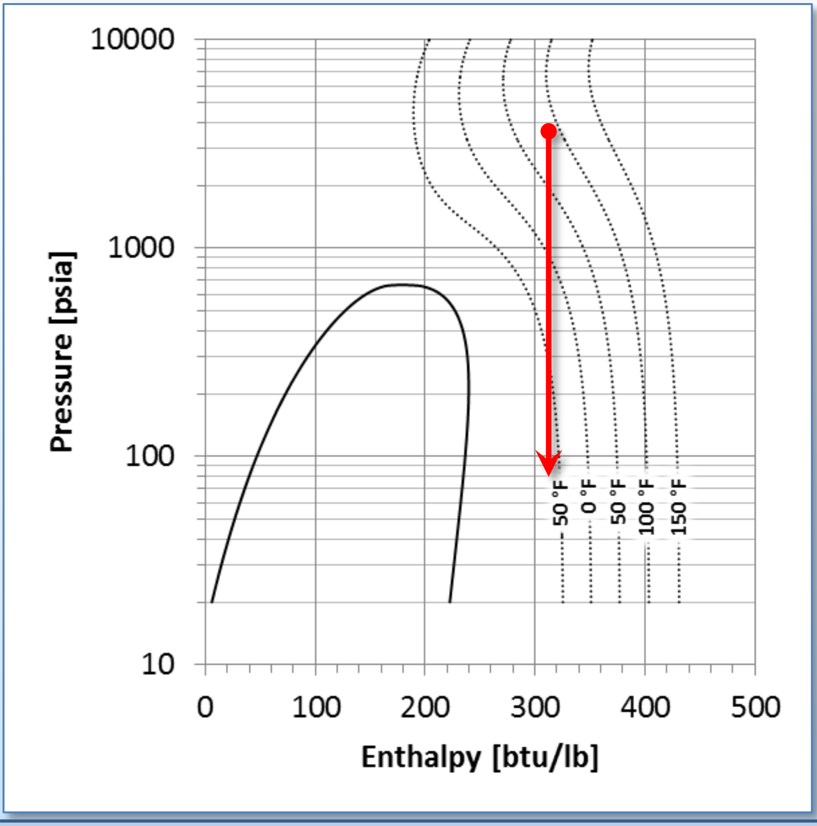
Fig. 13—60-quality 20 lbm-HPG/1,000-gal water foam data with mathematical model.

- Published data[5] (N_2 foam data shown) indicate that, for a given tube size, the data all collapse to a single curve regardless of quality in the **turbulent regime**.
- A similar trend is observed from the small tube data.

5. **Reidenbach V.G., et al.,** "Rheological Study of Foam Fracturing Fluids Using Nitrogen and Carbon Dioxide," *SPE Production Engineering*, **1** (1) pp. 31-41, (Jan. 1986).

Key operational issues were identified during testing





- Hydrate formation suspected to have clogged dP sensing lines during some tests
- dP sensor provided an erroneous reading
- Measurement coincided with operation during cold ambient conditions

- Ice formation suspected to have clogged main flow lines
- Expansion of NG can result in significant cooling
- Consideration must be taken to prevent ice formation for all process conditions including process upsets

Several accomplishments have been made and additional tasks are planned for the future

Year 1 – System Design and Optimization	
Brainstorm different paths for processing natural gas	Complete
Identify top process (based on thermodynamics and cost/availability)	Complete
Design lab scale test set-up	Complete
Investigate the rheological properties of natural gas foams	Complete
Year 2 – Lab Scale Testing	
Procure equipment for test system	Complete
Construct test system	Complete
Commission test system	Complete
Complete Testing and analysis of data	Complete
Evaluate lab scale testing and identify successes and areas for improvement	Complete
Year 3 – Expanded Lab Scale Testing	
Modify test facility	In progress
Evaluate additional base fluid chemistries	In progress
Complete testing and data analysis	2017-2018
Estimate cost for a large scale field demonstration	2017-2018

There are opportunities for collaboration between projects

Foam/Fracture Fluid Test Stand

- Lab-scale test stand can be used to investigate a variety of foams and other fracturing fluids **at field** conditions.
- Current and future investigations can utilize the facility at SwRI

Enhanced Oil Recovery (EOR)

- Use of natural gas as a fracturing fluid could enhance recovery
- Present and future research of enhanced recovery using natural gas can be leveraged to improve the NG foam fracturing methods investigated by the current project

Foam Fluid Data

- Limited NG foam rheology data published
- Foam rheology results from current work can be used in multiple simulation codes

At the conclusion of BP2, the test goals were achieved and several important insights were gained

Key Findings from Year 2

- Pilot scale facility was designed, built, and operated.
- Stable NG foam was generated at 4750 psi using a commercially available viscosifier and surfactant.
- Two mixing methods were explored and key differences were observed.
- NG foam is qualitatively similar to other foams.
  - Shear thinning, power law fluid
  - Increased viscosity with foam quality
  - Laminar and turbulent regimes
- Transient pressure data was generated.
- Key operational issues identified.
  - With NG, hydrate formation can occur
  - Considerations must be taken to prevent ice formation

Focus of Year 3 Efforts

- Modify the existing pilot scale facility to enhance measurement capability.
- Evaluate additional base fluid chemistries for compatibility with NG foam.
- Generate a larger experimental data set to fully characterize NG foam rheology.
- Identify appropriate foam mixing methods to deploy on a field scale.

Future Work

- Additional laboratory investigations
  - Fracture network evaluation test
  - Permeability evaluation in core samples
  - Speed of sound measurement for foam compressibility
  - Evaluation of enhanced oil and gas production from certain reservoirs
- Field demonstrations of technology

Questions?

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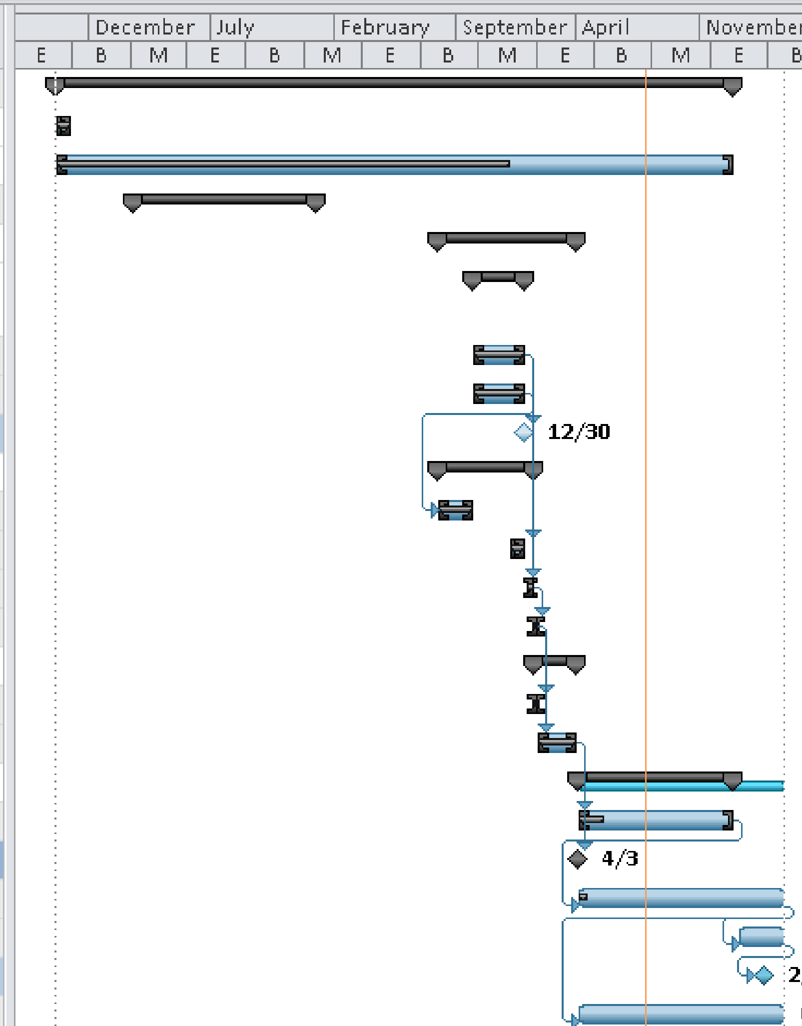
Appendix

Project Organization

SwRI	Schlumberger
PI Griffin Beck	**PI** Dr. Sandeep Verma (SDR)
Co-PI Dr. Klaus Brun & Kevin Hoopes	**PM** Alhad Phatak
Engineering Support Craig Nolen & Charles Krouse	**Engineering Support** Terrence Goettsch
Contracts Robin Rutledge	**Engineering Consultation** Dr. John Brisson (MIT)

Project Schedule

	Task No.	Task Name
1	**1.0**	**Project Management and Planning**
2	1.1	Revise project management plan
3	1.2	Coordination of particpants
4	**2.0**	**BP1 - Optimization and Design**
24	**3.0**	**BP2 - Reduced scale system construction and testing**
25	**3.1**	**Reduced scale system equipment procurement, construction, and calibration**
26	3.1.1	General
27	3.1.2	Safety
28		**Milestone D - Compressor/Pump Train Set-up Complete**
29	**3.2**	**Commissioning**
30	3.2.1	Operation procedure development
31	3.2.1a	Start-up testing
32	3.2.1b	Process tuning
33	3.3	Testing
34	**3.4**	**Data analysis**
35	3.4.1	Data collection
36	3.4.2	Data reduction
37	**4.0**	**BP3 - Continued Rheology tests**
38	4.1	Update test facility
39		**Milestone E - Test Facility Modifications Complete**
40	4.2	Natural gas foam rheology test matrix and testing
41	4.3	Evaluate mixing methods
42		**Milestone F - Test Data Acquired and Analyzed**
43	4.4	Industrial scale cost study



Bibliography

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4. **Beck, G., et. al.,** *"Development and Evaluation of a Mobile Plant to Prepare Natural Gas for Use in Foam Fracturing Treatments," presented at the 2017 ASME Turbo Expo, Charlotte, NC (June 26-30, 2017).*

References

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9. ***Nolen-Hoeksema, R.,*** *"Elements of Hydraulic Fracturing," Oilfield Review, 25 (2) pp. 51-52, (2013)*