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

Topical 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 year starting January 2002 through December 2002.

Accomplishments to date include the following;

**Review of 2001**

**Q1 2001**

- 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 the 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.

**Q2 2001**

- 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 has completed 13 drilling tests in Carthage Marble and hard Crab Orchard Sandstone with the SDS Digger Tool, Novatek tool, and a conventional rock bit. After some initial mud pump and flow line problems at TerraTek, we completed the testing matrix for the SDS Digger Tool and the Novatek hammer on 27 June 2001. Overall the hammers functioned properly at 'borehole' pressures up to 3,000 psi with weighted water based mud. 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.

**Q3 2001**

- 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.

**Q4 2001**

- TerraTek provided information and a drilled hard rock sample to highlight DOE's National Energy Technology Laboratory effort on Mud Hammer Optimization at the October 2001 Annual Conference and Exhibition for the Society of Petroleum Engineers. The original exhibit scheduled by NETL was however cancelled due to events surrounding the September tragedies in the US and the rock sample was returned to TerraTek for future use by NETL.
- In accordance to Task 7.0 (D. #2 Technical Presentations) TerraTek successfully completed the manuscript detailing phase 1 testing results for 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 present the paper in February of 2002.
- PDVSA has joined the advisory board to this DOE mud hammer project and has formally committed funds (cost sharing) for the upcoming effort in testing at TerraTek.

## Progress during current reporting year 2002

### Q1 2002

- 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.

### Q2 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 has 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 has agreed to join the Industry Advisory Group for the DOE project. The addition of Brian Tarr is 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.

- 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.

**Q3 2002**

- Smith International agreed to participate in the DOE Mud Hammer program.
- Smith International chromed collars for upcoming benchmark tests at TerraTek, now 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.

**Q4 2002**

- Smith International participated in the DOE Mud Hammer program through full scale benchmarking testing 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 step 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.

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## INTRODUCTION

The focus for the first quarter 2002 was 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.


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

The focus for the 2nd quarter was on the presentation material provided to DOE/NETL's exhibit at the Offshore Technology Conference May 2002.

Learnings to date

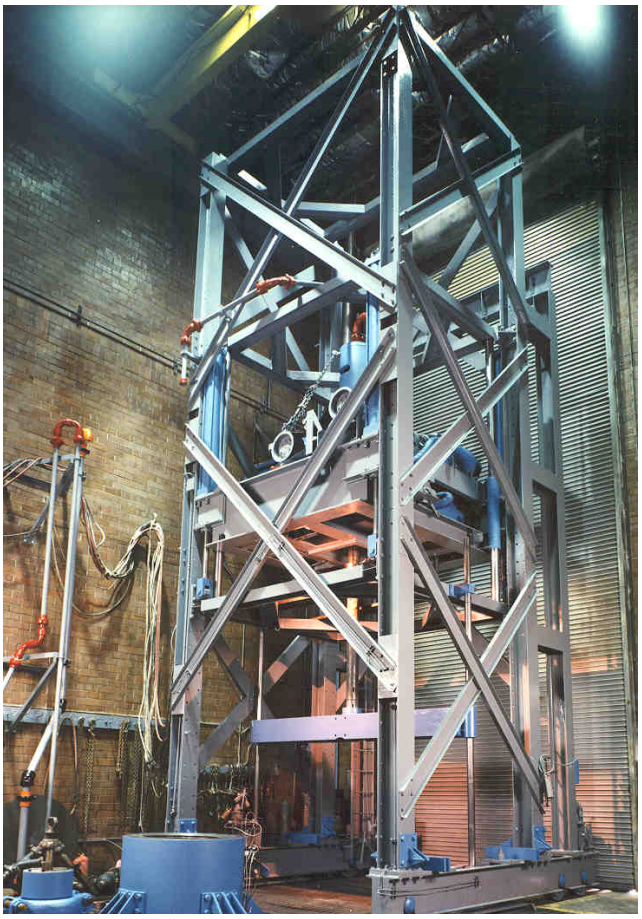
Fluid Hammers have the ability to operate in 10 to 15 ppg muds

Fluid Hammers drilled medium to hard rock effectively in muds

Competitive ROPs demonstrated at moderate borehole pressures

Mud Hammer suppliers now in 'optimization' phase of testing

Hammer - bit *system* can also be optimized for hard rock drilling



The focus of the third quarter was on the announced participation by Smith International to test their fluid hammer under 'benchmarking' conditions established by the program last year and to participate in the optimization phase now awaiting Novatek's progress likely in 2003.

Chroming of collar during late summer was done to accommodate testing in TerraTek's Wellbore Simulator. The smooth finish allows the tool to stroke through the seal pack and maintain downhole conditions within the sample.

The focus of the fourth this quarter was on the recently completed benchmark testing of the Smith International fluid hammer under conditions established by the program last year.

Following deployment of the Smith hammer offshore Vietnam during August and September of 2002, the hammer was stripped, inspected and readied for DOE testing at TerraTek. The hammer is a nominal 7" size and used a standard 8-1/2" air hammer bit shown in the photograph below.

## EXECUTIVE SUMMARY

Progress on the testing of fluid driven drilling hammers is encouraging and was on track during 2002;

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 2001 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".

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 has 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 agreed to join the Industry Advisory Group for the DOE project Spring 2002. The addition of Brian Tarr is 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 again 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. And finally, TerraTek's Sid Green presented a technical review for DOE / NETL personnel in Morgantown (December 17, 2002) 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.

## EXPERIMENTAL

Q1 and Q2; 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.

Experimental work for 'Benchmark' testing has been completed with the introduction of the Smith International hammer tests during the week of 4 November 2002.

Q3 and Q4; The following test matrix was followed (13 tests were previously done):

| DOE Number* | Hammer/Bit | Rock | Mud Density, ppg |
|---|---|---|---|
| 13 Test #14 | 3 cone IADC Code 537 | Carthage | 9 ppg brine |
| 14 Test #15 | Smith | Carthage | 9 ppg brine |
| 15 Test #16 | Smith | Carthage | 10 ppg water-based |
| 16 Test #17 | Smith | Crab Orchard | 10 ppg water-based |
| 17 Test #18 | Smith | Carthage | 15 ppg water-based |

***Prior reports reviewed Tests 1 through 13 using DOE #s to 12**

From previous testing, the comparison to 'conventional drilling' is available for 10 and 15 ppg fluids. Industry input at the February '02 planning meeting (particularly BP, PDVSA) prompted plans to use a lighter weight brine as extra data points.

## RESULTS AND DISCUSSION

### Q1

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**

| TEST | DESCRIPTION | ROCK SAMPLE |
|---|---|---|
| 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 re 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.

**ATTENDENCE 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 dung 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.

**Q2**

This section of the report will expand upon some of the major issues progressed during the three month time period.

Meetings with Smith International

**Dimensions of Smith's Mud Hammer**

| | Length (inches) | | | |
|---|---|---|---|---|
| | Start* | End | Diameter | Section |
| **Top Sub** | 0.0 | 22.2 | 6.75 | 22.2 |
| | 22.2 | 26.2 | 6.50 | 4.0 |
| | 26.2 | 36.2 | 7.00 | 10.0 |
| **Casing** | 36.2 | 61.2 | 7.00 | 25.0 |
| | 61.2 | 107.7 | 7.13 | 46.5 |
| | 107.7 | 124.8 | 7.25 | 17.1 |
| **Retainer** | 124.8 | 133.1 | 7.63 | 8.3 |
| **Bit** | 133.1 | 136.8 | 8.75** | 3.7 |

* Length is measured from the top of the tool (uphole side)
** Bit diameter (range 7.875 to 8.75")
*** The top sub and casing each are beveled .08x45 degrees

| | | |
|---|---|---|
| **Overall Length** | **136.8** | **inches** |

Memo June, 2002 to "Mr. Swadi [Smith International],

It was a pleasure to meet you and discuss this project over the phone this morning.

After our discussion on the appropriate placement of the chrome on your tool, I took a more detailed look at the test scenario. I believe the optimum placement of the chrome on the 7.13" diameter x 46.5" would be the following:

Start the chrome 4" from the top of the sub and end the chrome 3 1/2" from the bottom of the sub. This will provide for a limited tong area on both the top and bottom just in case we have to break the tool down while it is here at the drilling laboratory. The top 4" should be undercut to allow burrs from "tonging" to not contact the seal surfaces during installation throughout the test program. The diameter might be the same as the adjacent sub.

This placement of the chrome will provide a total drilled depth of 28" into the test sample. The 28" will provide ample rock to gather the needed operational parameters for the tool. 8 1/2" diameter bits were used in the previous testing programs and as such will most likely be the choice for these tests also. The chrome specification that we have used in the past is as follows:

.006" to .008" Hard chrome Mil spec. QQC-320A Type II Class 2A. Grind to a 16 finish. Diametrical tolerance is +000 -002".

Gordon Tibbitts, TerraTek"

Industry Partner (PDVSA) and SDS Digger Tools)

Mamo June 2002 to "Alejandro [PDVSA],

Gordon is on well deserved holiday, thus I will answer your questions.

First of all, I have attached the 1Q '02 progress report as delivered to the US Department of Energy. The second quarter report will be written end July '02.

Progress on the 'optimization' of the two tools has been slow, though here is my assessment of the situation. Novatek is building a completely new tool with a redesigned valve. The DOE is funding another project at Novatek (telemetry) thus they have put their resources on that project. The DOE and TerraTek expect a September schedule of tests at TerraTek.

SDS Digger has been difficult to reach. Gary Algate again informed me this week Malcolm in Australia needs money to ship the tool here plus personnel. I have not yet been contacted by him directly, though this indicates that their 'cost sharing' commitment is difficult to meet. If the amount is small, perhaps SDS can ask BP or ExxonMobil for some direct costs (?). TerraTek must certify Industry Cost sharing as we spend/invoice the DOE - that is mandatory per contract. I do not have a clear schedule for them, however Gary said that September is likely. SDS are also sending a tool to Vietnam for the Conoco application, thus that may be occupying their time. Have you contacted Malcolm since our planning meeting?

TerraTek has approached other suppliers with good success. Smith is willing to provide their hammer and test at TerraTek sometime in August. We are seriously considering this new opportunity given the fact that TerraTek's contract with the DOE will now need time extension and the DOE has approved the option of 'benchmarking' the Smith hammer "immediately". The DOE acknowledges that delays by Novatek (also a DOE contractor) and SDS Digger are commercially unacceptable to TerraTek.

Andergauge is also willing to test their 'hammer'(longer tool though) at TerraTek. They do not have funds to cover testing costs on their own.

Other operators are indeed interested too, though getting money has been difficult. Most prominent is Shell however there has been silence since May '02 from them. Any further operator interest and cost sharing could result in immediate testing of the Smith and possibly Andergauge tools, followed by a September re-test of the delayed Novatek and SDS tools.

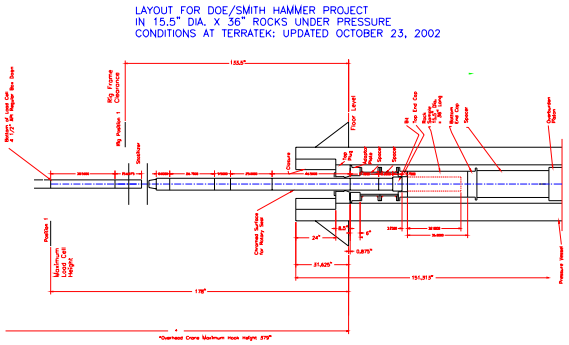
I hope this helps. If you have better contacts with SDS or other operators, please let me know.

Arnis Judzis
TerraTek
judzis@terratek.com
+1(801) 584-2483”

**Q3**

This section of the report will expand upon some of the major issues progressed during the three month time period.

Plans were underway to add the Smith collar to the testing program. Various experimental programs and layouts to fit TerraTek’s Wellbore Simulator were discussed and drawn up.




Scope of Work Changes

**Task 3.1.1 Addition**

The following table will be inserted or added to the agreement in order to test Smith international mud hammer tool in Subtask 3.1.1 Test program under test sequence. All other testing specifications will remain as in the original agreement

| Test | Hammer/Bit | Rock | Mud Density, ppg |
|---|---|---|---|
| 13 | Smith | Carthage | 10 |
| 14 | Smith | Crab Orchard | 10 |
| 15 | Smith | Carthage | 15 |
| 16 | Smith | Crab Orchard | 15 |
| 17 | Conventional | Carthage or Crab | * |
| 18 | Smith | * | * |

* From previous testing, the comparison to 'conventional drilling' is available for 10 and 15 ppg fluids. Industry input at the February '02 planning meeting (particularly BP, PDVSA) prompted plans to use a lighter weight brine as extra data points.

**Task 5.1: Promoting Industry Development and Experience with Fluid Hammers** The task will seek out other hammer suppliers (e.g. Andergauge) and operators not currently in the program and determine if mud hammers could increase significantly hard rock drilling performance in their operations

**Subtask 5.1.1:** TerraTek and its Industry partners will implement the recommendations from the Industry Advisory Board planning meeting and reassess the capabilities of the early developers of Mud Hammers.

**Subtask 5.1.2** TerraTek will evaluate information available from field trials available from its contacts within the industry (e.g. PDVSA in Venezuela, Conoco's hard rock drilling program, and BP's domestic hard rock drilling areas).

**Subtask 6.3.1** The difficulties experience by both Novatek and SDS Digger are attributed in part to the challenge imposed by the DOE – that is ensure the satisfactory 'performance of mud hammers at depth and with actual drilling fluids'. TerraTek's tests under Task 4 provided the Industry partners with learnings perhaps exceeding what was originally expected – tools would require greater development times to optimize and could require different testing methods; e.g. SDS Digger is considering the use of a combination pressure balanced stroke sub – hammer system to deliver weights-on-bit independent of drill string extensions. Testing of these tools will require more extensive set-ups and time at TerraTek.

The Industry suppliers have already been working on Tasks 6.1, 6.2, and 6.4 as part of the preparation for Large-Scale testing.

**Schedule and Milestones**

Original portion of Task 3 has already been completed. The addendum to Task 3.1.1. (above) will be conducted during September and October 2002. Milestone will be the test results of the Smith tool benchmark performance
Original portion of Task 5.0 has already been completed. Proposed Tasks under 5.1 would commence immediately and continue through completion of Task 6.3 July 2003. An interim project meeting with Industry Advisors is now planned subsequent to benchmarking the Smith Tool (ca. November 2002).

Task 6.3 will commence end 2002 pending resources allocated by another DOE contractor Novatek. Testing is projected to commence November 2003 and end May 2003, assuming that SDS will continue to have prototype development deficiencies and scheduling problems identified in the completed 'benchmark' testing.

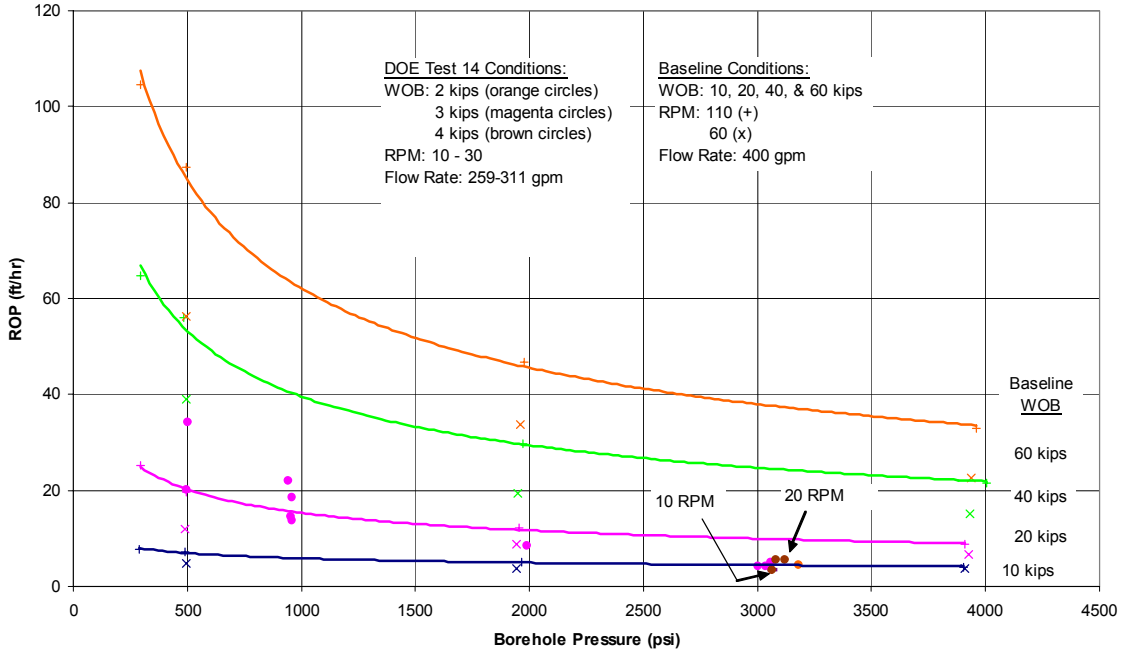
Task 7.0 Final Report will be completed by August 2003.

End of Scope of Work Changes section

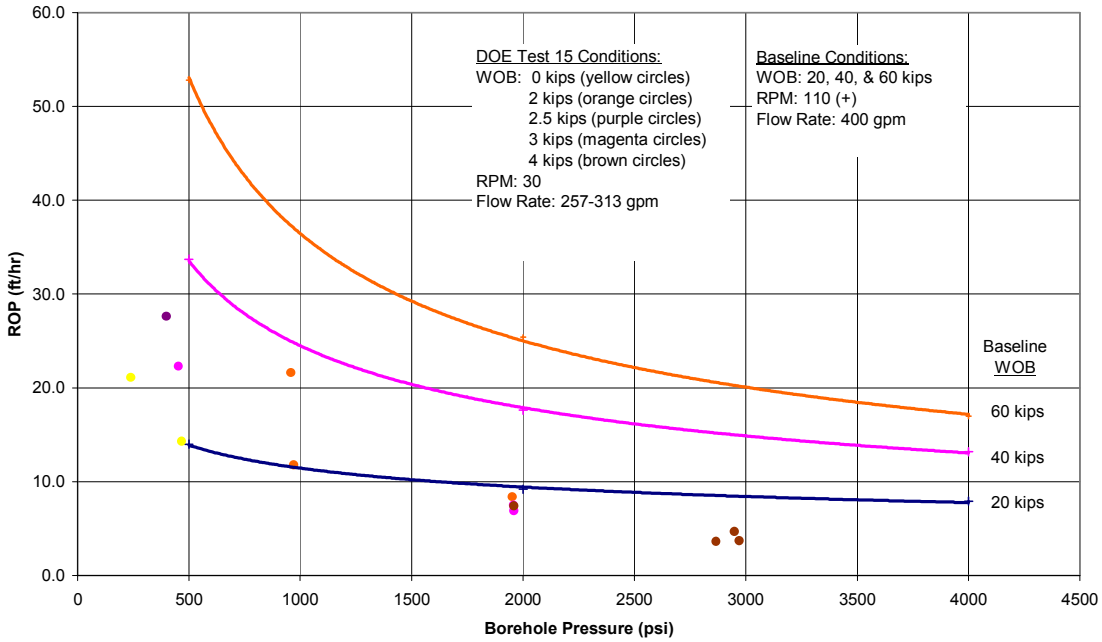
**Q4**

This section of the report presents performance results of the Smith Hammer during the three month time period.

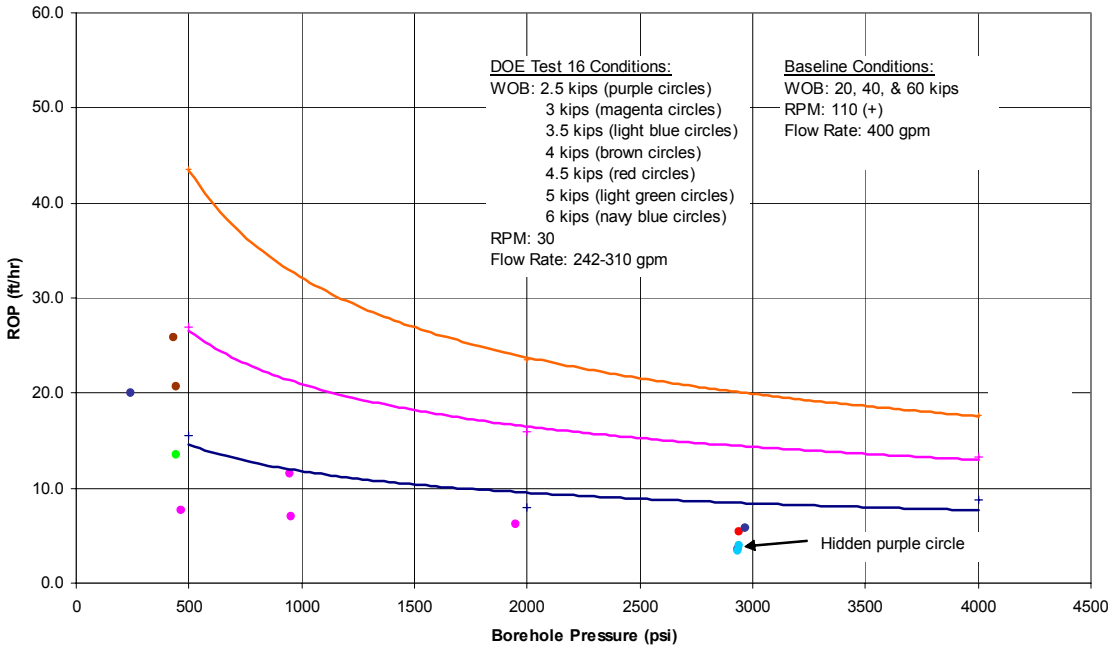
**DOE Test 14 with Smith Hammer Compared with 8 1/2" Reed HPSM Baseline Bit for 9.0 ppg NaCl Brine and Carthage Marble**



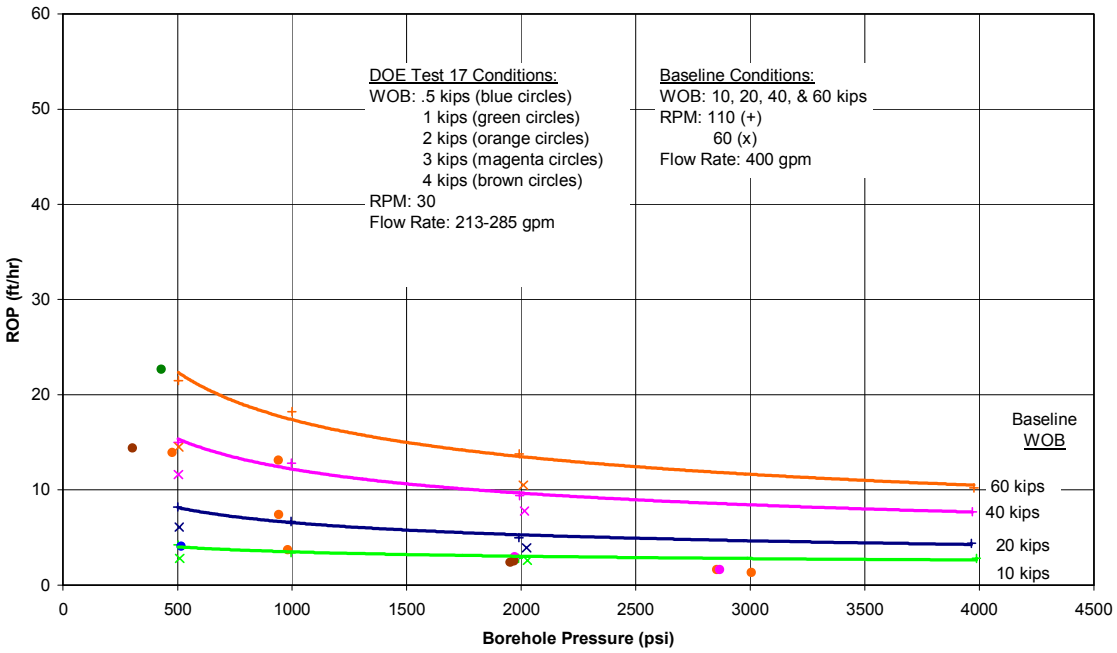

**DOE Test 15 with Smith Hammer Compared with 8 1/2" Reed HPSM Baseline Bit for 10 ppg Water-Base Mud and Carthage Marble**



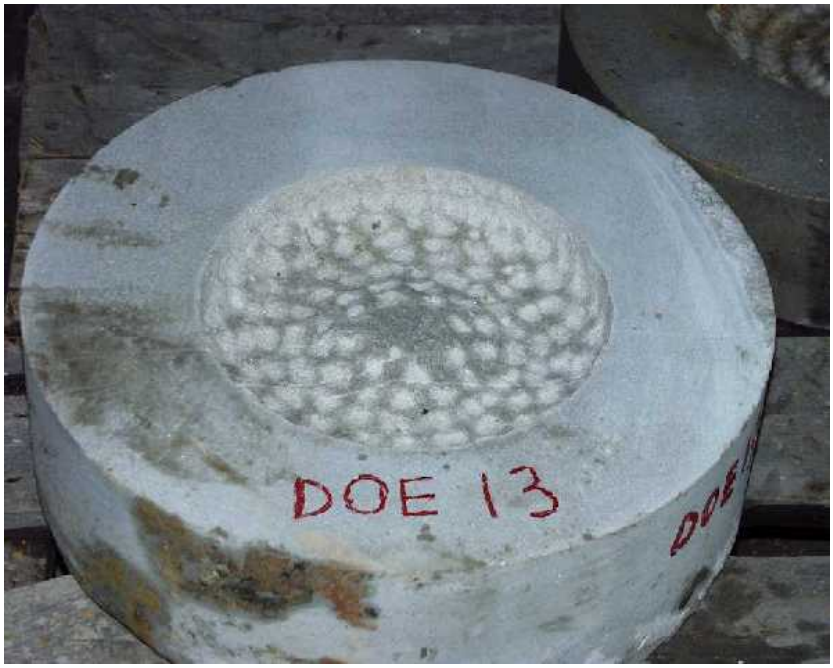
**DOE Test 16 with Smith Hammer Compared with 8 1/2" Reed HPSM Baseline Bit for 10 ppg Water-Base Mud and Crab Orchard Sandstone**




**DOE Test 17 with Smith Hammer Compared with 8 1/2" Reed HPSM Baseline Bit for 15 ppg Water-Base Mud and Carthage Marble**

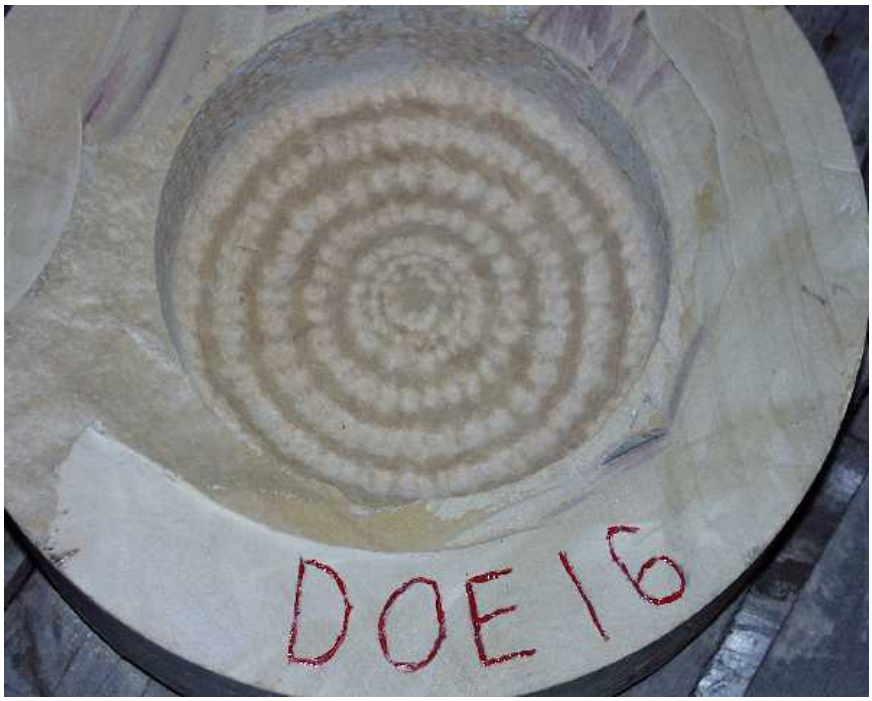


Bottomhole patterns were also photographed;





DOE 15


DOE 16


**Lesson Learned Meeting Summary November 7, 2002**

Attendees; John Rogers (DOE / NETL), Lance Underwood and Shantanu Swadi (Smith International), Alejando Lagreca and Delcio de Santana (PDVSA), and Arnis Judzis (TerraTek). Regrets from Rich Reiley (BP) and Gary Collins (ConocoPhillips).

Discussion;

Lance Underwood (Smith) – Some field experience [data] better than observed at TerraTek; performance did not beat 3 cone bit especially with high borehole pressures. 80% of their forecasted market is at 10 ppg or less. Smith views energy input and bit design important for optimization. Check into higher rate data collection for optimization tests. Smith potential markets for mud hammer – Brazil, Travis Peak and Cotton Valley sandstones, cherts in W. Texas, carbonates various locations. Lance is also interested in rock destruction by looking at impact testing of single cutters, etc. Need to quantify effects and energy requirements at high borehole pressures among other things.

Shantanu Swadi (Smith) – Also views energy input as being crucial.

Alejandro Lagreca (PDVSA) – Need to understand fundamental relationships such as energy input. ROP can be studied . . will have to also look at longevity. 9 or 10 ppg fluid seen as biggest current use for hammers.

John Rogers (NETL) – Parameters such as mud weight can be suggested by operators and service companies. 15 ppg mud weight could be representative of Tuscaloosa or deep Anadarko. DOE's aim is to improve gas productivity in the domestic market and fluid hammers should make a difference. What do we need to change for upcoming optimization tests? . . . energy level, hammer/bit system, etc. Make ROP good and reliable.

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JPT ONLINE

Mud-Hammer Drilling Performance

This article, written by Assistant Technology Editor Karen Bybee, contains highlights of paper SPE 74540, "World's First Benchmarking of Drilling Mud-Hammer Performance at Depth Conditions," by Gordon A. Tibbits, TerraTek; Roy C. Long, SPE, U.S. Dept. of Energy; Brian E. Miller, SPE, BP; and Arnis Judzis, SPE, and Alan D. Black, SPE, TerraTek, originally presented at the 2002 IADC/SPE Drilling Conference, Dallas, 26-28 February.

Operators continue to look for ways to improve hard-rock drilling performance. A consortium of Dept. of Energy (DOE), operator, and industry participants assembled an effort to test and optimize mud-driven fluid hammers as an emerging technology that shows promise to increase penetration rates in hard rock. The full-length paper details the results of full-scale testing of two 7 3/4-in.-diameter mud hammers with 8 1/2-in. hammer bits and compares their performance with a conventional tricone bit.

**Introduction**

The majority of drilling-related costs are incurred drilling harder rock. Improved rate of penetration (ROP) in hard rock has the potential to reduce overall well costs. Estimated costs to drill hard rock in the U.S. is U.S. $1,200 million. Potential savings of U.S. $200 million to $600 million are possible if ROP in hard rock is doubled with reasonable bit life. Mud-hammer development has been going on for some time, but performance and endurance have not been tested adequately for mud hammers to be a viable commercial tool in deep drilling applications. Hammer performance had been sketchy at best, and mud hammers are reported to have performance problems at high borehole pressures and in muds containing high solids percentages. Full-scale testing under simulated drilling conditions offered an economical alternative to high-day-rate field testing as well as a clear performance comparison of different power levels, rotary speeds, weight on bit (WOB), bit types, mud densities, and rock types.

**Background**

The DOE implements its Office of Fossil Energy upstream natural-gas technology development program by cost-shared research projects. These projects are initiated and managed by DOE's Natl. Energy Technology Laboratory (NETL). In response to the Energy Information Admin. forecast that gas consumption will increase 60% by 2020, NETL is cost-sharing various technology-development projects to enhance deep-gas development. NETL's focus on mud hammers is a direct result of its attempt to reduce drilling costs and make deep-gas exploration economics more attractive to industry. The mud hammer was considered to be a technology with potential to reduce deep-gas drilling costs because of demonstrated capabilities of existing air and water hammers in hard-rock drilling applications and ease of incorporating mud hammers into existing drilling systems.

**Operator Needs**

For hard and abrasive drilling conditions in deep wells drilled with mud, tricone bits have the highest ROP, but their susceptibility to wear and bearing failure limits their drilling time. In deeper hole sections, where tripping times are longer, thermally stable polycrystalline or natural diamond bits are chief competitors of the tricone bit, especially in smaller hole sizes. Thermally stable polycrystalline and natural diamond bits have a much longer bit life to offset their lower ROP and reduce overall cost per foot compared with tricone bits. Hammer drilling with simple percussion drill bits has proved to be an economical alternative for a range of hard-rock drilling applications including drilling with air or clear water as drilling fluid. Air drilling results in the highest ROPs, and air-hammer drilling is a widely used alternative for many air-drilled hole sections. Hammer drilling with percussion bits in clear water is a relatively new alternative that has been limited to relatively shallow holes (i.e., less than 3,000 ft). Because of hammer drilling performance in clear-water applications, operators are interested in learning if these drilling systems can provide an economic alternative in hard-rock drilling applications with weighted muds at deeper hole depths. The controlled drilling tests reported in the full-length paper provide key insights into mud-hammer drilling not available from random field tests.

**Test Program**

To determine economic viability of hammer drilling with percussion bits in deep hole sections drilled with weighted mud, the test program was designed to explore only the ROP performance of available fluid-driven hammer tools. An advisory board composed of representatives from the DOE/NETL, ExxonMobil, BP, TerraTek, Novatek, SDS Digger Tools, and Pajarito Enterprises directed the test program. Carthage marble was selected to represent a moderately hard limestone. Crab Orchard sandstone was selected to represent hard sandstone. Two water-based muds (WBMs), 10.0 and 15.0 lbm/gal, were used for high-solids-content drilling fluids to provide realistic comparisons to field muds used in conventional drilling. Performance of an 8 1/2-in. tricone bit [Intl. Assn. of Drilling Contractors (IADC) 537 tungsten carbide insert bit] was documented in paper SPE 15620, "Roller-Bit Penetration Rate Response as a Function of Rock Properties and Well Depth." The tests described were run using a 10.0-lbm/gal WBM while drilling Carthage marble and Crab Orchard sandstone at various WOB conditions and constant rotary speed. Additional tests were performed with the same bit with 15.0-lbm/gal WBM.

As borehole pressure increases, ROP decreases. The highest borehole pressure was 3,000 psi. Data also were obtained at 2,000, 1,000, and 500 psi. Confining stress and overburden stress were held constant at 4,000 psi and 5,000 psi, respectively. Although the main goal of the program was to examine drilling performance at the 3,000-psi borehole pressure, the lower-borehole-pressure data provided information about the performance transition from low to higher borehole pressure. All mud-hammer and conventional drilling tests were run in a wellbore simulator that can perform drilling experiments with full-scale bits, high flow volumes, and high fluid pressure with a variety of drilling muds and rock samples stressed to in-situ conditions. The laboratory has extensive instrumentation and data collection equipment to measure and record information from drilling experiments. In a typical test, the 15 1/2-in. jacketed rock sample was connected to the top vessel plug that sealed the mud hammer and bit combination. The assembly then was lowered into the wellbore simulator. The upper closure of the wellbore simulator would be inserted and the drillstring made up to the drilling rig. Because the rock samples were relatively strong, confining and overburden stresses were applied to the rock before flowing the pressurized mud into the borehole. When rock stresses and borehole pressure were established, the sample was drilled following a procedure that outlined tool pressure drop, rotary speed, and WOB.

**Results**

The tricone bit did not perform as well in the 15-lbm/gal WBM as in the 10-lbm/gal WBM. Rotary speed for both mud weights was 110 rev/min, but the data for the 15-lbm/gal WBM contains some data taken at 60 rev/min. Hydraulic horsepower per square inch for the 15-lbm/gal mud was maintained by running different nozzle diameters in the bit at the same flow rate. Results of the tricone bit tests comprise the baseline and comparison data for mud-hammer performance.

SDS Tool Performance. The SDS tool operates (cycles) only after a predetermined weight is applied to the tool. The tool cycles very smoothly. The bypass nozzles were blocked off during these tests, although in field operation they are directed uphole and may be fitted with different diameter nozzles to match drilling rig hydraulic requirements. Fig. 1 shows the impact bit used with the SDS mud hammer. In Carthage marble, ROP performance at 3,000-psi borehole pressure appears to be approximately the same at all pressure drops and rotary speeds. ROP is 2 to 4 ft/hr. WOB was a constant 10,000 lbf.


Fig. 1—Impact bit used with the SDS mud hammer.

Performance was similar in Crab Orchard sandstone with 10-lbm/gal WBM. Performance at various pressure drops and rotary speeds is lower than with a conventional bit, especially at borehole pressures greater than 1,000 psi. ROP was 2 to 4 ft/hr. Similar results were obtained in the two rock types when mud weight was increased to 15 lbm/gal, although ROP was lower in the higher-weight mud system. ROP ranged from 1 to 3 ft/hr. When a more aggressive percussion-type bit was run with the mud hammer, significant improvement was seen at lower borehole pressures, and, in some cases, performance was better than the tricone performance. As the borehole pressure was increased, performance improved moderately. ROP at 3,000-psi borehole pressure ranged from 3 to 7 ft/hr.

Novatek Performance. The Novatek tool operates (cycles) when a minimum amount of fluid is pumped through the tool, and it will cycle with no WOB. As WOB is applied, the tool closes until the anvil is loaded and then transfers the impacts to the cutting structure.

When a Novatek N5 mud hammer was run with an IADC 537 tricone bit in 10-lbm/gal mud, the resulting ROPs clustered around the performance of the standard IADC 537 tricone rotary drilling results at its lowest WOB and 110 rev/min. ROP ranged from 4 to 10 ft/hr. Although performance levels for the Novatek tool and the polycrystalline diamond cutter bit (Fig. 2) were in the lower range or below the comparison bit in early tests, a couple of points were observed that showed moderate performance increases over the IADC 537 bit. The performance level of the Novatek tool and polycrystalline diamond cutter bit exceeded that of the rotary-drilled tricone bit in Crab Orchard sandstone and came close to the best-case performance curve when drilling the Carthage marble.

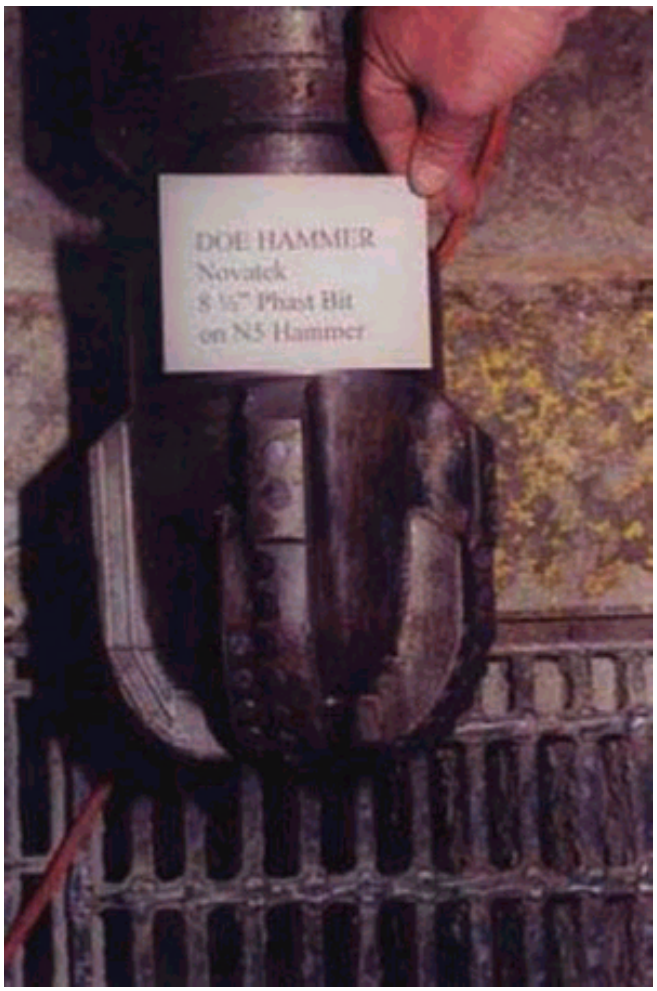


Fig. 2—Novatek bit.

**Conclusions**

1. New generation mud hammers have the ability to operate in 10- to 15-lbm/gal WBM.
2. There is no advantage in using mud hammers with conventional IADC 537 tricone bits.
3. Drill bits designed to exploit both rotary and impact-applied loads provide better performance used with mud hammers.
4. Performance improvement is significant for the Novatek mud hammer in the transition region between low and high WOB.

********** ***End of publication*** **********

## 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 concluded a Planning Meeting in February 2002 to determine the test matrix for the next phase of testing. The Industry Advisors will reconvene an additional time prior to formalizing the optimization test matrix.
- Task 7 D2 completed with formal presentations / papers as encouraged by DOE/NETL.

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6. 'Mud-Hammer Drilling Performance', Journal of Petroleum Technology, December, 2002, pg 38.