Quarterly Research Performance Progress Report

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Prime Recipient type	Not for profit organization
Project Title	**Development and Field Testing Novel Natural Gas Surface Process Equipment for Replacement of Water as Primary Hydraulic Fracturing Fluid**
Principal Investigator(s)	Griffin Beck and Kevin Hoopes – *SwRI* **Subcontractor and Co-Funding Partner**: Sandeep Verma, Ph.D. – *Schlumberger*
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1 INTRODUCTION

Southwest Research Institute® (SwRI®) and Schlumberger Technology Corporation (SLB) are working to jointly develop a novel, optimized, and lightweight modular process for natural gas (NG) to replace water as a low-cost fracturing medium with a low environmental impact. Hydraulic fracturing is used to increase oil and NG production by injecting high-pressure fluid, primarily water, into a rock formation, which fractures the rock and releases trapped oil and NG. This method was developed to increase yield and make feasible production areas that would not otherwise be viable for large-scale oil and NG extraction using traditional drilling technologies.

Since the fracturing fluid is composed of approximately 90% water, one of the principal drawbacks to hydraulic fracturing is its excessive water use and associated large environmental footprint. According to recent data, fracturing applications in North America can consume as much as 11 million gallons of water per well [1]. During the fracturing process, some of the fracturing fluid is permanently lost and the portion that is recovered is contaminated by both fracturing chemicals and dissolved solids from the formation. The recovered water or flow-back represents a significant environmental challenge, as it must be treated before it can be reintroduced into the natural water system. Although there is some recycling for future fracturing, the majority of the flow-back water is hauled from the well site to a treatment facility or to an injection well for permanent underground disposal.

To mitigate these issues, an optimized, lightweight and modular surface process using NG to replace water is being developed as a cost-effective and environmentally clean fracturing fluid. Using NG will result in a near-zero consumption process since the gas that is injected as a fracturing fluid will be mixed with the formation gas and extracted as if it were from the formation itself. This eliminates the collection, waste, and treatment of large amounts of water and reduces the environmental impact of transporting and storing the fracturing fluid.

There are two major steps involved in utilizing NG as the primary fracturing medium: (1) increasing the supply pressure of NG to wellhead pressures suitable for fracturing and (2) mixing the required chemicals and proppant needed for the fracturing process at these elevated pressures. The second step (NG-proppant mixing at elevated pressures) still requires technology advancements but has previously been demonstrated in the field with other gases such as nitrogen (N_2) and carbon dioxide (CO_2). However, the first step (a compact, on-site unit for generating high-pressure NG at costs feasible for fracturing) has not been developed and is currently not commercially available. The inherent compressibility of NG results in significantly more energy being required to compress the gas than is required for pumping water or other incompressible liquids to the very high-pressure required for downhole injection. This project aims to develop a novel, hybrid method to overcome this challenge.

The project work is being performed in three sequential phases. The first phase included a thorough thermodynamic, economic, and environmental analysis of potential process concepts, as well as detailed design of three, top-performing processes. The work completed in the first phase allowed the selected thermodynamic pathway of direct compression to be optimized for the intended application. In the second phase, a pilot-scale facility was constructed at the SwRI facilities in San Antonio, TX. The pilot-scale facility was used to generate NG foam at elevated pressures similar to those found in a field application. The facility was used to investigate various properties of NG; such data are not available in the literature. In the third, the pilot-scale facility will be used to further explore the feasibility of this novel technology and will provide a more substantial data set that can be used to implement the technology in the field.

The first budget period (BP1) for this project was completed in December 2015. Work from this first effort demonstrated that the use of a direct-compression system for fracturing is commercially viable and has economic potential. Work for the second budget period (BP2) was completed on March 31, 2017, and included pilot-scale investigations that demonstrated that stable NG foam can be generated at elevated pressures.

This report covers work completed in the seventh quarter of the third budget period (BP3). The project goals and accomplishments related to those goals are discussed. Details related to any products developed in the quarter are outlined. Information on the project participants and collaborative organizations is listed and the impact of the work done during this quarter is reviewed. Any issues related to the project are outlined and, lastly, the current budget is reviewed.

2 ACCOMPLISHMENTS

2.1 *Project Goals*

The primary objective of this project is to develop and test a novel approach to use readily available wellhead (produced) NG as the primary fracturing fluid. This includes development, validation, and demonstration of affordable non-water-based and non-CO_2-based stimulation technologies, which can be used instead of, or in conjunction with, water-based hydraulic fracturing fluids to reduce water usage and the volume of flow-back fluids. The process will use NG at wellhead supply conditions and produce a fluid at conditions suitable for injection.

The project work is split into three budget periods. The milestones for each budget period are outlined in Table 6-1. This table includes an update on the status of each milestone in relation to the initial project plan. Explanations for deviations from the initial project plan are included.

2.2 *Accomplishments*

In the past quarter, project activities only focused on providing the necessary documentation to proceed with additional project phases. Technical work related to the project was delayed until the additional project phases were initiated.

2.3 *Opportunities for Training and Professional Development*

No opportunities for training and professional development occurred during this last quarter.

2.4 *Dissemination of Results to Communities of Interest*

No publications or presentations were released in the past quarter.

2.5 *Plan for Next Quarter*

In the next quarter, the budget period 4 work will begin

Summary of tasks for next quarter

- Kick-off meeting between SwRI, SLB, and Chevron
- Kick-off presentation to DOE NETL (via telecon)
- Begin literature reviews to identify:
  - Relevant reservoir operating temperatures
  - Relevant natural gas compositions
  - Effects of temperature and water quality on N_2 and CO_2 foam stability
- Begin design of pilot-scale facility upgrades to operate with natural gas foam at an elevated temperature

3 PRODUCTS

With any technical work, results will be documented and reported to the appropriate entities. In addition, the work may produce new technology or intellectual property. This section provides a summary of how the technical results of this project have been disseminated and lists any new technology or intellectual property that has been produced.

3.1 *Publications*

No publications were submitted during the past quarter

3.2 *Technologies or Techniques*

No new techniques or technologies have been developed in the last quarter.

3.3 *Intellectual Property*

No intellectual property, such as patents or inventions, has been submitted or developed in the last quarter.

4 PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

The work required to develop the high-pressure NG processing system for fracturing requires the technical knowledge and effort of many individuals. In addition, two organizations, SwRI and SLB, are collaborating to complete the work. This section provides a summary of the specific individuals and organizations who have contributed in the last quarter.

4.1 *SwRI – Prime Contractor*

The following list provides the name of the Principal Investigator (PI) and each person who has worked at least one person-month per year (160 hours of effort) in the last quarter.

- Griffin Beck
    - Project role: PI
    - Nearest person-month worked: 0.0
    - Contribution to project: BP3 test design, commissioning, and project management
    - Funding support: DOE
    - Collaborated with individual(s) in foreign country(ies): No
    - Country(ies) of foreign collaborator(s): None
    - Traveled to a foreign country(ies): Yes, Mexico
    - If traveled to a foreign country(ies), duration of stay: 5 days

4.2 *Other Organizations*

In this project, SwRI is collaborating with SLB. SLB is a subcontractor and cost-share supporter for this project. More information about their participation is listed below.

- SLB
    - Location of organization: United States
    - Partner’s contribution to the project: Analysis and design support
    - Financial support: N/A
    - In-kind support: Labor hours in the third budget period
    - Facilities: N/A
    - Collaborative research: SLB staff supported the testing tasks for the third budget period
    - Personnel exchanges: N/A

5 IMPACT

The use of NG foam is expected to have a smaller environmental footprint and may enhance gas and oil recovery compared to traditional, water-based fluids. Despite these potential benefits, fracturing with NG foams has not been widely adopted due in part to limited fluid property data. The BP2 tests have provided much-needed information to industry to advance fracturing with NG foams.

As noted in previous reports, past research efforts by others have investigated the rheological properties of foams generated with nonflammable gases, namely nitrogen and carbon dioxide. However, published literature is not available for the rheological properties of NG foam. The data generated by the BP2 tests provided the first set of publically available NG foam rheology data. The BP3 tests have provided additional rheology data needed by the oil and gas industry. These data will be critical in future design work, particularly in understanding the impact of the gas compression machinery.

6 CHANGES/PROBLEMS

In the past quarter, an additional *no-cost time extension* (NCTE) was added to extend the project end date to December 31, 2018. The primary reason for the delay is to permit additional time to finalize the details of future project work awarded by DOE. The updated dates and milestones reflecting these changes are documented below and in Table 6-1.

- Milestone G – Test Data Acquired and Analyzed
  - Original Milestone G Completion Date: March 31, 2018
  - New Milestone G Completion Date: December 31, 2018

Table 6-1. Summary of Milestone Completion Status

Budget Period	Milestone Letter	Milestone Title/Description	Planned Completion Date	Actual Completion Date	Verification Method	Comments (Progress towards achieving milestone, explanation of deviations from plan, etc.)
1	A	Top 2 to 3 Thermodynamic Cycles Identified	January 2, 2015 **New: June 9, 2015**	Complete June 9, 2015	At least two combinations of thermodynamic paths and sets of equipment have been identified as being capable of accomplishing natural gas compression from approximately 200-1,000 psi inlet to 10,000 psi outlet.	Completion of this milestone has been delayed by execution of full contract. Actual completion date was June 9, 2015.
	B	Top Thermodynamic Cycle Identified	May 1, 2015 **New: September 30, 2015**	Complete September 30, 2015	At least one combination of thermodynamic paths and sets of equipment has been identified as being capable of accomplishing natural gas compression from approximately 200-1,000 psi inlet to 10,000 psi outlet in an economically feasible fashion. This is considered a critical path milestone.	Start of this work was delayed due to delay in execution of full contract. Actual completion date was September 30, 2015.
	C	Finalized Detailed Design	September 30, 2015 **New: December 31, 2015**	Complete, December 31, 2015	A laboratory-scale compression/pump test train will be designed to accomplish natural gas compression from approximately 200-1000 psi inlet to 10,000 psi outlet in an economically feasible fashion. This is considered a critical path milestone.	With the delay in execution of the full contract, this milestone was completed on December 31, 2015.
2	D	Compressor/Pump Train Set-up Complete	March 17, 2016 **New: December 30, 2016**	Complete, December 30, 2016	The laboratory-scale compression/pump test train will be assembled/constructed. This is considered a critical path milestone.	Due to a delay in contract execution, delays with component deliveries, and delays related to comissioning, the construction was completed Dec. 30, 2016.
	E	Test Data Acquired and Analyzed	September 30, 2016 **New: March 31, 2017**	Complete, March 31, 2017	Measured data will confirm that the laboratory-scale compression/pump test train is able to accomplish natural gas compression from approximately 200-1000 psi inlet to 10,000 psi outlet in an economically feasible, compact, and portable fashion. This is considered a critical path milestone.	With the delayed completion of the test stand, testing and data analysis was completed March 31, 2017.
3	F	Test Facility Modifications Complete	October 31, 2017 **New: March 31, 2018**	Complete March 30, 2018	Modifications to the BP2 test stand are complete and the test matrix has been generated.	The test stand modifications were completed on March 30, 2018.
	G	Test Data Acquired and Analyzed	3/31/2018 **New: December 31, 2018**	Complete December 31, 2018	Measured data will provide detailed information about the rheology properties of NG foam.	Initial data processing is complete. Further processing will occurr as needed.

7 BUDGETARY INFORMATION

A summary of the budgetary data for the project is provided in Table 7-1. This table shows the initial planned cost, the actual incurred costs, and the variance for the current budget period. The costs are split between the Federal and Non-Federal share.

In the seventh quarter of BP3, $234.21 was spent. This value reflects essentially no project activities occurring while the additional project funds and the required documentation were finalized. A baseline cost plan for the entirety of BP3 is included in the table to reflect the planned activities.

Table 7-1. Budgetary Information for Period 7

Baseline Reporting Quarter	Budget Period 3							
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Cumulative Total
	4/1/2017 - 7/07/2017	7/8/2016 - 9/29/2017	9/30/2017 - 1/5/2018	1/6/2018 - 3/30/2018	3/31/2018 - 7/6/2018	7/7/2018- 9/28/2018	9/29/2018- 1/4/2019	
Baseline Cost Plan	$13,064	$254,225	$163,039	$86,168	$72,053	$0	$0	$588,548
Federal Share	$13,064	$223,620	$132,434	$55,563	$41,448	$0	$0	$466,129
Non-Federal Share	$0	$30,605	$30,605	$30,605	$30,605	$0	$0	$122,419
Total Planned	$13,064	$254,225	$163,039	$86,168	$72,053	$0	$0	$588,548
Actual Incurred Cost	$5,686	$21,953	$206,202	$128,235	$169,570	$10,484	$234	$542,130
Federal Share	$5,686	$21,953	$158,920	$128,235	$115,175	$10,484	$234	$440,453
Non-Federal Share	$0	$0	$47,282	$0	$54,395	$0	$0	$101,677
Total Incurred Costs	$5,686	$21,953	$206,202	$128,235	$169,570	$10,484	$234	$542,130
Variance	$7,378	$232,272	($43,163)	($42,067)	($97,517)	($10,484)	($234)	$46,418
Federal Share	$7,378	$201,667	($26,486)	($72,672)	($73,727)	($10,484)	($234)	$25,676
Non-Federal Share	$0	$30,605	($16,677)	$30,605	($23,790)	$0	$0	$20,742
Total Variance	$7,378	$232,272	($43,163)	($42,067)	($97,517)	($10,484)	($234)	$46,418

8 REFERENCES

[1] 2016, *Trends in U.S. Oil and Natural Gas Upstream Costs*, U.S. Energy Information Administration.