Progress Report

DE-SC0015766: Development and Testing of Advanced Inter-well and Inter-Stage Pressure Pulse Analysis for Fracture Diagnostics

Accomplishments

1. What are the major goals of the project?

The objective of this Phase II project is to develop and demonstrate with field data a more accurate and cost-effective technique to estimate fracture height, length, and orientation than currently available technology. First, we will perform detailed numerical modeling studies of pulse testing for a multi-stage fracture system in horizontal wells for a range of fracture geometries and formation characteristics. Then we will apply the inversion technique to several real-world application examples to demonstrate its validity for characterizing multi-stage fractures. Field testing and collecting pressure pulse test data for both single-fracture and multi-fracture systems from a horizontal well will also be conducted. Finally, we will compare the numerical results with field test data to demonstrate and validate the fracture characterization technique.

At the conclusion of the research funded by this DOE grant, GeoMechanics Technologies will have accomplished the following goals:

- Perform detailed numerical modeling studies of pulse testing for a multi-stage fracture system in horizontal wells for a range of fracture geometries and formation characteristics;
- Demonstrate inversion techniques to characterize the multi-stage fracture system and apply the inversion techniques with several real-world application examples;
- Perform field testing and collect pressure pulse test data for both single-fracture and multi-fracture systems from a horizontal well; and
- Compare the numerical results with field test data to demonstrate and validate the fracture characterization technique.

To maintain productivity and establish accountability, four major milestones were scheduled throughout this Phase II project. A major goal during year one of this project involved the completion and submission of the first Milestone Report. The Milestone 1 Report involved a summary of findings and results from Task 2: Detailed numerical modeling studies of multi-stage fracture systems for a range of fracture geometry and formation characteristics. In particular, this report summarized the development of the geomechanical and fluid flow models as well as the numerical techniques to determine fracture properties. This milestone report was submitted to our project manager, Mr. David Cercone at the end of March 2018.

Milestone 2 is represented as a Go-No Go Decision Point Report and was scheduled at the end of year one. The criteria for the Go-No Go decision point is described below:

1. Results from numerical modeling show that the pressure pulse from observation locations can be detected and analyzed within a reasonable and practical distance to injection locations.
2. The inversion technique developed is capable of characterizing the multi-stage fracture system.

Milestone 2 Report was submitted in August 2018 to our DOE project manager and we were approved for continued research funding.

Milestone 3 Report is scheduled to be submitted at the end of month 19 (March 2019) and will summarize the findings of Task 4: Field test and data collection. The pulse testing design, the pulse testing supervision, and the data collection will be summarized in the Milestone 3 Report.

A Milestone 4 Report is scheduled to be submitted at the end of month 23 and will include a summary of Task 5: Comparison of Numerical Results with Field Test Data. A final project report will be provided at the project completion.

2. What was accomplished under these goals?

The following accomplishments have been divided and summarized by task:

Task 1 – Project Management and Planning

Major Activities:

GeoMechanics Technologies has conducted weekly project meetings with the PI and the senior and staff geological and engineering team to update progress on field data acquisition and model development.

Specific Objectives:

The PI, Dr. Michael Bruno, provides overall management and direction to the GeoMechanics team. The Senior Engineers work closely and provide direct supervision to the Staff Geologists and Engineers to maintain project development. We have continued communication with our DOE Project Manager and provided him with the first two milestone reports. We will submit the remainder of the milestone reports at their scheduled due dates and a final report at the end of the project.

Significant Results:

We submitted our first and second milestone reports to the DOE PM.

Key Outcomes: None to report.

What we expect to accomplish during the next period:

We will continue weekly meetings to ensure work is on track and within budget.

Task 2 – Detailed numerical modeling studies of multi-stage fracture system for a range fracture geometry and formation characteristics

Major Activities:

This task was completed during the previous Progress Reporting Period and summarized in the progress report submitted at the end of May 2018.

Specific Objectives: N/A

Significant results: N/A

Key Outcomes: N/A

What we expect to accomplish during the next period: N/A

Task 3 – Inversion Techniques Development for Multi-Stage Fracture

Major Activities:

1) An inversion technique was developed for fracture geometry characterization.
2) Demonstration and validation of the inversion technique with numerical simulation data from an injection test was performed to characterize the fracture geometry.
3) Injection test sensitivity analyses were numerically performed involving variations in reservoir permeability.
4) To further validate the capability of the inversion technique for variations in reservoir permeability, we also performed the production test to characterize the fracture geometry.

Specific Objectives:

The objectives of this task include (1) Developing an inversion technique to characterize the fracture geometry and (2) Developing a numerical model for a multi-fracture system with zipper frac completion to demonstrate the efficiency of the inversion technique for fracture characterization.

Significant results:

The demonstration results of the inversion technique using the numerical simulation data shows that the inversion technique developed is capable of characterizing the multi-stage fracture system. The pressure response from pulse testing at different monitoring locations in an offset well were estimated for a range of fracture geometry for a reservoir with a zipper frac completion. The results suggest that the difference in pressure behavior at the same monitoring

location can be identified for different fracture geometries. The fracture length, height, and orientation can be effectively predicted by the inversion technique.

From the injection test sensitivity analyses, the results suggest that, for a reservoir with permeability as low as 0.1 md, the inversion technique is applicable as the pressure change can be detected within a reasonable distance and timeframe. However, for a reservoir with permeability as low as 0.01 md and with the absence of natural fractures to enhance fluid flow, it takes longer (~2 days) for the pressure to propagate to monitoring points, therefore the inversion technique may be less effective in such very tight reservoirs. A high-resolution pressure sensor is recommended for tight formations for more accurate fracture characterization results.

Key Outcomes:

The development and demonstration of the inversion technique modeling studies of charactering the multi-stage fracture system have been performed in Task 3 and the goals for this task have been met.

What we expect to accomplish during the next period:

This task was completed.

Task 4 – Field Test and Data Collection

Major Activities:

1) To prepare for Task 4 field test, we performed a review and documented the major existing hydraulic fracture operations throughout the United States to determine likely operators and collaborations for field testing demonstrations.
2) We obtained an agreement with operator SM Energy to collaborate in this Phase II field test.
3) We reviewed and processed the field data including geology data, log data, and existing hydraulic operating data from SM Energy, which currently operates in the Eagle Ford shale.
4) Geomechanical rock property analyses were performed based on log data.
5) We developed the geology model for the field, which will be used as the base input for fluid and geomechanical modeling to characterize the fracture geometry.
6) The geomechanical models for the field were developed to perform numerical simulations, which take into account the stress shadowing effect and coupling with fluid flow during the hydraulic fracture.

7) Based on available hydraulic fracture operation data, we performed the hydraulic fracture history match to characterize the fracture geometry, and a reasonable history match of the pressure data during hydraulic fracturing was achieved.
8) The field pulse testing procedure was designed based on specific field conditions.

Specific Objectives:

The specific objectives of Task 4 include performing field testing and pulse test data collection for both single and multi-fractures.

Significant results:

We have finished summarizing the ten main hydraulic fracture plays in the United States. A complete description of the top ten plays were included and submitted in the second milestone report. We have collected and processed existing field data to analyze the rock properties, develop the geology and geomechanical models. Based on existing hydraulic fracture operation data, a reasonable history match of the pressure data was obtained. From the numerical history match results, the preliminary fracture geometry was characterized. The pressure pulse field testing procedure was designed for the specific field conditions.

Key Outcomes:

The preparation of the field testing was completed, and the pressure pulse testing procedure was designed based on specific field conditions. The preliminary fracture characterization based on existing hydraulic fracturing was also performed. The outcome of these results will lead us to complete this task in a timely manner.

What we expect to accomplish during the next period:

During the next few months, we will continue field testing. Once we get approval from SM Energy for the field test design, we will perform the field testing and provide supervision of data collection.

Task 5 – Comparison Numerical Results with Field Test Data

Major Activities:

This task will start in March 2019, however, we already initiated this task while working with Task 4. We prepared the geology and geomechanical models for the field site for further numerical simulations.

Specific Objectives:
The objectives of this task is to perform the fracture characterization based on the field data, and compare with the numerical results.

Significant results:

The geology and geomechanical models were developed for the field testing site. A reasonable history match result was obtained based on existing hydraulic fracture operation data. And the preliminary fracture geometry was characterized for the zipper frac completion wells.

Key Outcomes:

The preparation for the field numerical modeling and field test has been completed.

What we expect to accomplish during the next period:

For the next few months, we will continue to perform this task to characterize the fracture geometry with existing hydraulic fracture operation data, as well as with the planned field pulse testing data.

Task 6 – Reports, Documentation and Technology Transfer

Major Activities: We prepared and submitted the first and second milestone reports as well as the Go-No-Go Decision Report.

Specific Objectives: The objectives of this task involve reporting, documenting, and any activities involved with technology transfer.

Significant results: We prepared a full paper titled "Development and Testing of Advanced Inter-Well Pressure Pulse Analysis for Fracture Diagnostics in Tight Gas Reservoirs". One of our Senior Engineers, Mr. Juan Ramos, presented our paper at the ARMA 2018 conference in Seattle, WA in June 2018.

Key Outcomes: None to report.

What we expect to accomplish during the next period: We plan to continue preparing and submitting milestone reports summarizing our work over the next 6 months.

3. **What opportunities for training and professional development has the project provided?**

GeoMechanics Technologies employs senior and staff earth scientists and engineers. We are testing different coupling methods of fluid flow and geomechanical models to evaluate the pressure behavior in multi-stage fracture systems. In additional, we provide training in different softwares including Tough2, Flac3D, and Xsite.

4. **How have the results been disseminated to communities of interest?**

Some preliminary results for the multi-stage fracture system are available. From the review of the ten main hydraulic fracture plays in the United States, we already targeted the main operators to disseminate this information. We will send out the flyers very soon. In addition, we have submitted a paper based on the results of Phase I. This paper was presentation at the 52nd US Rock Mechanics / Geomechanics Symposium held in Seattle, Washington, USA, 17–20 June 2018. This paper was also selected and published in the Journal of American Rock Mechanics Association (ARMA 18–879). .

5. **What do you plan to do during the next reporting period to accomplish the goals?**

GeoMechanics Technologies has been working diligently to research this innovative technique. Our weekly progress meetings have been a key component to keep the project on-track and within budget. We plan to continue maintaining this overall communication between the PI, Senior and Staff Engineers for the remainder of this project. A major foreseeable goal we look forward to accomplishing is getting approval from SM Energy for the designed field testing procedure and perform the pressure pulse testing in the field. At the same time, we will put our best effort to use existing field data to characterize the fracture geometry using the inversion technique.

Products- Details

Publication Details:

1. Conference Paper/ Presentation: Development and Testing of Advanced Inter-Well Pressure Pulse Analysis for Fracture Diagnostic in Tight Gas Reservoirs

   Conference Name: 52nd US Rock Mechanics/ Geomechanics Symposium

   Conference Location: Seattle, Washington

   Publication Status: Published

   Conference Date: 06/18/2018

   Author (s): Ramos, J., Wang, W., Bruno, M.S., Lao, K., Oliver, N.

2. Journal Paper: Advanced Hydraulic Fracture Characterization Using Pulse Testing Analysis

   Journal Name: Rock Mechanics and Rock Engineering

   Publication Status: Awaiting Review

   Authors: Ramos, J., Wang, W., Diessl, J., Oliver, N., Bruno, M.

Intellectual Property:

There are no intellectual properties to report.

Technologies and Technique Details:

There are no technologies or techniques to report.

Other Products

There are no other products to report.

Participants and Other Collaborating Organizations

1. Participant: Dr. Michael S. Bruno
   Project Role: Principal Investigator/ Project Director
   Person Months Worked: 2.15
   Contribution to the Project: Dr. Michael Bruno is the Principal Investigator on this project. He has worked a total of 2.15 calendar months on this project from the start of the project to the end of December 2018. He is the lead technical adviser for the Senior and Staff Engineers on this project. He leads the weekly project status meetings and provides guidance and direction for the project.
   International Collaboration and Travel: No
2. Participant: Mr. Kang Lao
   Project Role: Senior Geomechanics Engineer
   Person Months Worked: 1.63
   Contribution to the Project: Mr. Kang Lao is a Senior Geomechanics Engineer for GeoMechanics Technologies. He has worked 1.63 calendar months on this Phase II project. Mr. Lao has provided research and numerical modeling assistance. Mr. Lao participates in the weekly project progress meetings and contributes to report writing.
   International Collaboration and Travel: No
3. Participant: Mrs. Nicky Oliver
   Project Role: Senior Geologist

Person Months Worked: 1.06
Contribution to the Project: Mrs. Nicky Oliver is a Senior Research Geologist for GeoMechanics Technologies. She has worked 1.06 calendar months on this Phase II project. Mrs. Oliver has provided research assistance on Task 4: Field Test and Data Collection. Mrs. Oliver also participates in the weekly project progress meetings and contributes to report writing.
International Collaboration and Travel: No

4. Participant: Mr. Juan Ramos
   Project Role: Senior Geomechanics Engineer
   Person Months Worked: 6.80
   Contribution to the Project: Mr. Juan Ramos is a Senior Geomechanics Engineer for GeoMechanics Technologies. He worked a total of 6.80 calendar months on this project since the commencement to the end of December 2018. Mr. Ramos has provided assistance on Task 2, Task 3, and Task 4. Mr. Ramos also participates in the weekly project progress meeting and helps with reporting activities.
   International Collaboration and Travel: No
5. Participant: Mrs. Wenli Wang
   Project Role: Senior Geomechanics Engineer
   Person Months Worked: 9.35
   Contribution to the Project: Ms. Wenli Wang is a Senior Geomechanics Engineer for GeoMechanics Technologies. She has worked a total of 9.35 calendar months on this Phase II project since the beginning of this project to December 2018. Ms. Wang has worked primarily on Task 2, Task 3, and Task 4. Ms. Wang has also participated in our weekly project progress meeting to make sure the project is on track and being completed within budget. Ms. Wang also helps with technical report writing.
   International Collaboration and Travel: No
6. Participant: Ms. Jing Xiang
   Project Role: Staff Geomechanics Engineer
   Person Months Worked: 1.21
   Contribution to the Project: Ms. Jing Xiang was a Research Geomechanics Engineer for GeoMechanics Technologies. She worked 1.21 calendar months on this Phase II project since the commencement to the end of December 2018. Ms. Xiang assisted the Senior Engineers in Task 2: Detailed numerical modeling studies of multi-stage fracture system for a range fracture geometry and formation characteristics. She provided research and data collection assistance on this task. Ms. Xiang participated in the weekly project progress meetings and helped with reporting.
   International Collaboration and Travel: No
7. Participant: Ms. Jean Young
   Project Role: Senior Geologist
   Person Months Worked: 2.16

Contribution to the Project: Ms. Jean Young is a Senior Research Geologist for GeoMechanics Technologies. She has worked 2.16 calendar months on this Phase II project. Ms. Young has provided research assistance on Task 4: Field Test and Data Collection. Ms. Young also participates in the weekly project progress meetings and contributes to report writing.
International Collaboration and Travel: No

Partner Details

There are no partners to report.

Other Collaborator Details

We have obtained an agreement with operator SM Energy to collaborate in this Phase II field test. We are working with them on Task 4 to perform field testing and pressure pulse test data collection for both single and multi-fractures.

Impact

1. What is the impact on the development of the principal discipline(s) of the project?

Successful development and demonstration of this improved technical approach for fracture characterization will provide industry with a more cost-effective and efficient technique to monitor and diagnose fractures from horizontal wells. The technique is less costly than current fracture diagnostic alternatives, such as microseismic monitoring and downhole tiltmeter monitoring, and can provide more direct measurement of resulting formation transport properties and productivity.

2. What is the impact on other disciplines?

An improved technique for hydraulic fracture characterization can provide more secure environmental protection of groundwater resources. Also this technique can help advance fracture mechanics in similar industries such as geothermal and environmental remediation.

3. What is the impact on the development of human resources?

Not applicable.

4. What is the impact on physical, institutional, and information resources that form infrastructure?

Not applicable.

5. What is the impact on technology transfer?

Not applicable.

6. What is the impact on society beyond science and technology?

This technique can enhance and optimize production of oil and gas, thereby improving our domestic energy supply. An increase in energy supply would have a large impact on the growth of our society. In addition, characterization of fracture geometry and orientation will help to provide an optimum hydraulic fracture strategy and prevent potential out-of-zone fractures that may impact underground sources of drinking water. This would therefore provide a safer environment to the society.

Changes-Problems

1. Changes in approach and reason for change

No changes in approach were required. GeoMechanics Technologies understands that if significant changes are required, we will first obtain prior written approval from the Contracting Officer before proceeding.

2. Actual or anticipated problems or delays and actions or plans to resolve them

We have not encountered any problems or delays, and we do not anticipate any problems or delays.

3. Changes that have a significant impact on expenditures

No changes occurred during the reporting period that may have a significant impact on expenditures.

4. Significant changes in use or care of human subjects, vertebrate animals, and/or biohazards

Not applicable.

5. Change of primary performance site location from that originally proposed

No changes in primary performance site location were made last reporting period.

6. Carryover Amount

The estimated carryover amount for the next budget period: $$298,575.08