

**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 2002 through March 2002.

Accomplishments include the following:

- In accordance to Task 7.0 (D. #2 Technical Publications) TerraTek, NETL, and the Industry Contributors successfully presented a paper detailing Phase 1 testing results at the February 2002 IADC/SPE Drilling Conference, a prestigious venue for presenting DOE and private sector drilling technology advances. The full reference is as follows:
IADC/SPE 74540 “World’s First Benchmarking of Drilling Mud Hammer Performance at Depth Conditions” authored by Gordon A. Tibbitts, TerraTek; Roy C. Long, US Department of Energy, Brian E. Miller, BP America, Inc.; Arnis Judzis, TerraTek; and Alan D. Black, TerraTek. Gordon Tibbitts, TerraTek, will presented the well-attended paper in February of 2002. The full text of the Mud Hammer paper was included in the last quarterly report.
- The Phase 2 project planning meeting (Task 6) was held at ExxonMobil’s Houston Greenspoint offices on February 22, 2002. In attendance were representatives from TerraTek, DOE, BP, ExxonMobil, PDVSA, Novatek, and SDS Digger Tools.
- PDVSA has joined the advisory board to this DOE mud hammer project. PDVSA’s commitment of cash and in-kind contributions were reported during the last quarter.
- Strong Industry support remains for the DOE project. Both Andergauge and Smith Tools have expressed an interest in participating in the ‘optimization’ phase of the program. The potential for increased testing with additional Industry cash support was discussed at the planning meeting in February 2002.

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INTRODUCTION

The focus of the Introduction for this quarter will be on the continuing high interest this project has by the Industry. In anticipation the upcoming Offshore Technology Conference in Houston, TerraTek provided DOE / NETL with a drilled hard rock (Crab Orchard Sandstone) sample and presentation material for the DOE exhibit booth. The presentation material will be reported during the next quarter.



*Bottomhole pattern from Novatek hammer / bit drilling
in a Crab Orchard Sandstone sample*

EXECUTIVE SUMMARY

Progress on the testing of fluid driven drilling hammers is on schedule.

Background

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 Shaughnessy of BP Amoco. The Industry Partners for this program are SDS Digger Tools, Novatek, BP Amoco, and ExxonMobil. A test program was formulated and prepared for presentation at a meeting of the Industry Advisory Board in Houston on the 8th of February. The meeting was held and the DOE approved a test program was after thorough discussion.

DOE’s National Energy Technology Laboratory highlighted the Mud Hammer Project at an exhibit at the Offshore Technology Conference April 30 through May 3, 2001. TerraTek assisted NETL personnel with presentation materials appropriate for the project and a demonstration sample of ‘hard rock’ drilled in TerraTek’s wellbore simulator.

TerraTek completed 13 drilling tests by beginning July in Carthage Marble and hard Crab Orchard Sandstone with the SDS Digger Tool, Novatek tool, and a conventional rock bit. Overall the hammers are functioned properly at ‘borehole’ pressures up to 3,000 psi with weighted water based mud. Clearly the Department of Energy goals to determine hammer ***benchmark rates of penetration*** and ***ability to function at depth*** are being met. Additionally data on drilling intervals and rates of penetration specific to flow rates, pressure drops, rotary speed, and weights-on-bit have been given to the Industry Partners for detailed analysis. SDS and Novatek have gained considerable experience on the operation of their tools at simulated depth conditions. Some optimization has already started and has been identified as a result of these first tests.

TerraTek has completed analysis of drilling performance (rates of penetration, hydraulics, etc.) for the Phase One testing which was completed at the beginning of July. TerraTek also convened jointly with the Industry Advisory Board for this project and DOE/NETL a ‘lessons learned meeting’ to transfer technology vital for the next series of performance tests. Both hammer suppliers benefited from the testing program and are committed to pursue equipment improvements and ‘optimization’ in accordance with the scope of work.

PDVSA joined the advisory board to this DOE mud hammer project end 2001 and has formally committed funds (cost sharing) for the upcoming effort in testing at TerraTek. Additionally, TerraTek, DOE, and BP America (one of the industry contributing partners) has completed a publication entitled “World’s First Benchmarking of Drilling Mud Hammer Performance at Depth Conditions”.

Current

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EXPERIMENTAL

All experimental work for Phase 1 testing has been completed and reported. Discussions and planning for Task 6 are underway with addition experimental work commencing after the February 22, 2002 planning meeting.

RESULTS AND DISCUSSION

Planning meeting notes:

**MINUTES AND NOTES
OPTIMIZATION OF MUD HAMMER DRILLING PERFORMANCE
PHASE II PLANNING MEETING
HOUSTON
22ND FEBRUARY 2002**

PARTICIPANTS

John Rogers (DOE NETL), Tim Travis (EXXONMOBIL), David Pixton (NOVATEK), Malcolm McInnes (SDS Digger Tools), Richard Reiley (BP America), Adam Aylor (EXXONMOBIL), Alejandro Lagrecea (PDVSA), Jesse Holster (EXXONMOBIL), Arnis Judzis (TERRATEK), Gordon Tibbitts (TERRATEK)

GENERAL DISCUSSION

- A paper detailing the work and results from Phase I has been completed –SPE74540
- A presentation of this paper will be made at the SPE/IADC meeting in Dallas on the 28th of February (Completed)
- PDVSA has joined the program and has contributed to funding more testing for the program. Their representative at this meeting is Alejandro Legracea
- Meeting to proceed as outlined in the approved meeting agenda

PHASE I AND WAY FORWARD REVIEW

A brief review of the phase I test program was given. Emphasis was placed on what issues need to be addressed to move the hammer technology towards commercialization. For the Novatek tool the primary issues was learning about the “transition zone” improved performance mode of drilling that was observed in the latter part of phase I. For the SDS tool it was adapting the internal configuration to retain performance when the tool is used with denser, overbalanced drilling fluids, within recognized oil field pump pressure restraints.

SDS TOOL IMPROVEMENTS BASED ON THE RESULTS OF PHASE I

Malcolm McInnes SDS thanked the program sponsors and TerraTek for the valuable test data, which had closed some R&D loops and provided additional insight into tool characteristics. An appropriate design response was established early. The new knowledge also contributed to the achievement of an ROP of 5.5 times the offset rotary rate, at 5,000 feet in a subsequent Venezuelan hard formation drilling trial. The tool operates within a window of low WOB and good control is required. The tool cannot be considered in isolation from the deployment system because of dynamic interactions.

The presentation included graphs and charts of the data collected at TerraTek, which demonstrated the general characteristics of the tool, including strong relationships between key parameters such as ROP relative to offset and impact frequency. It appeared that bore hole pressure and formation were less important. There was also significant scope for the optimization of rotational speed, bit design, WOB and impact power. Extrapolations of fitted curves indicated the potential performance of the SDS tool if the target impact frequency had been achieved, without pressure constraints.

The next generation tool would be redesigned to reduce operating differential pressure. Phase II developments were only constrained by funding availability. The tool design originated in the hard, metalliferous mining industry where it was powered by a low flow rate of clean water, at high pressure. The typical operating differential pressure is 2,000 psi to 2,500 psi although a hole opening job has been done successfully at 850 psi, in Norway.

Tim Travis had suggested measuring tool performance in terms of total mechanical and hydraulic energy used to break a volume of rock. SDS had done this using units of Joules/litre of rock, but was concerned that the ultimate performance measuring scale was the \$/litre. Different drilling technologies could have different mixes of ROP, life,

operating cost and energy efficiency. Life testing is outside the scope of the current program.

A lively discussion ensued on the maximum pump pressure at which current contractors and TerraTek would allow their pumps to be run. This pump pressure determines the available hydraulic horsepower available to tools in the drill string after parasitic losses are addressed and the bottoms up pressure drop is added to the equation. At issue are the current operator needs for their applications and future requirements for these new tools in order to have performances above expectations. In the TerraTek facility, the bore hole pressure is achieved with the aid of a choke acting against the flow rate.

The levels suggested by EXXONMOBIL were 1500 to 1700 psi pressure drop through the tool as surface pump delivery systems are limited to operate at 3000 psi.

The SDS percussion tool would be required to perform on hydraulic power, against rotary and hybrid rotary tools, which could use similar amounts of hydraulic power supported by additional mechanical power. SDS has had little experience with Fluid Hammer commercial projects where pump pressure limited tool performance or where mud specific gravity was as high as that used in the TerraTek tests.

The SDS tool does not need any significant hydraulic HP at the bit face and does not need a heavy, narrow bore, BHA. In many cases, the SDS tool can operate at a lower flow rate.

NOVATEK TOOL IMPROVEMENTS BASED ON THE RESULTS OF PHASE I

David Pixton Novatek will be pursuing rotary percussive bits as the cutting structure for their tools. The mud hammer valve timing is affected by the mud weight and will need to be redesigned to operate optimally.

Novatek presented a graph comparing the rate of penetration of the tool/bit to the horsepower at the bit. For the most part the horsepower at the bit increase nominally with an increase in ROP. In the transition area of interest the horsepower at the bit remains the same for a drastic increase in ROP. This will be their focus moving forward. They will try to define the following:

- Operational factors leading to the high rate drilling
- The influence of jet assisted drilling on performance
- Influence of rock type on high rate drilling
- Understand the energy output of the hammer in heavier muds

Novatek believes the needed improvements for their hammer and bit system will encompass the following areas:

- Less influence of mud characteristics on the hammer operation
- Improve the robustness of the tool
- Gain more control over the applied WOB
- Improve the reliability of the jet assisted hammer bit

David thinks the redesign for the next generation hammer and bit to be completed in the summer of 2002. They are planning to build a complete new tool with a preliminary qualification of the tool in 90 days.

David suggested that testing for the optimization of their tool should be done at only one borehole pressure and that pressure should be as high as possible.

OPERATOR REQUIREMENTS

EXXONMOBIL

- Would like to see an “accounting” of hydraulic energy through the tool systems. How much energy is expended at each stage of the tool function and rock destruction? It would be helpful in establishing rig operating conditions.
- Would like to understand the mechanics of the “transition zone” drilling and ascertain whether or not we can drill at those conditions.
- Would like to see an expansion of the project to include other mud hammers

NOTE: Arnis Judzis mentioned that the prime way to get other mud hammer companies involved in the program was to have either a sponsor fund their participation or the companies that represent the hammers fund the testing directly. Arnis Judzis will report on progress as appropriate.

PDVSA

- Their applications require rock in the 25 to 30 KPa strength range.
- Suggested possibly performing the testing of the tools by performing “drill off” tests. Set the WOB and then drill off to establish the ROP data.
- Their applications to date are run with low weight mud systems.
- They have interest in the hammer/bit as a system.

BP AMERICA

- Current and near future applications are aimed at near balanced or under balanced directional drilling conditions or low WOB slide applications in the reservoir sections of the hole
- They would like to see Multi phase fluid tests to verify these tools can operate in such an environment
- Mentioned Oil/Water, Nitrogen/Diesel
- Needs to establish the performance of these tools in Shale sequences. Need to exhibit reasonable rates in shale as well as hard rock
- Would like to know the directional characteristics of mud hammers
- Concerned about Axial stick/slip vibration. Anything we can do in the testing to look at this?

PHASE II TEST PLAN

A test plan was presented that outlined the 15 tests now available to the program with PDVSA's sponsorship. Originally there were 12 tests planned for phase II. The suggested plan is shown below.

**TEST SCENARIO
PHASE II
MUD HAMMER OPTIMIZATION PROGRAM**

<u>TEST</u>	<u>DESCRIPTION</u>	<u>ROCK SAMPLE</u>
1	EXPLORE THE TRANSITION ZONE OF THE NOVATEK TOOL	CRAB ORCHARD S.S. OR CARTHAGE MARBLE
2	EXPLORE THE TRANSITION ZONE OR THE NOVATEK TOOL	CRAB ORCHARD S.S. OR CARTHAGE MARBLE
3	SDS TOOL OPTIMIZATION	COMBINATION SAMPLE
4	NOVATEK TOOL OPTIMIZATION	COMBINATION SAMPLE
5	SDS TOOL OPTIMIZATION	COMBINATION SAMPLE
6	NOVATEK TOOL OPTIMIZATION	COMBINATION SAMPLE
7	SDS TOOL OPTIMIZATION	COMBINATION SAMPLE
8	NOVATEK TOOL OPTIMIZATION	COMBINATION SAMPLE
9	SDS BIT OPTIMIZATION	COMBINATION SAMPLE
10	NOVATEK BIT OPTIMIZATION	COMBINATION SAMPLE
11	SDS BIT OPTIMIZATION	COMBINATION SAMPLE
12	NOVATEK BIT OPTIMIZATION	COMBINATION SAMPLE
13	SDS SHALE DRILLABILITY	SANDWICH SAMPLE
14	NOVATEK SHALE DRILLABILITY	SANDWICH SAMPLE
15	SDS BEST PRACTICE	to be determined

The test plan includes two tests using combination samples to test the Transition zone of the Novatek tool. It shows six tests for tool optimization, splitting the tests equally between the two tool manufactures. Additionally four tests are allocated for bit optimization work. Two tests have been included to test the response of these tools to

shale stringers by employing samples that have a shale interval sandwiched between harder rock. The final test is available to test the best practice of the SDS configuration.

Consensus was reached on performing the tests at one borehole condition of 3000psi. Discussion on running just one mud weight was left open. Although that mud weight was tentatively agreed upon at 15 ppg because of the data already in hand, it was left open to get additional feed back from PDVSA and BP.

The timing of the tests could not be detailed, as both the mud hammer manufactures needed to analyze the time necessary to redesign and build prototype tools. It was suggested however that if the tools could be ready for testing in late spring or the early summer it would accommodate the contract and the laboratory schedule well. It appears that SDS has a faster turn around time for the redesign and fabrication of their tool and might be the logical first tool to be tested.

ATTENDANCE LIST
Phase II Mud Hammer Planning Meeting
Houston
22 February, 2002

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***** End of February 22, 2002 planning meeting minutes *****

After kicking off the project beginning January 2001 progress has been made according to the schedule and scope of work proposed. Tasks 1, 2, 3, 4, and 5 have been completed, with progress now being made on Task 6 (completed planning meeting on February 22, 2002 with Industry Sponsors prior for next phase of testing) and Task 7 Reporting of Results through publication.

Review of January 2001 through March 2001 –

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 – Completed and described in previous quarterly report.

Task 3 – Prepared rock samples and finalized tool logistics with hammer suppliers.

Review of April 2001 through June 2001 –

Task 3 – Set-up of large scale experiments completed. The test program was completed on June 27, 2001 after 13 full-scale tests were completed. Initial flow line and mud pump problems were resolved at TerraTek. The Novatek bit experienced both washouts and nozzle failures at first. The bit was repaired and testing continued after some delay and extra set-up time. SDS Digger hammer experienced fewer problems.

Review of July through September 2001 -

Task 4 – Benchmarking of mud hammer performance was completed. Interval data from all tests has been transmitted to the DOE project manager and Industry Sponsors.

Task 5 – A Peer Review ('Lessons Learned' meeting) was held with members of the Industry Advisory Board and the DOE. The suppliers and operators reviewed their own learnings and progress in addressing performance problems. The summary notes are made a part of the quarterly report below.

Review of October through December 2001 –

Task 6 – Plans are underway to identify the testing for the Optimization task. A planning meeting was attempted at the end of 2001 however some of the Industry Partners had scheduling difficulties during the holiday season. That meeting was set for February 22, 2002 and will be reported in the next quarterly report. PDVSA has joined the hammer program through cost sharing, thus will sit with the other Industry Partners in recommending tests appropriate for the overarching objective of the program – to accelerate the commercialization and availability of fluid hammers which operate at depth conditions and with weighted drilling muds.

Task 7 – TerraTek has completed the publication for the 2002 SPE/IADC Drilling Conference entitled "World's First Benchmarking of Drilling Mud Hammer Performance at Depth Conditions".

Review of January through March 2002 –

Task 6 – The planning meeting for Phase 2 testing was conducted on February 22, 2002 (minutes in results section of this report). NETL's new Contracting Officer's Representative, Dr. John Rogers, was in attendance

Task 7 – TerraTek presented IADC/SPE 74540 described above.

CONCLUSIONS

- The project is on schedule with the same scope of work
- Industry interest in the project continues with renewed interest by Andergauge and Smith Tools to contribute
- Tasks 1, 2, 3, 4, and 5 are completed.
- Task 6 is progressing having concluded a Planning Meeting to determine the test matrix for the next phase of testing. In this context, Novatek is working with the DOE to optimize their tool (summer schedule) and SDS's optimization will primarily focus on internal flow clearances to enhance strike frequency.
- Task 7 D2 completed with formal presentation / paper as encouraged by DOE/NETL.