

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

Quarterly Progress Report

Reporting Period Start Date – January 1, 2005

Reporting Period End Date – March 31, 2005

Author; Arnis Judzis, TerraTek

Report Date – August, 2005

DOE Award Number – DE-FC26-00NT40918

TerraTek, Inc.
1935 South Fremont Drive
Salt Lake City, UT 84104

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

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 2005 through March 2005.

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 late 2005. Smith International's hammer was tested in April of 2004 and was covered in the 2Q 2004 report and Impact Testing was covered in part 3Q 2004. Accomplishments included the following:

- A proposal submitted for a paper in the Society of Petroleum Engineers' 2005 Annual Technical Conference and Exhibition was accepted. "Single Cutter Testing Improves Understanding of Deep-Well Hammer Drilling Performance" was co-authored by Sid Green/Arnis Judzis/Alan Black (TerraTek), John Rogers (DOE-NETL and Project Manager for the work), and David Curry/Umesh Prasad (Hughes Christensen).
- TerraTek continues to work with Novatek as requested to ensure progress in testing their updated mud hammer. Specifically engineering continued on a Novatek hammer fluid flow shroud and control systems via slip rings at TerraTek.

TABLE OF CONTENTS

Title Page	1
Disclaimer	2
Abstract	3
Table of Contents	4
Introduction	5
Executive Summary	6
Experimental	10
Results and Discussion	11
Conclusions	13

INTRODUCTION

The focus of the Introduction for this quarter will be on the engineering work by Alan Black, TerraTek's Chief Engineer, to progress re-testing of Novatek's fluid hammer. Engineering work to enclose bypass fluid flow was completed (John Fernandez was Novatek's contact) and now DOE continues to await delivery of the Novatek tool.



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 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 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.

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.

During 2Q 2004 TerraTek re-tested the ‘optimized’ fluid hammer provided by Smith International during April 2004. Many improvements in mud hammer rates of penetration were noted over Phase 1 benchmark testing from November 2002. Shell Exploration and Production in The Hague was briefed on various drilling performance projects including Task 8 ‘Cutter Impact Testing’. Shell interest and willingness to assist in the test matrix as an Industry Advisor is appreciated. TerraTek participated in a DOE/NETL Review meeting at Morgantown on April 15, 2004. The discussions were very helpful and a program related to the Mud Hammer optimization project was noted – Terralog modeling work on percussion tools. Terralog’s Dr. Gang Han witnessed some of the full-scale optimization testing of the Smith International hammer in order to familiarize him with downhole tools. TerraTek recommends that modeling first start with single cutters /

inserts and progress in complexity. The final equipment problem on the impact testing task was resolved through the acquisition of a high data rate laser based displacement instrument. And finally TerraTek provided Novatek much engineering support for the future re-testing of their optimized tool. Work was conducted on slip ring [electrical] specifications and tool collar sealing in the testing vessel with a reconfigured flow system on Novatek's collar.

During 3Q 2004 TerraTek continued the analysis of the full-scale testing of the 'optimized' fluid hammer provided by Smith International during April 2004. Many improvements in mud hammer rates of penetration were noted over Phase 1 benchmark testing from November 2002 and initial results were reported in the 2Q 2004 report to the DOE. Novatek's inability to provide an optimized mud hammer to the DOE and TerraTek on schedule mandated a no cost extension for this project. Engineering work to test the new tool at simulated depth conditions however continued with Novatek. The majority of the tests for Task 8 'Impact Testing' were conducted during 3Q 2004 with preliminary results reviewed with Industry Advisors. ReedHycalog personnel visited TerraTek and reviewed the 'Impact Testing' program with great interest on August 10, 2004 and Hughes Christensen visited TerraTek to review the 'Impact Testing' program on September 22, 2004. Roy Ledgerwood viewed the Task 8 experiments as a significant step forward. TerraTek commenced the analysis of the impact testing program with assistance by Lawrence Berkeley's Dr. Seiji Nakagawa. Early analysis has confirmed the robustness of the experimental work and validity of the data sets.

During 4Q 2004 the majority of the tests for Task 8 'Impact Testing' were conducted during 3Q 2004 with preliminary results reviewed with Industry Advisors. More data sets were analyzed during 4Q 2004. Also, TerraTek assisted the DOE in preparing a review and workshop of the Terralog 'Fundamentals of Percussion Drilling' program.

Current

During 1Q 2005 the abstract for the paper entitled "Single Cutter Testing Improves Understanding of Deep-Well Hammer Drilling Performance" (co-authored by Sid Green / Arnis Judzis / Alan Black, TerraTek; John Rogers, DOE-NETL and Project Manager for the work; and David Curry / Umesh Prasad, Hughes Christensen) was prepared and subsequently accepted by the Society of Petroleum Engineers. TerraTek continued engineering work with Novatek's John Fernandez on testing equipment related to a fluid flow shroud and control systems tied in to the TerraTek slip rings on the rig. During 2Q 2005 discussions with John Rogers to evaluate the options of testing the Novatek tool versus more impact testing will be held.

EXPERIMENTAL

Reported previously.

RESULTS AND DISCUSSION

Publication Abstract Accepted by the Society of Petroleum Engineers

Single Cutter Testing Improves Understanding of Deep-Well Hammer Drilling Performance

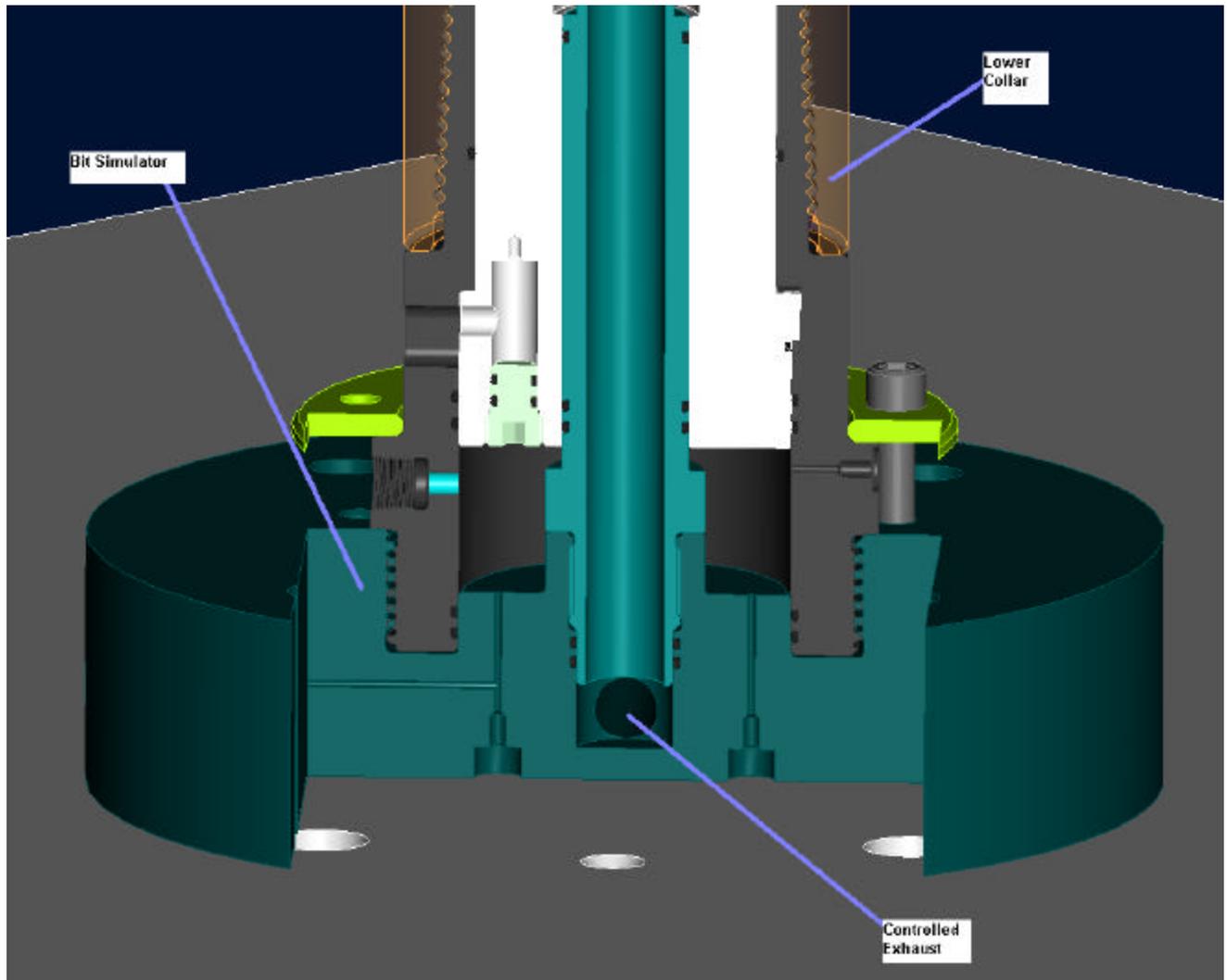
Sid Green/Arnis Judzis/Alan Black (TerraTek), John Rogers (DOE-NETL), and David Curry/Umesh Prasad (Hughes Christensen).

The use of a percussion hammer can provide high penetration rates through hard rocks when air drilling. This paper describes work partly sponsored by the DOE to develop hammer drilling techniques for drilling deep hard rocks with liquid drilling fluids. Understanding rock breakage and cuttings removal under dynamic loading conditions of hammer drilling is difficult. Historically, empirical relations have been used to relate hammer blow energy and rate with drilling under atmospheric conditions. This paper presents results of carefully measured single cutter impact and high rate rock indentation tests under high borehole pressure conditions simulating deep-drilling, using real muds. The results include force-displacement, energy inputs and crater volumes for both first stress wave (impact) and long-time (quasi static) rock indentation.

Specific energy, the energy required to excavate unit volume of rock, indicates the efficiency of the drilling process. Specific energy values have been estimated for rock breakage under first stress wave and long time loading, and used to investigate the significance of various parameters on rock drilling by impact loading. Rock type, cutter configuration, wellbore pressure, and mud type are shown to be critical parameters. A key observation is that most of the rock breakage occurs during the first stress-wave, provided the initial impact stress exceeds the rock confined indentation strength. For higher impact stresses above this confined indentation strength, relatively little additional rock breakage occurs.

The specific energy values measured in these single cutter impact tests show the rock destruction efficiency that can be achieved by impact loading. They are compared with specific energies measured during full scale hammer and rotary drilling experiments under equivalent conditions to evaluate the potential for improving deep well drilling performance, which is significant for optimum design of bits.

Engineering for Novatek Test



CONCLUSIONS

- 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 in progress having conducted a Planning Meeting and testing of Smith International's optimized tool. Novatek plans are still pending with the DOE.
- 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 experimental work has been completed. Most experimental work was conducted during 3Q 2004.
- TerraTek was instrumented in organizing for DOE an Industry Review of the project entitled 'Fundamental Research on Percussion Drilling'. This was a task added in to the TerraTek program and partially paid through a sub-contract from Terralog.
- A new publication will be prepared through the SPE as a result of the acceptance of the recent abstract related to the 'impact' testing work.