

**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 July 2001 through September 2001.

Accomplishments to date include the following:

- TerraTek highlighted DOE's National Energy Technology Laboratory effort on Mud Hammer Optimization at the recent Annual Conference and Exhibition for the Society of Petroleum Engineers. The original exhibit scheduled by NETL was cancelled due to events surrounding the September tragedies in the US.
- 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 jointly with the Industry Advisory Board for this project and DOE/NETL conducted 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.
- An abstract for a proposed publication by the society of Petroleum Engineers/International Association of Drilling Contractors jointly sponsored Drilling Conference was accepted as an alternate paper. Technology transfer is encouraged by the DOE in this program, thus plans are underway to prepare the paper for this prestigious venue.

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## INTRODUCTION

The focus of the Introduction for this quarter will be on the high interest this project has by the Industry. The Drilling Engineering Association invited TerraTek to present an update at their 16<sup>th</sup> August meeting (hosted by the Energy Research Clearing House in The Woodlands, Texas). Some operators in particular are interested in hard rock drilling application for fluid percussion tools. The other area of emerging interest is ‘bit-hammer’ optimization . . . some of the early results of testing have definitely shown the need for improved systems thinking along the lines of both mud hammer and drill bit improvements.



## EXECUTIVE SUMMARY

Progress on the testing of fluid driven drilling hammers is encouraging and on track.

Background - On January 9<sup>th</sup> 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 8<sup>th</sup> 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. 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.

Finally, 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.

## EXPERIMENTAL

Background – from previous quarterly reports

### 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.

Owing to the early equipment problems experienced by Novatek (nozzles, bit washout) and to a lesser extent SDS, some of the experiments were started and stopped numerous times, thus adding to set-up, changeover, and waiting on equipment times. Nonetheless, the test matrix was completed under DOE's guidance as follows (multiple tests with letter designations indicate performance interval data was taken at different times and on separate files due to interruptions, hammer modifications, etc. The exception is test #3 where a change out to a different bit was made):

1.	DOE 1 ( plus 1A & 1B)	SDS
2.	DOE 2 (plus 2A & 2B)	SDS
3.	DOE 3, Novatek bit	Novatek
4.	DOE 3A, roller cone bit	Novatek
5.	DOE 4	Conventional
6.	DOE 5	Conventional
7.	DOE 6 (plus 6A)	SDS
8.	DOE 7	SDS
9.	DOE 8 (plus 8A & 8B)	SDS
10.	DOE 9	SDS
11.	DOE 10	Novatek
12.	DOE 11 (plus 11A)	Novatek
13.	DOE 12	Novatek

Summary data and charts for these tests were published in the last quarterly report. In this report, the archived photos of the bottomhole patterns are presented (DOE Test #3 had no bottomhole pattern since the entire sample was drilled through to the lower steel plate):



DOE 1



DOE 2





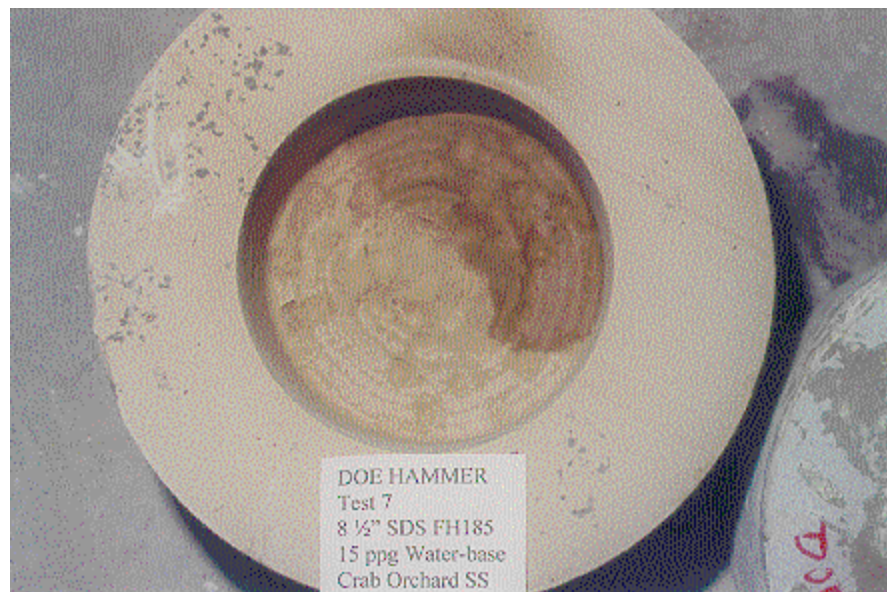
DOE 4



DOE 5



DOE 6



DOE 7





DOE 8



DOE 9

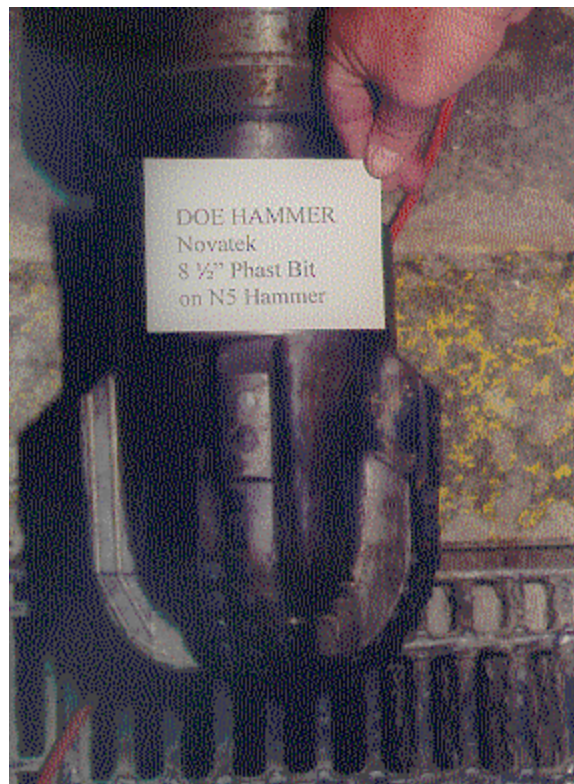


DOE 10



Baseline Bit





Novatek Bit



SDS Digger Bit

## 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, 2, 3, 4, and 5 have been completed, with progress now being made on Task 6 (convene planning meeting with Industry Sponsors prior to next phase of testing).

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.

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**MINUTES AND NOTES  
OPTIMIZATION OF MUD HAMMER DRILLING PERFORMANCE  
LESSONS LEARNED MEETING  
HOUSTON  
27 SEPTEMBER, 2001**

### PARTICIPANTS

Tim Travis (EXXONMOBIL), John Rogers (DOE NETL), Jim Powers (EXXONMOBIL), Brian Miller (BP), David Pixton (NOVATEK), Arnis Judzis (TERRATEK), Gordon Tibbitts (TERRATEK)

### GENERAL DISCUSSION

- An abstract was submitted to the spring IADC/SPE conference that details the mud hammer testing in this first phase. The abstract was accepted as an alternate paper. It was decided to proceed with this paper and present it at this conference.
- Approval was obtained to open this program to additional industry cost sharing.
- If other industry cost sharers join the program, testing will be performed at TerraTek in the USA and be within the scope of the DOE program.
- A second phase planning meeting will be held prior to the next testing program. Test conditions and procedures will be determined at that meeting. It is hoped the information from the lessons learned meeting will be used to help define the next test program.
- Concurrent field testing by the operators is welcomed and would add another dimension to this program.

### PRESENTATIONS

#### NOVATEK David Pixton

- Key to Novatek design philosophy to design and operate a tool which could function on typical oil field capabilities ( pump pressure and flow rates )
- Designed a bit to operate using the unique functions of a rotary percussive tool.
- Bit designated as the PHAST bit.
  - PDC bit containing both high back rake PDC cutters and pressure intensified nozzles in front of the cutters
  - Cutters had large chamfers as well as diamond well into the cylindrical portion of the cutter substrate
- This was a prototype bit and as such several issues in the construction and the operation of the bit need to be addressed in the future for this system to perform effectively.
  - A more robust design might be required to house the internal porting to the nozzles.
  - A different mounting system for the nozzles should be looked at.
- The tool did not exhibit optimal operation in the heavier than water mud systems. The tools will need to be "retuned" for these types of fluids. Possibly the stroke length and other parameters could be altered through design.
- Letting the tool stand for any period of time, which allows the drilling mud to dry, can foul the present hammer valve. This condition was experienced even though the tool was flushed with clear water. Modification of the valve can relieve this issue.
- The same performance was obtained with their hammers and tricone bits as conventional rotary drilling. Hammers with roller cone bits do not provide increased penetration rates.
- During these tests, increased performance was noted at two distinct areas. One was at higher bit horsepower (rpm x WOB). The other was observed at lower bit horsepower and was unexpected.
  - The new drilling mode was observed in the transition of low WOB to higher WOB. At these lower WOB levels, elevated penetration rates were observed in spite of lower horsepower being applied.
  - The mode was observed at a variety of conditions and is believed to be real.
- This new drilling mode needs to be explored and better understood.

### NEXT STEPS

- Explore this new drilling mode and expand the transition zone
- Test both with jet augmentation as well as without
- Look at bit design and tool design
- Retune tool to operate in these drilling fluids
  - Test both the next generation tool and bit. The next generation bit will be tested first to help answer fundamental rotary percussion drilling questions. Based on these results, the next generation tool will be designed and built (the redesign would mainly provide operational and robustness benefits, not answer fundamental questions).

SDS Malcom McInnis (was not able to attend due to flight issues after the incidents of 11 September)

- A report was sent to the meeting
  - The SDS tool performed in the mud systems used in the program
  - The tool did not run in an optimized manner while using these muds as a drilling fluid
- Additional information on the next steps to make this tool more viable commercially will be requested from SDS.

## **OPEN DISCUSSION**

### **OPERATORS**

Brian Miller BP

- One of the major issues in drilling hard rock is the inability of drilling tools to penetrate “soft” intervals or stringers at appreciable penetration rates. Brian suggested that some shale should be included in the next phase to demonstrate the feasibility of drilling these materials with hammer systems. *Note: It is possible to build samples for the Wellbore Simulator that embodies a shale lens sandwiched between the host material. It is also possible to drill into whole shale samples.*
- It appears that a quick opportunity for these tools is the underbalanced drilling applications and low weight on bit applications.
- There would be benefit in running baseline bit tests of the Novatek bit in a straight rotary drilling scenario. Should allow the measure of performance increase when used in the hammer system compared to conventional rotary systems.
- A question exists as to whether the Phast bit should be compared to a PDC bit rather than a roller cone bit.
- It appears that there is no advantage to drilling with a system utilizing both hammers and roller cone bits in terms of Rate of Penetration.
- The higher ROP data points in the Novatek system (transition points) need to be investigated and better understood.
- A question exists as to whether these tools will work on multi phase fluid.
- Would like to see more analysis of the high-speed data.

Tim Travis ExxonMobil

- Rate of Penetration is king particularly in gas well drilling. Would like to focus on 25ksi formations (pore pressures in the range of 8 to 10 ppg).
- Would like to see the program expanded to include more tool suppliers (Smith mentioned as well as a German program at Claustal) as well as bit companies. The thought is to get more expertise being applied to the bit portions of these systems.
- The bits are a huge and critical component of these drilling systems.
- Value is a key driving force in the success of this technology. The systems must provide value in the field in order to be utilized. These systems must be “user friendly “ to the rig hands that run them. They appear to be quite complex in getting the optimum pressure drops, weight on bit, and rotary speed for performance at this time.
- Underbalanced drilling applications are there. Currently drilling with air hammers. Also straight hole low weight on bit applications are potential applications.
- The performance of these tools must be proven at realistic rig capabilities.
  - For 7 7/8” to 8 3/4” hole sizes 400GPM max. 2700 psi for on shore rigs. 500 GPM 2500 to 3000psi (max 3500psi) for others
  - For 12 1/4” hole size 800 GPM max same pressure constraints.
  - Tim will supply current rig operating constraints.*

## **PLANS LOOKING FORWARD**

- Judzis to request more details of Phase 1 “lessons learned” from SDS. (*Completed 9 October and will augment the next quarterly report.*)



- Judzis to invite PDVSA and Halliburton to join the DOE program. (*Completed*)
- TerraTek to schedule Phase II planning meeting for the Advisory Board. This meeting is tentatively planned to be in the late November early December time frame.

\*\*\*\*\* end lessons learned summary

## CONCLUSIONS

- The project is on schedule with the same scope of work
- Industry interest in the project is increasing. Industry interest in determining ‘energy into the rock’ relationships for the hammers is also growing. Effort is underway to define an Industry Sponsor program for additional measurements.
- Tasks 1,2, and 3, 4, and 5 are completed.
- Task 6 is progressing and will include a Planning Meeting to determine the test matrix for the next phase of testing.