Optimization of Mud Hammer Drilling Performance – A Program to Benchmark the Viability of Advanced Mud Hammer Drilling

Quarterly Progress Report

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ABSTRACT

This document details the progress to date on the OPTIMIZATION OF MUD HAMMER DRILLING PERFORMANCE – A PROGRAM TO BENCHMARK THE VIABILITY OF ADVANCED MUD HAMMER DRILLING contract for the quarter starting January 2001 through March 2001.

Accomplishments to date include the following:

- On January 9th of 2001, details of the Mud Hammer Drilling Performance Testing Project were presented at a "kick-off" meeting held in Morgantown.
- A preliminary test program was formulated and prepared for presentation at a meeting of the advisory board in Houston on the 8th of February.
- The meeting was held with the advisory board reviewing the test program in detail.
- Consensus was achieved and the approved test program was initiated after thorough discussion.
- This new program outlined the details of the drilling tests as well as scheduling the test program for the weeks of 14th and 21st of May 2001.
- All the tasks were initiated for a completion to coincide with the test schedule.
- By the end of March the hardware had been designed and the majority was either being fabricated or completed.
- The rock was received and cored into cylinders.

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INTRODUCTION

In accordance with the award requirements from the Department of Energy and NETL, TerraTek (Arnis Judzis and Sidney Green) presented details about the Mud Hammer Drilling Performance Testing Project at a January 'kick-off' meeting in Morgantown. Industry support for this project is high and BP Amoco's John Shaughnessy presented information surrounding the operator's 'hard rock drilling' business challenge. The BP presentation used the Tuscaloosa trend difficulties in attaining drilling rates of penetration to exemplify the need for new technologies in improving hard rock drilling performance. Fluid hammer use at depth is one such option. Roy Long, NETL, graciously hosted the kick-off meeting with NETL attendees in Morgantown on January 9, 2001.

TerraTek presentation

1. Optimization of Mud Hammer Performance - Goal

This program proposes to accelerate the commercialization of mud hammers through benchmark testing and optimization of drilling performance (Fiscal Years '01 and '02).

2. Context –

Economic Benefit
- Domestic developments in tools and testing
- Potential for increased activities in gas and deep gas plays

Fluid Hammer Market Entry
- A D Little study for SDS Digger - estimates include:

  >US $500 MM North America value if ROP can be increased 200 to 300% over conventional. A 10% market penetration in the US still supports a ~US $50 MM 'cost benefit'.

  Size in '97 - ~80% of US $1,200 MM spent on drilling hard rock in the US; ~12 MM hard rock feet drilled; growing pace

Drilling Performance
- Air and fluid percussion applications for rate of penetration
- Non fixed cutter applications
- Directional drilling applications

Target Markets
- Gas, deep gas plays
- Mid continent, Overthrust, Appalachian Basin, etc.

3. Technical Context / Large Scale Testing

Mud hammer developments have lagged behind air percussion methods –

- Commercial developments underway at various paces
- Limited ROP data with muds at great depth
- Hydrodynamic 'tuning' effects at depths less understood

Sustained performance in high pressure wellbores limited
Design features vary, thus offering pros and cons for hydraulics, etc.
Longevity
Clear fluids vs. operation in heavier muds with solids
Percussion methods are viable options for hard rock environments
Tool availability?

Advantages in large-scale experiments in wellbore simulator –

Economics (start-up with high day rates difficult with prototype tools)
Ability to compare tools and performance directly
Test rig 'height' offers easy access to tools/handling
Drilling conditions are carefully controlled & measured (data acquisition)
Equipment can be modified and retested
Provides wide range of experiments simulating field conditions - flow rates, impact energy, rock types, rotary speed, etc.

4. Scope of Work

Characterization of applications –

Seek operator input and requirements (e.g. BP Amoco Hard Rock Workshop)

Perform large-scale hammer drilling tests –

This program will test SDS and Novatek hammers in two hard rock types
Vary hammer energies, WOB, borehole pressures, mud weights
Limited changes of overburden, confining pressure, and mud types
Drilling tests are planned on 15-1/2" diameter x 36" rock samples

Benchmark hammer performance –

Determine 'drillability' with various analyses
Assess ROP/performance relative to conventional drilling
Transfer lessons learned to suppliers and operators

Optimization of hammer performance -

'Tune' hammers for range of borehole pressures
Model impact mechanics and propose design changes
Retest hammers with a view to encourage subsequent field trials

5. Looking forward –

TerraTek plans to convene entire team (NETL, TerraTek, Novatek, SDS Digger, BP, ExxonMobil, Pajarito Enterprises) in Houston within one month to finalize test conditions and review hammer provider tools/bit(s) – *completed*

BP is keen to conduct possible field trials of fluid hammers as the TerraTek performance tests proceed

TerraTek and both Novatek and SDS were represented at BP's recent Hard Rock Drilling Workshop in Houston. Benchmarking and performance testing (in part through this program) will accelerate the pace of tool deployment as well as optimization of hard rock rate of penetration.

Discussions with the larger service companies have shown that interest in fluid hammers includes directional and seismic-while-drilling applications.

BP Amoco presentation (John Shaughnessy)

1. Mud Hammer Performance Project - Improving ROP

Over 50% of rig time is spent in the last 10% of the hole.
Drilling faster directly cuts rig time and saves money.
It also cuts down on the number of bits required so the benefits are multiplied.
Most problems are associated with trips.

2. Where can drilling engineer impact cost?

Location costs are driven by the area.
Casing Points are set by pore pressure.
Casing sizes are driven by flow requirements
Rig size and capability driven by casing and depth.
Impact cost with ROP.

3. How Impact ROP?

Bit Selection
Hydraulics – more pump, more flow rate, bigger drill pipe
Overbalance against the formation (or under-balance)

4. Cost Driven Basin (e.g. Tuscaloosa project)

Improving ROP cuts well costs
Improves cycle time
Driving costs and time down improves the economics – fewer reserves are required per well.

Both BP Amoco and ExxonMobil continue to be industry contributors to this program as operators and have various domestic applications in mind for fluid hammers. A recent Society of Petroleum Engineers paper also highlighted some of the early engineering challenges that require advances and more study in the Venezuela Basin (reference 1).

EXECUTIVE SUMMARY

On January 9th of 2001, details of the Mud Hammer Drilling Performance Testing Project were presented at a "kick off" meeting held in Morgantown. Industry support is high and the importance to the drilling industry, as the business challenge of "hard rock drilling", was presented by John Shaughnssy of BP Amoco.

A preliminary test program was formulated and prepared for presentation at a meeting of the advisory board in Houston on the 8th of February. The meeting was held with the advisory board reviewing the test program in detail. The Advisory Board was made up of the NETL contracting officer, industry representatives, consultants, and the contractors

for this program Consensus was achieved and the approved test program was initiated after thorough discussion. The test results will be compared to a baseline set of data obtained at the Drilling Research Laboratory using a roller cone bit. This same bit will be included in the test program and run using higher mud weight. The original data and the data from the higher mud weight will complete the parameters necessary for a comparison and analysis of the mud hammer performance to conventional roller bit drilling. The approved programoutlined the details of the drilling tests as well as scheduling the test program for the weeks of the 14th and 21st of May 2001.

The test matrix, detailed in the body of the report, will start by running the SDS and Novatek tools in 10ppg mud in both Carthage Marble and Crab Orchard Sandstone. The mud system will be weighted up to 15 ppg. The conventional bit will be run to obtain the baseline data first. The two hammers will then be run in both rock types in the heavier mud. If rock remains after these tests are performed, each of the two hammers suppliers will have the opportunity to equally share the remaining rock to obtain other needed data for their tools.

Based on the approved test program, work performed in February and March proceeded at the fastest pace to obtain the rock, fabricate samples, detail lab layouts, design hardware, fabricate that hardware, and basically prepare every detail for the tests scheduled for mid May. All the tasks were initiated for a completion to coincide with the test schedule.

By the end of March the hardware had been designed and the majority was either being fabricated or completed. Two types of rock were ordered after approval from the Board, Carthage Marble, which will e used to simulate medium hardrock applications and Crab Orchard Sandstone simulating harder rock applications. The rock was received in large quarried blocks and was cored into 15 ½” diameter by 36” long cylinders. These cylinders will be placed between large steel end caps and be jacketed to form the samples in which the mud hammers and conventional bit will drill.

Both mud hammer suppliers were contacted with the appropriate tool layouts for their tests. Final dimensions were communicated from both the suppliers and the contractor. The suppliers fabricated the chrome outer surfaces necessary for the seals in the test set up.

April and the first part of May will see the completion of the associated hardware in preparation for the setting up of the experiment hardware for the tests.

EXPERIMENTAL

Task 2.0 Characterization of Applications

Published and unpublished documentation of mudhammer performance was gathered and analyzed. Dr. John Rowley of Pajarito Enterprises supplied documentation from searches and discussions. The were several papers and articles from Russia in regards to hammer drilling and experimentation but little information of use for these experiments. Two SPE papers (referenced in this document) were identified and reviewed for applicability. These papers proved to have the most merit in setting up the parameters and conditions for the test program. The proposed test program was based on these papers and reviewed at the Advisory Board meeting in Houston.

The key operational parameters, rock types, final tools, bits, and conventional bit test parameters were reviewed by the Advisory panel during the Houston meeting on the 8th of February. Participants were as follows:

- Roy Long — Gov't. NETL
- Peter Whitehead — SDS Digger Tools
- David Pixton — Novatech
- John Rowley — Pajarito Enterprises
- Darrell Howard — BP Amoco
- John Shaughnessy — BP Amoco
- Brian Tarr — ExxonMobil
- Tim Travis — ExxonMobil
- Alan Black — TerraTek
- Gordon Tibbitts — TerraTek

Consensus was reached on all the points brought up in the meeting and are reflected in the following information detailing the results of the meeting. This information was distributed to Dona Sheehan and Roy Long a week after the meeting.

KEY MEETING RESULTS

TEST SEQUENCE

TEST	HAMMER/BIT	ROCK	MUD DENSITY
1	SDS	Carthage Marble	10 ppg
2	SDS	Crab Orchard S.S.	10 ppg
3	Novatek	Carthage Marble	10 ppg
4	Novatek	Crab Orchard S.S.	10 ppg
5	Conventional	Carthage Marble	15 ppg

6	Conventional	Crab Orchard S.S.	15 ppg
7	SDS	Carthage Marble	15 ppg
8	SDS	Crab Orchard S.S.	15 ppg
9	Novatek	Carthage Marble	15 ppg
10	Novatek	Crab Orchard S.S.	15 ppg
11**	SDS	Carthage Marble	15 ppg
12**	SDS	Crab Orchard S.S.	15 ppg
13**	Novatek	Carthage Marble	15 ppg
14**	Novatek	Crab Orchard S.S.	15 ppg

* Use the data from SPE paper No. 15620 for conventional bit performance (HPSM rollercone bit) in 10ppg mud.

** Tests 11 through 14 will have a priority in obtaining the data necessary to characterize the performance of the mud hammers. If there are any rock samples remaining after this task, they will be allocated evenly to both SDS and Novatek to run tests of their choice exploring bit performance or expanding the parametric ranges

SDS DIGGER MUD HAMMER TEST CONFIGURATION

- Spud 3" into the rock sample at 1000 psi borehole pressure conditions, 1900 psi pressure drop through the tool, rotary speed of 20 RPM, WOB high enough to start the tool and ending at 2000 lbs at 3" depth into the rock
- At 3" start test condition 1 - 1000 psi borehole conditions, 2000 lbs WOB, 20 RPM and a 1900 psi pressure drop through the tool. 4" of rock have been allocated for this test condition. If possible obtain data points at 15 RPM and 25 RPM if rock is available.
- At 7" pull off bottom and establish borehole conditions at 3000 psi maintaining the 1900 psi pressure drop through the tool.
- Engage the bottom hole at these conditions and drill 2 ½" of rock in transition as the tool function becomes steady state.
- At 9 ½" start test condition 2 – 3000 psi borehole conditions, 2000 lbs WOB, 20 RPM, and 1900 psi pressure drop through the tool. 6" of rock has been allocated for this test condition. If rock exists get data points at 15 RPM and 25 RPM.
- At 15 ½ " pull off bottom and change the pressure drop through the tool to 1600 psi.
- Engage the bottom hole at this new condition and drill 2 ½ " of rock in transition as the tool function becomes steady state.
- At 18" start test condition 3 – 3000 psi borehole conditions, 2000 lbs WOB, 20 RPM and 1600 psi pressure drop through the tool. 6" of rock has been allocated for this test condition. If rock is available obtain data points at 15 RPM and 25 RPM.
- At 24" pull off bottom and change the pressure drop through the tool to 2200 psi.
- Engage the bottom hole at this new condition and drill 2 ½" of rock in transition as the tool function becomes steady state.
- At 26 ½" start test condition 4 – 3000 psi borehole conditions, 2000 lbs WOB, 20 RPM, and 2200 psi pressure drop through the tool. 6 ½" of rock has been allocated for this test condition. If rock is available obtain data points at 15 RPM and 25 RPM.
- At 33" pull off bottom and end test.

NOVATEK MUD HAMMER TEST CONFIGURATION

- Spud 3" into the rock sample at 1000 psi borehole pressure conditions, 1000 psi pressure drop through the tool, 30 RPM, and WOB to10,000 lbs at 3" depth into the rock
- At 3" start test condition 1 – 1000 psi borehole conditions, 30 RPM, 10,000 WOB and 1000 psi pressure drop through the tool. 4""of rock have been allocated for this test condition. If rock is available, get data points at 10 RPM and 60 RPM.
- At 7" pull off bottom and establish 3000 psi borehole conditions while maintaining the 1000 psi pressure drop through the tool.
- Engage the bottom hole and bring WOB up to 10,000 lbs at the 3000 psi borehole conditions and 30 RPM. ½" of rock has been allowed for this transition to WOB. 4" of rock has been allocated for this test condition (2). If rock exists, obtain data points for 10 RPM and 60 RPM.
- At 11 ½" increase WOB to 20,000 lbs (test condition 3) at 30 RPM and 1000 psi pressure drop through the tool. 4" of rock has been allocated for this test condition. If rock exists obtain data points at 10 RPM and 60 RPM.
- At 15 ½" pull off bottom and increase the pressure drop through the tool up to 1500 psi.
- Engage the bottom hole at this new condition and bring WOB up to 10,000 lbs in the ½" of transition rock. Start test condition 4 – 3000psi borehole pressure, 30 RPM, and 10,000 lbs WOB. 4" of rock has been allocated for this test condition. If rock exists obtain data points at 10 RPM and 60 RPM.
- At 20" increase the WOB to 20,000 lbs to establish test condition 5 – 3000 psi borehole conditions, 30 RPM, 20,000 lbs WOB, and 1500 psi pressure drop through the tool. 4" of rock has been allocated for this test condition. If rock exists obtain data points at 10 RPM and 60 RPM.
- At 24" pull off bottom and decrease the pressure drop through the tool to 750 psi.
- Engage the bottom hole at this new condition and bring WOB up to 10,000 lbs in the ½" of transition rock. Establish test condition 6 – 3000 psi borehole conditions, 30 RPM, 10,000 lbs WOB, and 750 psi pressure drop through the tool. 4" of rock has been allocated for this test condition. If rock exists, obtain data points at 10 RPM and 60 RPM.
- At 28 ½" increase the WOB to 20,000 lbs (test condition 7) and get data point at 30 RPM, 3000 psi borehole conditions, and 750 psi pressure drop through the tool. If rock exists, obtain data points for 10 RPM and 60 RPM.
- Pull off bottom at 32 ½" end test.

The schedule for the laboratory testing was set for the weeks of the 14th and the 21st of May with set up days on the 10th and 11th of May 2001.

RESULTS AND DISCUSSION

After kicking off the project beginning January, 2001 progress has been made according to the schedule and scope of work proposed. Tasks 1 and 2 have been completed, with progress now being made on Task 3 (large-scale testing preparations).

Task 1 – As confirmed by Roy Long, COR at NETL, the information required for the National Environmental Policy Act was submitted in calendar year 2000.

Task 2 – Described in previous EXPERMENTAL section.

Alan Black reviewed the data and paper (reference 2) describing the tests with the conventional tricone (Reed HPSM) as agreed in the Houston meeting. The performance of the drill bit using the same mud as will be used for the first part of the test program was analyzed and documented. By utilizing this data, expensive pressure tests will be conserved and used to obtain more hammer data.

Task 3.1

In preparation for the test program, the rocks were ordered, the layouts were completed, the seals were designed, the associated hardware and cross over subs were designed, the rocks were cored, and the coordination with the tool suppliers and involved parties to the test was established and maintained.

Inkind support from industry including document research, travel and attendance at meetings, and fabrication of tool/test specific parts has been logged and is documented in the financial Status Report.

The fabrication of the remaining hardware and obtaining the mud for the project will be completed in April and first week in May, in order to meet the set up days of the 12th and 11th of May and the subsequent test program during the weeks of the 14th and 21st of May.

CONCLUSIONS

- The project is on schedule with the same scope of work.
- Industry interest in the project continues to be very strong.
- Tasks 1 and 2 are completed.
- Task 3 is planned and is on schedule to be completed in concert with the set up date for the project.
- Both tool suppliers have their tools ready for the test program.

REFERENCES

1. Ramirez, J., Geraud, M., Salazar, V., and Algate, G., "Fluid Percussion Drilling in Deep Hard Rock in Eastern Venezuela", SPE Paper 69520 presented at the SPE Latin American and Caribbean Petroleum Engineering Conference held in Buenos Aires, Argentina, 25-28 March, 2001.
2. Walker, B.H., Black, A.D., Klauber, W.P., Little, T., and Khodaverdian, M., "Roller-Bit Penetration Rate Response as a Function of Rock Properties and Well Depth", SPE Paper 15620 presented at the 61st Annual Technical Conference and Exhibition of the Society of Petroleum Engineers held in New Orleans, LA 5-8 October, 1986.