

**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 2004 through March 2004.

The DOE and TerraTek continue to wait for Novatek on the optimization portion of the testing program (they are completely rebuilding their fluid hammer). The latest indication is that the Novatek tool would be ready for retesting only 3Q 2004. Smith International's hammer will be tested in April of 2004 (2Q 2004 report). Accomplishments included the following:

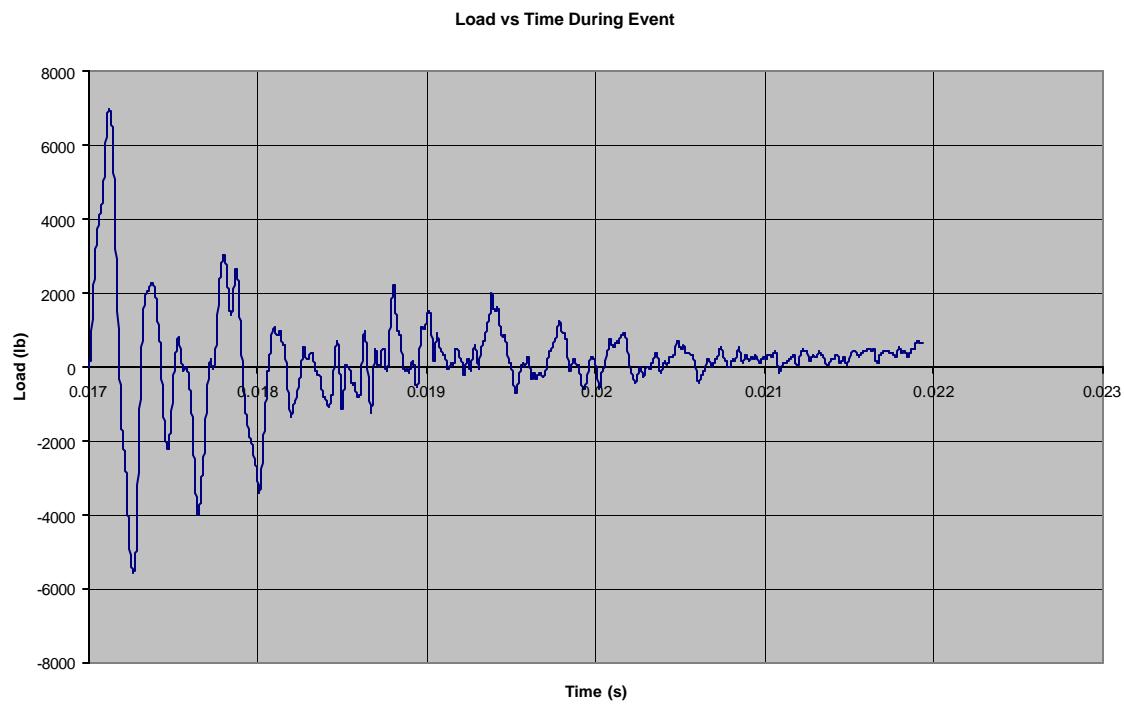
- TerraTek presented a paper for publication in conjunction with a peer review at the GTI Natural Gas Technologies Conference February 10, 2004. Manuscripts and associated presentation material were delivered on schedule. The paper was entitled "Mud Hammer Performance Optimization".
- Shell Exploration and Production continued to express high interest in the 'cutter impact' testing program Task 8. Hughes Christensen supplied inserts for this testing program.
- TerraTek hosted an Industry / DOE planning meeting to finalize a testing program for 'Cutter Impact Testing – Understanding Rock Breakage with Bits' on February 13, 2004.
- Formal dialogue with Terralog was initiated. Terralog has recently been awarded a DOE contract to model hammer mechanics with TerraTek as a sub-contractor.
- Novatek provided the DOE with a schedule to complete their new fluid hammer and test it at TerraTek.

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INTRODUCTION

The focus of the Introduction for this quarter will be on initial start-up testing on the “impact tester” (related to Task 8 of project). Results will be presented next quarter. Sample information appears below:



EXECUTIVE SUMMARY

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 Shaughnssy 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 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 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”.

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.

Presentation material was provided to the DOE/NETL project manager (Dr. John Rogers) for the DOE exhibit at the 2002 Offshore Technology Conference. Two meeting at Smith International and one at Andergauge in Houston were held to investigate their interest in joining the Mud Hammer Performance study.

SDS Digger Tools (Task 3 Benchmarking participant) apparently had not negotiated a commercial deal with Halliburton on the supply of fluid hammers to the oil and gas business. TerraTek is awaiting progress by Novatek (a DOE contractor) on the redesign and development of their next hammer tool. Their delay will require an extension to TerraTek's contracted program. Smith International has sufficient interest in the program to start engineering and chroming of collars for testing at TerraTek.

Shell's Brian Tarr then agreed to join the Industry Advisory Group for the DOE project. The addition of Brian Tarr was welcomed as he has numerous years of experience with the Novatek tool and was involved in the early tests in Europe while with Mobil Oil. Finally, Conoco's field trial of the Smith fluid hammer for an application in Vietnam was organized and has contributed to the increased interest in their tool.

Smith International agreed to participate in the DOE Mud Hammer program mid 2002 and chromed collars for upcoming benchmark tests at TerraTek, scheduled for 4Q 2002. ConocoPhillips had a field trial of the Smith fluid hammer offshore Vietnam. The hammer functioned properly, though the well encountered hole conditions and reaming problems. ConocoPhillips plan another field trial as a result.

DOE/NETL extended the contract for the fluid hammer program to allow Novatek to 'optimize' their much delayed tool to 2003 and to allow Smith International to add 'benchmarking' tests in light of SDS Digger Tools' current financial inability to participate. ConocoPhillips joined the Industry Advisors for the mud hammer program

and TerraTek acknowledges Smith International, BP America, PDVSA, and ConocoPhillips for cost-sharing the Smith benchmarking tests allowing extension of the contract to complete the optimizations tests.

During 4Q 2002, Smith International participated in the DOE Mud Hammer program through full scale benchmarking testing (5 tests) during the week of 4 November 2003. TerraTek acknowledges Smith International, BP America, PDVSA, and ConocoPhillips for cost-sharing the Smith benchmarking tests allowing extension of the contract to add to the benchmarking testing program. Following the benchmark testing of the Smith International hammer, representatives from DOE/NETL, TerraTek, Smith International and PDVSA met at TerraTek in Salt Lake City to review observations, performance and views on the optimization steps for 2003. The December 2002 issue of Journal of Petroleum Technology (Society of Petroleum Engineers) highlighted the DOE fluid hammer testing program and reviewed last years paper on the benchmark performance of the SDS Digger and Novatek hammers. TerraTek's Sid Green presented a technical review for DOE / NETL personnel in Morgantown on 'Impact Rock Breakage' and its importance on improving fluid hammer performance. Much discussion has taken place on the issues surrounding mud hammer performance at depth conditions.

At the start of 2003 the DOE and TerraTek continued to wait for Novatek on the optimization portion of the testing program (they are completely rebuilding their fluid hammer). ExxonMobil expressed interest in the possibility of a program to examine cutter impact testing, which would be useful in answering how hammers break rock and ultimately how to improve their performance. Additionally, The March 2003 issue of Drilling (American Association of Drilling Engineers) highlighted the DOE fluid hammer testing program. Information from Smith International, TerraTek and PDVSA (one of the Industry partners) provided interesting insights for the future of hammer technology. Finally, Novatek (cost sharing supplier of tools) informed the DOE project manager that their tool may be ready for 'optimization' testing late summer 2003 (August – September timeframe).

Hughes Christensen had expressed during 2Q 2003 interest in the possibility of a program to examine cutter impact testing, which would be useful in a better understanding of the physics of rock impact. Their interest however is not necessarily fluid hammers, but to use the information for drilling bit development. Novatek (cost sharing supplier of tools) informed the DOE project manager that their tool may not be ready for 'optimization' testing late summer 2003 (August – September timeframe) as originally anticipated. A task for an addendum to the hammer project related to cutter impact studies was written during 2Q 2003 and submitted to the DOE project manager. Finally, Smith International internally was busy upgrading their hammer for the optimization testing phase. One currently known area of improvement is their development program to significantly increase the hammer blow energy.

During 3Q 2003, Task 8 'Cutter Impact Testing' was added to the Mud Hammer Optimization program. Hughes Christensen confirmed interest in the program to examine cutter impact testing. Shell E&P is also highly interested in this program and they are

now part of the Industry Team. Novatek personnel (4 of them) met with TerraTek on August 14, 2003 to discuss progress with their tool for 4Q 2003 testing. The tool has been redesigned as part of another DOE program and will not be ready until 2004. And finally, a review of studies conducted at Clausthal University was undertaken and summarized by TerraTek. The PhD dissertation and accompanying post-doctorate work in German was performed on hard impermeable rocks and concluded that pressure rapidly diminishes rock breakage with cutter impact.

During 4Q 2003 'Cutter Impact Testing' was contractually added to the Mud Hammer Optimization program and TerraTek prepared the equipment for testing now scheduled to begin 1Q 2004. TerraTek also met with Smith International on November 18, 2003 in Houston to prepare 'optimization' testing plans for the DOE program aimed at assessing the performance of their completely re-designed tool. Its longer collar necessitated revision of breakout procedures and placement of the hammer in TerraTek's wellbore simulator. A revised program for testing the smith tool was subsequently developed to address inclusion of an aggressive bit and the performance of the 'optimized' tool under a variety of conditions, both considered by the Industry Advisory Board to be important. And finally at the request of the DOE project manager, TerraTek prepared a paper for publication in conjunction with a peer review session at the GTI Natural Gas Technologies Conference in February. Manuscripts and associated presentation material were delivered during 4Q 2003 on schedule.

Current

During 1Q 2004, TerraTek presented a paper for publication in conjunction with a peer review at the GTI Natural Gas Technologies Conference (February 10, 2004). Manuscripts and associated presentation material were delivered on schedule. The paper was entitled "Mud Hammer Performance Optimization". Shell Exploration and Production continued to express high interest in the 'cutter impact' testing program Task 8. Hughes Christensen supplied inserts for this testing program. TerraTek hosted an Industry / DOE planning meeting to finalize a testing program for 'Cutter Impact Testing - Understanding Rock Breakage with Bits' on February 13, 2004. Finally two items - Formal dialogue with Terralog was initiated. Terralog has recently been awarded a DOE contract to model hammer mechanics with TerraTek as a sub-contractor and Novatek provided the DOE with a schedule to complete their new fluid hammer and test it at TerraTek.

EXPERIMENTAL

Experimental work for 'Benchmark' testing has been completed with the introduction of the Smith International hammer tests during the week of 4 November 2002. Experimental work completing Task 6 is awaiting Smith's tool for April 2004 and Novatek's tool late summer 2004.

Start-up tests on the Impact Tester for Task 8 will be presented next quarter.

RESULTS AND DISCUSSION

'Cutter Impact Testing' Industry / DOE meeting at TerraTek February 13, 2004

'Cutter Impact Testing' Planning Meeting at TerraTek Understanding Rock Breakage with Bits February 13, 2004

Attendees; John Rogers, DOE/NETL
Roy Ledgerwood, Hughes Christensen
David Pixton, Novatek
Sidney Green, CEO TerraTek
Arnis Judzis, Executive Vice President TerraTek
Alan Black, General Manager Drilling and Completions TerraTek
Regrets; Brian Tarr, Shell
James Rigby and Tim Travis, ExxonMobil

Objective of Meeting – “To finalize testing plans within the sanctioned DOE program.”

Discussion –

Arnis Judzis presented an overview and background of the program (presentation attached). Most pertinent to the discussion was input obtained from the Industry Advisors to date (slide 12 – information summarized from previous communications from Roy Ledgerwood, Hughes Christensen; Jesse Holster, ExxonMobil; Brian Tarr, Shell; and Shantanu Swadi, Smith International). David Pixton confirmed his interest in the program for high wellbore pressures and determination of ‘rock damage’.

Alan Black presented (attached also) some details about the testing program and equipment status. A higher data acquisition system (PC with a/d board, etc.) was implemented after the meeting allowing satisfactory measurement of load vs. time. Work continues to upgrade the velocity and/or displacement measurements.

Issues of interest;

1. Rock damage assessment – damage ‘volume’ may be derived from a routine method such as a casting. Additional work was proposed for some samples using thin sections / petrographic analysis, CT scan, etc.
2. Mike Bruno’s DOE project with Terralog – John Rogers will work with the appropriate project manager to ensure there is connectivity of efforts with these projects. Terralog has already been in contact with Alan Black regarding the upcoming large-scale mud hammer tests with Smith International.
3. Test matrix –

<u>Rock types</u>	Crab Orchard Sandstone, Carthage marble, and Mancos shale
<u>Inserts</u>	2 types; hemispherical and conical
<u>Fluid types</u>	10 and 15 ppg WBM
<u>Impact energies</u>	To be checked; however 75, 150, and 225 Joules were proposed (beyond Claustal work). Wellbore pressure would be maintained at 3000 psi, replicate testing would be included.
<u>Specialty tests</u>	Vary impact duration, vary borehole pressure, limited tests of indexing, and aggressive PDC type cutter. Rock samples would be prepared with metal sleeves and a nominal total number of tests will exceed 50 (budgeted).

John Rogers added that this experimental work should help form the basis of subsequent analytical work and that the Industry Team see the testing program. Testing will commence in March after the equipment is

fully operational. TerraTek will supply DOE with a schedule of activities after Novatek confirms their own schedule for their new tool.

Arnis Judzis, Executive Vice President TerraTek, February 18, 2004

***** end of executive summary *****



Cutter Impact Testing

John Rogers, DOE/NETL
Roy Ledgerwood, Hughes Christensen
Tim Travis, ExxonMobil
David Pixton, Novatek
regrets Brian Tarr, Shell Exploration
Jim Rigby, ExxonMobil

February 13, 2004



Discussion topics

Introductions and context
Technical objectives
Status and testing matrix
Impact testing equipment
Closure

Meeting objective -
To finalize testing plans within DoE program

Sample readied for full-scale mud hammer test





Context

- Benchmark testing on the 3 fluid hammer systems has demonstrated their ability to operate under severe environments of high wellbore pressures in weighted mud. ROP however decreases significantly with increasing wellbore pressures.
- Fluid hammers can be optimized to provide better performance at pressure. Impact energy, pressure drop, bit design and tool unload / rock breaking are valid avenues of research.
- Some operators have harder rock applications using lower fluid weights, thus could expect reasonable performance.
- 2 of these hammers will be re-tested during 1Q and 2Q 2004.
- 'Cutter impact testing' will address the complex issue of understanding rock breaking mechanisms and challenges at pressure conditions.



Impact Testing – “Understanding Rock Breakage”

Obtain quantitative information with single cutter tests to better understand the effects of stress/borehole pressure in presence of fluid, impact energy, rock types, cutter geometry, and indexing.



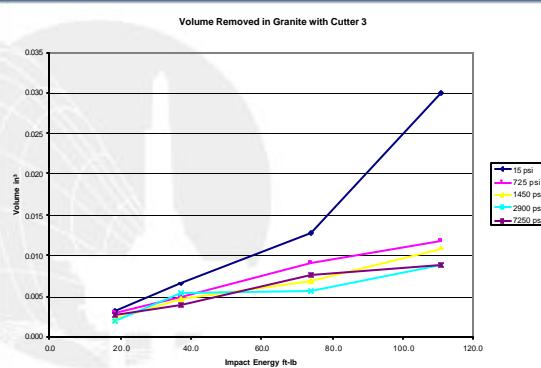
Claustal University
Per Ralf Luy 1992



TerraTek

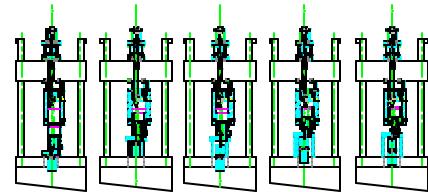


From Claustal University – Volume of rock removed vs. impact energy at various pressures w/chisel cutter





TerraTek Impact Tester Layout



Industry Partner Team Input

- Hughes Christensen; energy partitioning, function of effective stress, impact type, rock types (sandstone and carbonate)
- ExxonMobil; at wellbore pressures, ductile or fracture [observations], rock types, pore pressure, impact loading/energy, indexing
- Shell Exploration; effect of wellbore pressure, pore pressure, range of impact energies, indexing, mud weight, hard sandstone
- Smith International; rock breakage as pressures increase, threshold impact energy for 'damage', impact type
- Novatek; to be discussed at meeting
- Basis of test matrix discussion (common industry challenges)
Pressure – elevated wellbore pressures, pore pressure
Impact energy – low to high
Rock types – restrict to sandstone and carbonate
Cutter type – limit to one or two type
Record damage – photos, etc.



Photograph of sample



Communication with Terralog to witness Smith Hammer testing at TerraTek March, 2004

To: Dr Gang Han, INTERNET:ghan@terralog.com
CC: Arnis Judzis, INTERNET:judzis@terratek.com
From: Alan Black, INTERNET:abblack@terratek.com
Date: 3/29/2004, 11:38 AM
Re: Re: Schedule for Smith Hammer Testing

Dr. Gang,

I spoke with Smith this morning and they successfully tested their hammer last week. However, they now want to fabricate several backup parts for their hammer and in order to have these parts for the test, they have requested that the test be put off until the week of April 19th. We would prefer testing the week of April 12th and we are still negotiating. But it is obvious that we will not be testing during the week of April 5th. We will keep you informed whether the testing will occur during the week of April 12th or April 19th. Hopefully, this new schedule however it turns out should be firm. Thanks.

**** end of communication ***

Novatek schedule

To: [unknown], INTERNET:abblack@terratek.com
To: "Arnis Judzis", ArnisJudzis
CC: "Thegn Wise", INTERNET:TWise@novatekonline.com
CC: "Eric Terrell", INTERNET:ETerrell@novatekonline.com
CC: "John Fernandez", INTERNET:JFernandez@novatekonline.com
From: "David Pixton", INTERNET:DPixton@IntelliServ.net
Date: 3/5/2004, 11:10 AM
Re: Hammer testing schedule

Arnis, Alan:

Enclosed is the schedule we have submitted to the DOE. As shown, we expect being ready for testing under the hammer optimization program in mid June, and have allocated approximately a month for this (to accommodate your scheduling, possible reworks, etc). From our last phone conversation, the overall scope of the testing is understood to include 6 rock samples, with possible downward adjustment depending on test complexity and timing issues. We anticipate two groups of tests with a short period of time between each group to accomplish any fine tuning of the design that may be suggested by the initial group of tests. I will be in further contact with you regarding the specifics of the program.

Best regards,

David S. Pixton
Novatek, Inc.

***** end *****

CONCLUSIONS

- Benchmarking of the Smith International fluid hammer was completed in November 2002.
- Tasks 1, 2, 3, 4, and 5 are completed in the original format, now complete also with respect to Task 3 Smith tool benchmarking during 4Q 2002.
- Task 6 started having conducted a Planning Meeting and more recently discussions with Smith International for the performance evaluation of their optimized tool. Novatek plans are still pending.
- Task 7 D2 completed with formal presentation / paper as encouraged by DOE/NETL at the SPE/IAD Drilling Conference. A couple additional publications in Drilling and Hart's E&P (latter an editorial) further emphasized the results to date for the oil and gas industry. The latest publication at the request of DOE for a GTI Gas Technologies Conference was presented February 10, 2004.
- Novatek is delaying TerraTek's completion of Task 6, however the DOE is aware of this and they are separately funding the re-build of the Novatek hammer in another project.
- Task 8 started with equipment set-up and a review of cutter impact testing at Claustal University circa 1992. A joint Industry Team / DOE meeting was held on February 13, 2004 at TerraTek.