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

Quarterly Progress Report

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DISCLAIMER

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 April 2004 through June 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 4Q 2004 or later. Smith International's hammer was tested in April of 2004 (2Q 2004 report). Accomplishments included the following:

- 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.
- 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.

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INTRODUCTION

The focus of the Introduction for this quarter will be on relatively successful testing of the optimized Smith International tool. Results appear in the experimental section. The key features contributing to an overall improved performance from Phase 1 testing includes increased blow energies and the addition of internal components to achieve higher efficiencies, thus horsepower. Aggressive bit designs such as a chisel inserts also have the opportunity for further improvements.

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.

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.

<u>Current</u>

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.

EXPERIMENTAL

Experimental work for 'Optimization' testing has been completed with the Smith International hammer tests during the weeks of April 19 and 26, 2004. Experimental work completing Task 6 is awaiting Novatek's tool late 2004 or early 2005.

The following test matrix was followed (17 tests were previously done):

DOE Number	Hammer/Bit	Rock	Mud Density, ppg
18 Baseline	3 cone IADC Code 537	Crab Orchard / Carthage	10 ppg water-based
19	Smith, standard bit	Crab Orchard / Carthage	9 ppg brine
20	Smith, standard bit, but with torque 'feed-back'	Crab Orchard / Carthage	10 ppg water-based
21	Smith, standard bit	Crab Orchard	10 ppg water-based
22	Smith, aggressive bit with chisel cutters	Carthage	10 ppg WBM followed by 15 ppg water-based

Industry input at the February '02 planning meeting (particularly BP, PDVSA) prompted plans to use a lighter weight brine as extra data points. Test #22 was interrupted before weighting up to 15 ppg due to some hammer tool problems.

<u>Details</u> – 8-1/2" bits (including aggressive chisel shaped)
Addition of internal 'accumulator' system to hammer
350 to 400 gpm flow rate. Pressure drops ~2500 psi
Servo control on torque signal – Many data points at 600 to 800 ft-lb

DOE - Smith Hammer Drilling Test Plan Updated April 7, 2004

1. Number of Tests: 5 plus torque checkout test

2. Type Tests:
   1 baseline, 10 ppg water-base, roller-cone, Crab Orchard/Carthage composite
   1 torque control checkout, 10 ppg water-base, roller-cone, Carthage
   1 hammer, 9 ppg NaCl brine, standard bit, Crab Orchard/Carthage composite
   1 hammer, 10 ppg water-base, standard bit, Crab Orchard/Carthage composite
   1 hammer, 10 ppg water-base, standard bit, Crab Orchard ss with pore pressure
   ½ hammer, 10 ppg water-base, aggressive bit, Carthage marble ½ drilled
   ½ hammer, 15 ppg water-base, aggressive bit, Carthage marble ½ drilled
   *Composite: Spud 1", drill CO 17", drill Carthage 16", leave 3" at bottom

3. Test Control: TerraTek will attempt to set up the torque signal as feed back to the servo-controller and will check out this torque feed back mode prior to the DOE tests. If successful, torque feed back will be used to control the four hammer tests in the 500 to 1000 ft lbs torque range.

4. Test 18 Baseline Test: Using the standard 8 ½" diameter Reed HPSM baseline bit, drill a composite sample of Crab Orchard ss/Carthage marble using a 10 ppg water-base mud and limit WOB 40,000 lbs and RPM 60 rpm. Run 10, 40 and 60 kips WOB, 60 rpm and borehole pressures of 500, 1000, 2000 and 4000 psi.

5. Test 19 Hammer Test: Using Smith hammer with 8 ½" standard bit, drill a composite sample of Crab Orchard ss/Carthage marble using 9 ppg NaCl brine in torque feed back between 500-1000 ft lbs with 500, 1000, 2000 and 3000 psi borehole pressures and flow rates 400 gpm or less as specified by Smith. RPM will be specified by Smith. Near the end of the test, drill a short distance at 0 psi borehole pressure by directly flowing back to the mud tank.

6. Test 20 Hammer Test: Using Smith hammer with 8 ½" standard bit, drill a composite sample of Crab Orchard ss/Carthage marble using 10 ppg water-base mud in torque feed back between 500-1000 ft lbs with 500, 1000, 2000 and 3000 psi borehole pressures and flow rates 400 gpm or less as specified by Smith. RPM will be specified by Smith. Three times during the test (after 500 and 3000 psi borehole pressure in the Crab Orchard sandstone and 500 psi borehole in the Carthage marble) the test will be stopped and the cuttings screen emptied and the vessel opened up and sample removed to photograph the bottom hole pattern. After test, collect cuttings from 3000 psi in the Carthage marble and photograph bottom hole pattern. Near the end of the test, drill a short distance at 0 psi borehole pressure by directly flowing back to the mud tank.

7. Test 21 Hammer Test: Using Smith hammer with 8 ½" standard bit, drill a full saturated sample of Crab Orchard ss using 10 ppg water-base mud in torque feed back between 500-1000 ft lbs with differential pressure across the filter-cake from underbalanced to balanced to 3000 psi overbalanced. Initially pump fluid at a known rate into the bottom of the sample and through the borehole to create an underbalanced drilling condition. After drilling a short distance, stop pumping and with a borehole pressure and pore pressure equal at 3000 psi (0 psi differential) begin drilling and then open the pore pressure valve and begin bleeding off pore pressure at a reasonably controlled rate from 3000 to 0 psi. As differential pressure across the filter-cake increases, then ROP should decrease. With flow rate 400 gpm or less as specified by Smith, RPM as specified by Smith, drill the entire sample. During the drilling test, continuously monitor borehole and pore pressure and the amount of pore fluid volume expelled versus time. Knowing the permeability of the Crab Orchard sandstone, back calculate the pressure drop across the rock and the resulting differential pressure across the filter-cake as (Borehole Pressure minus Pore Pressure) – (Calculated Pressure Drop Across the Rock).

8. Test 22 Hammer Test Using Smith hammer with 8 ½" an aggressive bit, drill ½ of a full Carthage marble sample using a 10 ppg water-base mud in torque feed back between 500-1000 ft lbs with 500, 1000, 2000 and 3000 psi borehole pressures and flow rates 400 gpm or less as specified by Smith. RPM will be specified by Smith. Stop the test and increase mud density to 15 ppg and drill the remaining ½ of the Carthage marble sample at the same conditions. Three times during the test (after 500 and 3000 psi borehole pressure with 10 ppg mud and at 500 psi borehole with 15 ppg mud, the test will be stopped and the cuttings screen emptied and the vessel opened up and sample removed to photograph the bottom

hole pattern. After test, collect cuttings from the 15 ppg and 3000 psi condition and photograph bottom hole pattern. Near the end of the test, drill a short distance at 0 psi borehole pressure by directly flowing back to the mud tank.

9. Data Acquisition: Smith will bring their own data recording equipment to record the dynamic WOB and torque signals at 500 to 1000 Hz continuously. TerraTek will provide the cables to direct the signals to the Smith data acquisition system in the form of +/- 10 volt DC signals.

10. Accumulators: Set up and tie down two 10 gallon accumulators if available or one only and set gas pressure to 600-800 psi.

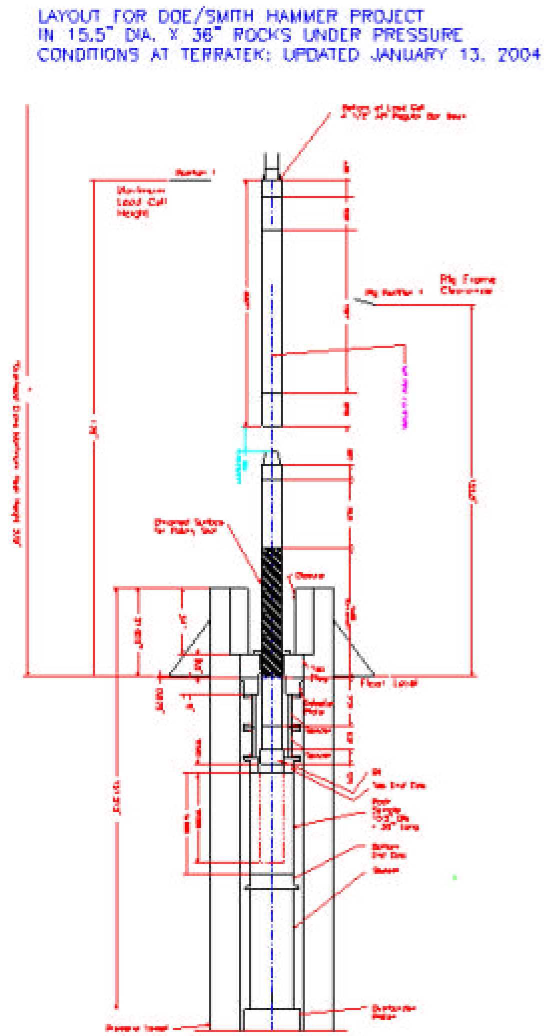
11. Make up/breakout: TerraTek will provide a Scorpion make up/breakout unit with up to 30,000 ft lbs capacity to assist Smith in disassembling a section of the hammer, modifying the tool for the next mud weight and then assembling it again.

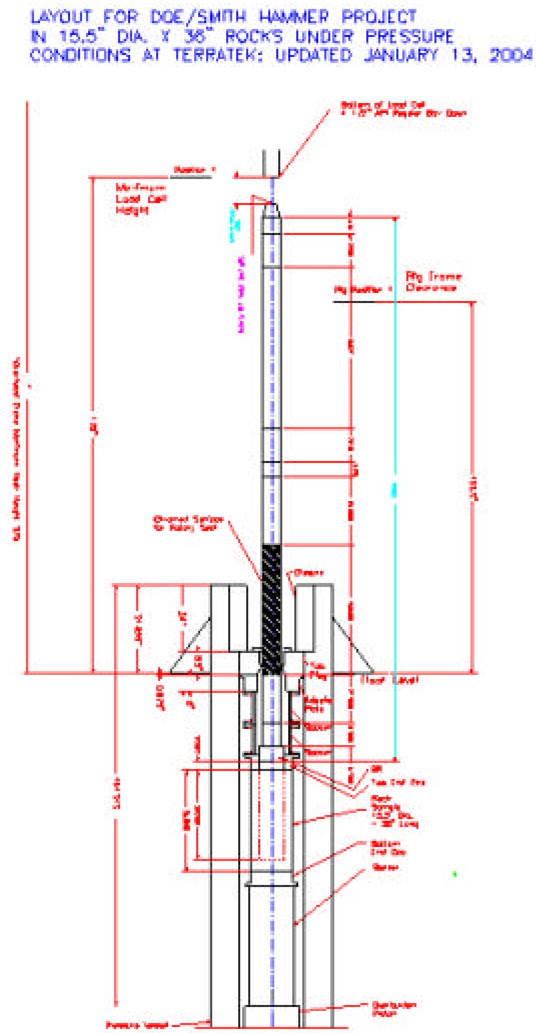
12. Cuttings collection: During Tests 20 and 22, the test will be stoppedthree times (at 500 and 3000 psi in the Crab Orchard ss and at 500 psi in the Carthage marble) to empty the cutting collection screen in an attempt distinguish the differences in cuttings size and shape for these conditions. Also, after the test the cuttings from the 3000 psi borehole pressure in the Carthage marble will be collected. Therefore, a comparison can be made between cuttings generated at 500 and 3000 psi borehole pressure in both rock types.

13. Bottomhole Photos: During Tests 20 and 22, the sample will be removed three times during the test (at the same time the cuttings are recovered as noted above) and the mud from the bottomhole will be cleaned out and the bottom hole pattern photographed. It will be necessary to mount the camera on an extension rod and to provide lighting to get the camera close enough to the bottom hole to distinguish the bottom hole pattern clearly.

14. Test 21 Pore Pressure: Prior to Test 21, a 15.5” diameter by 35.5” long Crab Orchard sandstone sample will be evacuated and saturated with water. After placing the sample inside the pressure vessel and applying confining pressure, water will be pumped into the bottom of the sample via a flow distributor plate to flow through the sample. A 100 psi back pressure will be maintained on the water flowing out of the sample to help distribute the water throughout the sample and to absorb any residual gas into the pressurized water. Since the Crab Orchard sandstone has a relatively low permeability, this process will likely take at least 24 hours to complete the saturation. After the saturation is complete and just prior to the drilling test, the borehole pressure will be raised to 3000 psi and the pore pressure will be increased to 3000 psi by pumping water into the bottom of the sample to elevate the pore pressure to 3000 psi. As drilling commences, water will be pumped at a know rate to create an underbalanced drilling condition and then the pumping will be stopped and the pore pressure stabilized again at 3000 psi. At this balanced condition, drilling with the hammer at a fixed RPM and torque will again commence. A valve will then be opened on the pore pressure outlet to allow the pore pressure to be reduced (hopefully in a controlled manner) from 3000 psi to zero while the sample of Crab Orchard sandstone is being drilled up with the Smith hammer. The objective is to determine the effect of overbalance (borehole minus pore) on penetration rate. As noted, it will be necessary to measure the pore fluid volume with time to determine a filtration rate in order to calculate the pressure drop across the rock as the hole is deepened. The resulting differential pressure across the filter-cake as (Borehole Pressure minus Pore Pressure) – (Calculated Pressure Drop Across the Rock).

16. Test Schedule: Baseline and torque check out week of April 12th and hammer testing week of April 19th.





RESULTS AND DISCUSSION

Optimization testing of Smith International Fluid Hammer

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

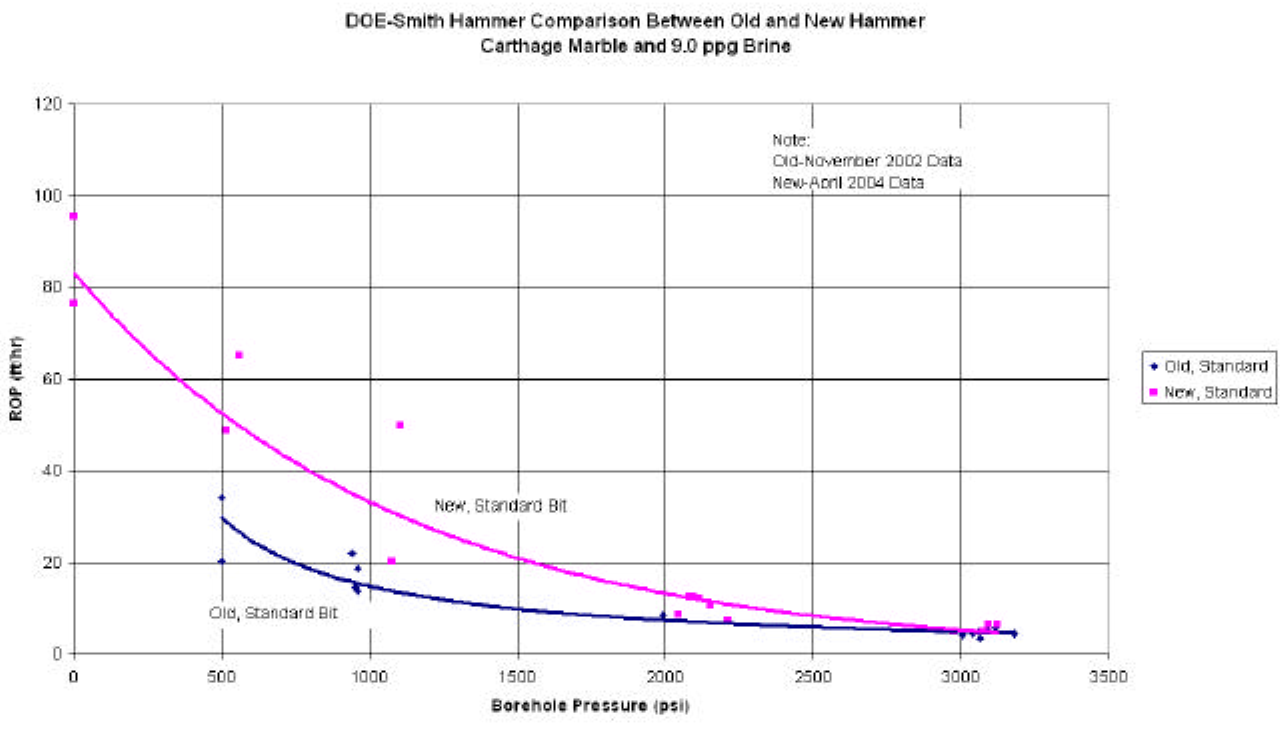


Figure 1 - Reference DOE Test 19

Figure 1 Carthage marble, 9.0 ppg brine with old hammer design and standard bit
Carthage marble, 9.0 ppg brine with new hammer design and standard bit

As seen in Figure 1, the new hammer/standard bit ROP performance was significantly improved at borehole pressures lower than 2000 psi. At 2000 psi borehole pressure, there was a smaller improvement and at 3000 psi the performance was about the same.

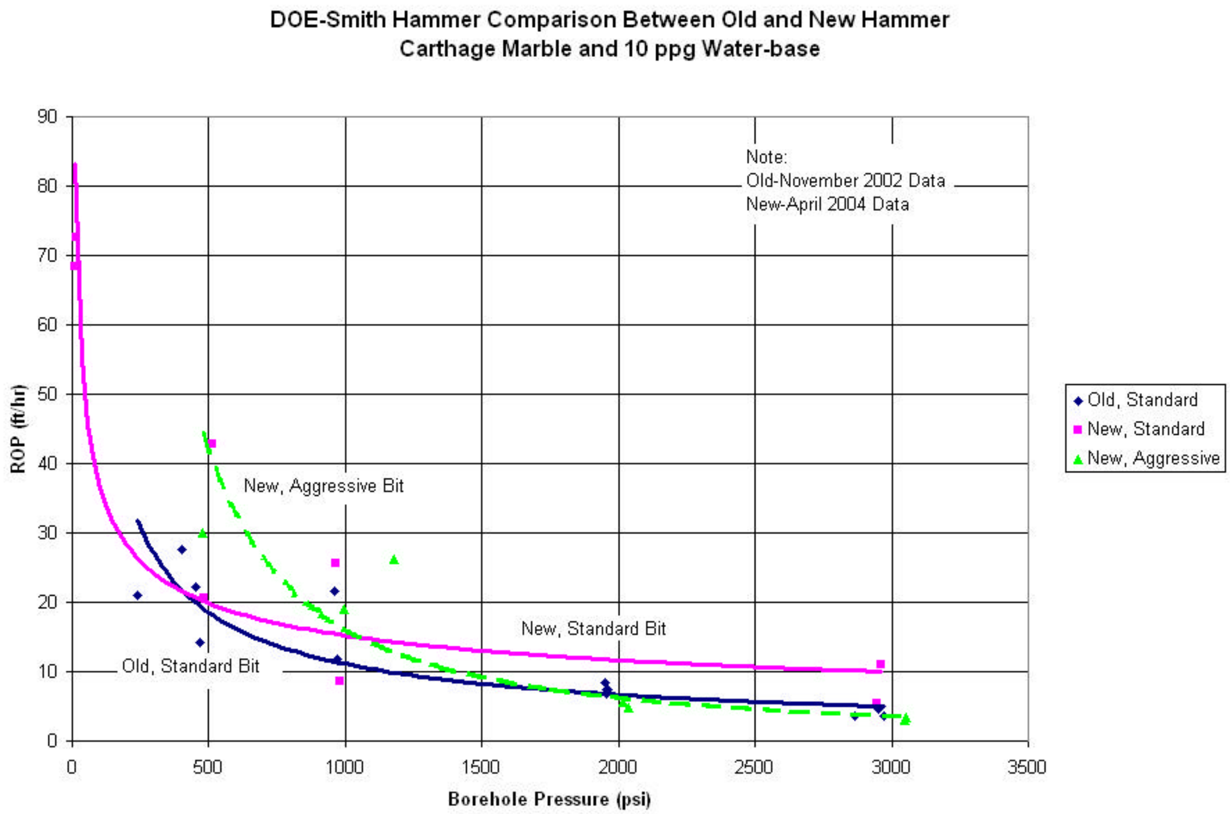


Figure 2 – Reference DOE Tests 20 and 22

Figure 2 Carthage marble, 10 ppg WB with old hammer design and standard bit
Carthage marble, 10 ppg WB with new hammer design and standard bit
Carthage marble, 10 ppg WB with new hammer design and aggressive bit

As seen in Figure 2, the ROP performance of the new hammer/standard bit was in general greater than the old hammer/standard bit, however, the ROP performance was not consistent with the new hammer/standard bit. In some cases, the ROP performance was significantly greater, but then in other cases it was about the same. The new hammer / aggressive bit showed significant ROP improvement below 2000 psi borehole pressure, but at 2000 and 3000 psi borehole pressures, the performance was about the same as the old hammer/standard bit.

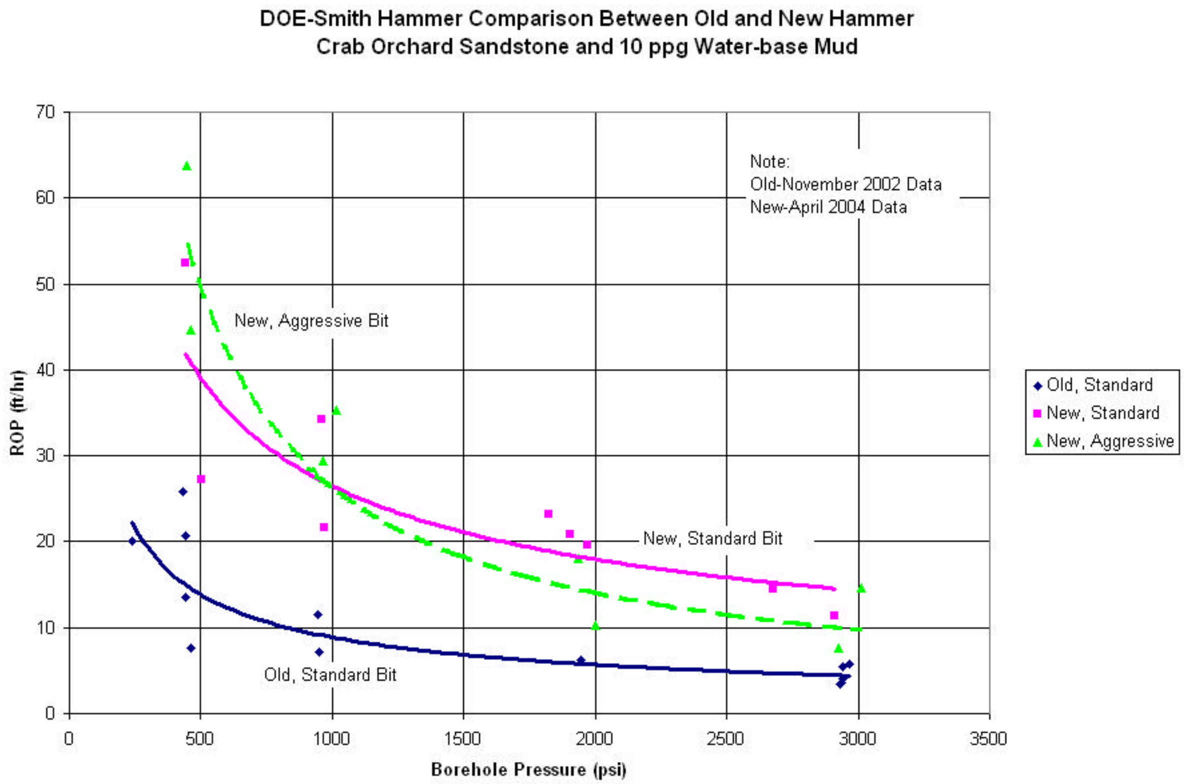


Figure 3 – Reference DOE Tests 20 and 22

Figure 3 Crab Orchard ss, 10 ppg WB with old hammer design and standard bit
Crab Orchard ss, 10 ppg WB with new hammer design and standard bit
Crab Orchard ss, 10 ppg WB with new hammer design and aggressive bit

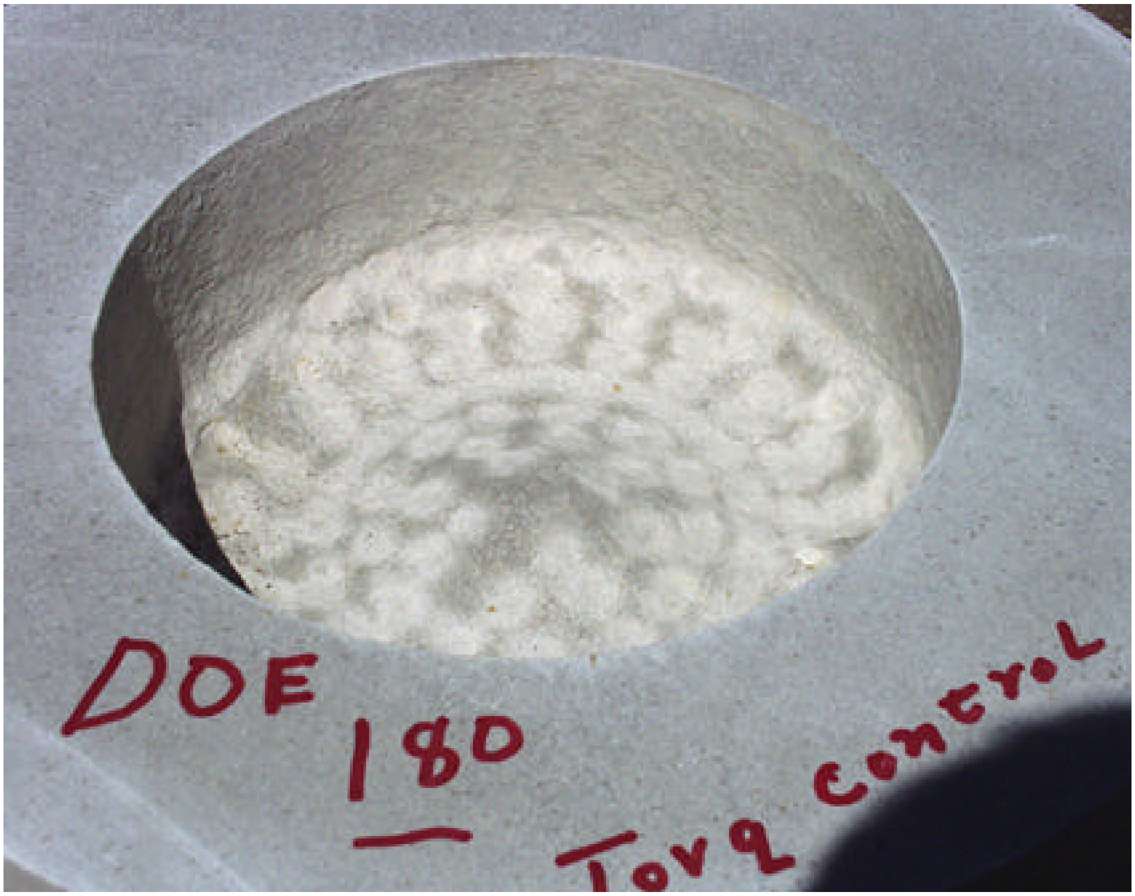
As seen in Figure 3, in the Crab Orchard sandstone both the new hammer/standard bit and the new hammer/aggressive bit had very significant (2-3 times greater) ROP improvements over the old hammer/standard bit even at the higher borehole pressures. The ROP performance between the new hammer and standard and aggressive bit was similar.

The new hammer design failed during the end of the 10 ppg water-base fluid testing. As a result, the testing of the Smith hammer was ended and no testing was performed with 15 ppg water-base fluid. The rock sample was saved and Smith indicated a desire to fix the problem and finish the testing around the same time the Novatek hammer is tested at TerraTek. This will be evaluated and considered depending upon budget constraints.

Analysis of Test 18 will be done for the next report as will Test 21. The Crab Orchard sandstone was rather tight making pore pressure control difficult.

Representative photos of bottomhole patterns;

Test 18



Part of Test 20

Part of Test 21

Part of Test 22

Engineering for Novatek tool re-test

*****

To: John Fernandez, INTERNET:JFernandez@novatekonline.com
CC: Arnis Judzis, INTERNET:judzis@terratek.com
From: Alan Black, INTERNET:ablack@terratek.com
Date: 6/18/2004, 8:04 AM
Re: Re: Scissors Adaptor axial location

John,

I have been working on the layout for the Novatek hammer test and have attached an ACAD file and a Word file with a possible layout. Study it and then let's discuss. It looks like it will be feasible to have our stabilizer installed which will provide a place to mount the upper sealing device. The layout includes a concept for mounting the upper sealing unit. I believe it would need to be a split (two part) assembly to allow makeup of the API thread and then to bolt the two parts together after the thread is made up. This would require a way to support the upper sealing device prior to the make up. The slip ring would be mounted under the slip ring on a short (7") sub. As you can see, things are tight and getting the layout correct will be critical. Let's discuss after your review.
*****

To: John Fernandez, INTERNET:JFernandez@novatekonline.com
CC: Arnis Judzis, INTERNET:judzis@terratek.com
From: Alan Black, INTERNET:ablack@terratek.com
Date: 6/23/2004, 11:40 AM
Re: Re: Scissors Adaptor axial location

John,

Concerning the gland dimensions for the seals. I believe the seals we use to seal the 7" diameter chrome shaft are probably larger than you would want to use for the leak seals, however, let me give you the information and then you can decide. The OD of the steel part that receives the seal is 8.750 +.005/-.000 diameter. The seals we use are custom made by Economos 79 West 4500 South #2 Murray, Utah 84107 281-3800 Brian is contact. They have both a concave and convex 90 degree V-grooves on opposite sides and the seal thickness and width are both about 0.8" thick. The seals have some type of teflon fill and the material is identified at ECOFLON 2. We also have a bearing bronze ring on both sides of the seal with matching V-grooves. The OD and ID of the bearing bronze we have been using is 8.746" and 7.127", respectively. It is critical to have the bearing bronze in contact with the chrome shaft and to keep any steel housing or support away from the chrome shaft. These seals typically have a very sharp sealing edge and so it is important to provide chamfers or other lead in's so the seals do not have to pass over sharp lips or edges that could cut into the sealing lip. The stack of bearing bronze (2 rings) and seal need to have some clearance in the mounting groove for thermal expansion. In other words, the seals are activated and seal by pressure and are not pre-loaded on the seal. We have an example of what the seal looks like we could loan you if that would help.

Concerning the mud outlet port and scissor arrangement, since the flow is small I now think we would be better off with a reinforced rubber hose and therefore suggest for now that we put a 3/4" or 1" NPT female thread in your fixture for directing the flow out and then purchase a 5000 psi hose of the appropriate length to allow the rig movement. We should verify that we can get such a hose before committing to the tapped hole size. The ID of the hose should be large enough to avoid any possibility of erosion inside the hose. If there was such a thing as a urethane lined hose, we find urethane very good for minimizing erosion. The steel scissor idea would also work, but it is almost impossible to design in advance and would be more of a trial and error type arrangement. What do you think?

I will be here today and tomorrow, gone on Friday, in the office on Monday of next week and then will be gone until the Tuesday after the 4th holiday should you need to contact me before I leave. Thanks.

----- Original Message -----
From: John Fernandez
To: Alan Black
Sent: Monday, June 14, 2004 8:21 AM
Subject: Scissors Adaptor axial location

Alan,

I trust you had a good vacation at you son's graduation.

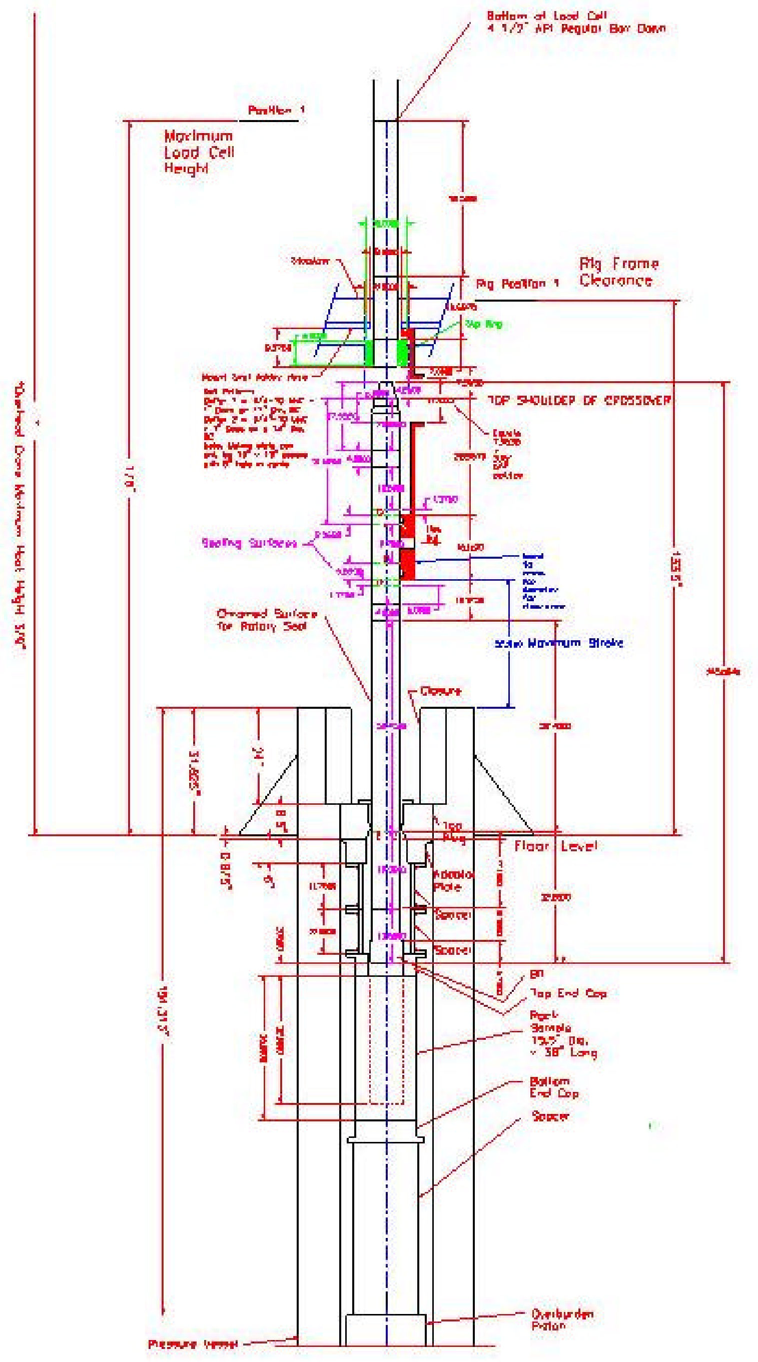
We are developing the adaptor for the upper exhaust at the moment. We would like to know the gland dimensions for the seal that is used at the bottom location to use it at the top adaptor. Additionally, what is the size of the scissors device connection?

We forgot to photocopy the drawing of the layout that was used in the previous test; could you fax it to 1-800-373-4707.

Thanks,

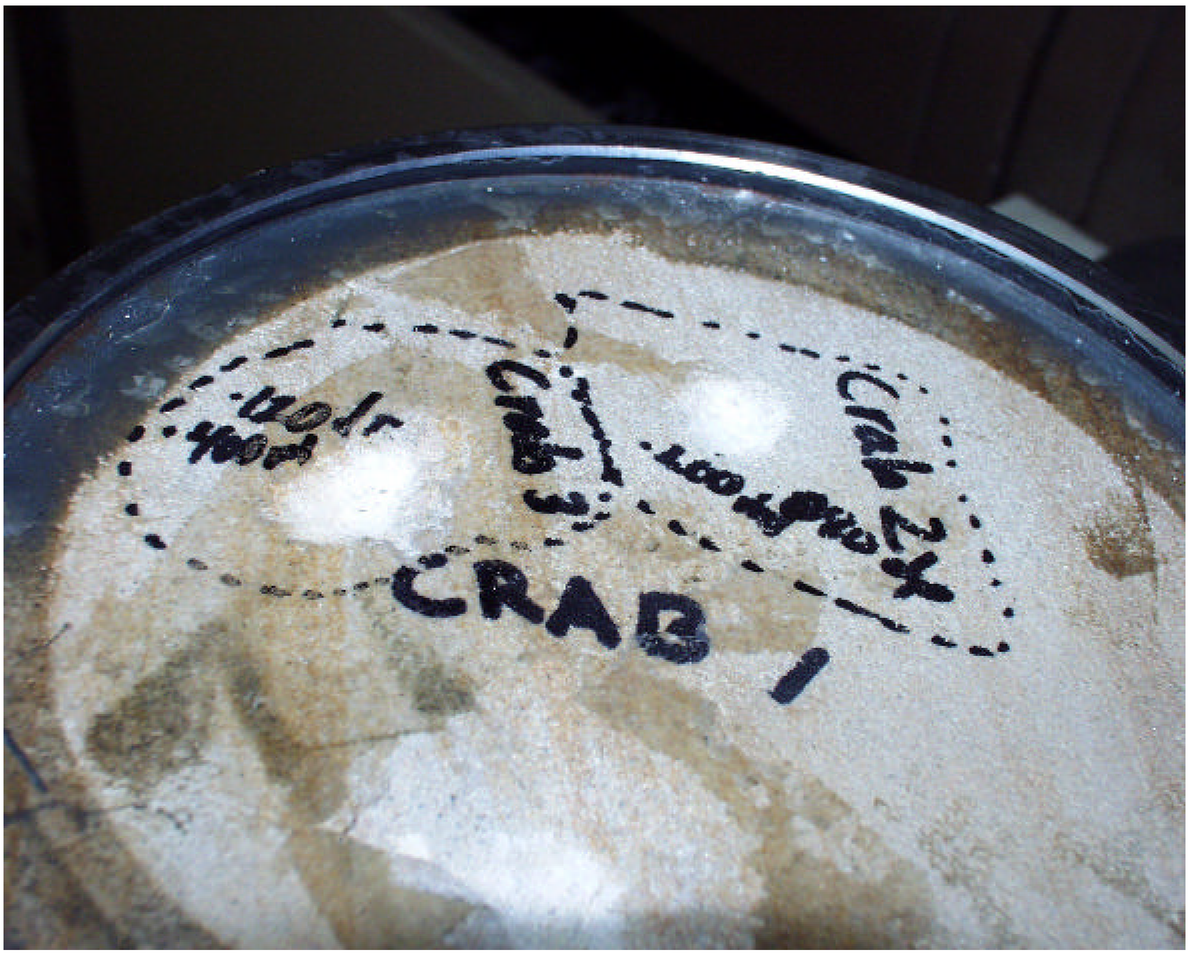
John Fernandez

LAYOUT FOR DOE/NOVATEK HAMMER PROJECT
IN 15.5" DIA X 36" ROCKS UNDER PRESSURE
CONDITIONS AT TERRATEK: UPDATED JUNE 17, 2004



Task 8 Impact Testing

After significant delays in instrumentation, the equipment was thoroughly tested with a number of trial checkout tests. The 3Q 2004 will report on the result of testing and analyses completed.



Variables, Measurements and Calculations

- Main Variables
  - Rock Type
  - Fluid Type
  - Borehole Pressure
  - Cutter Type
  - Gas Pressure-Input Energy
  - Piston Travel-Input Energy
  - Gas Dump Orifice-Loading Rate
  - Others-Impact spacing, cutter contact vs gap
- Measurements
  - Iload (strain gaged load cell on impact rod)
  - Idispl (laser displacement transducer
  - Borehole pressure, H-Gas, L-Gas
  - Cutter indention
  - Crater volume
- Calculations
  - Energy (load vs displ)
  - Specific energy

DOE Test Matrix

- Rock Types
  - Carthage marble
  - Crab Orchard ss
  - Mancos shale
- Fluid Density
  - 10 ppg WB
  - 15 ppg WB
- Borehole Pressure
  - 3000 psi
- Cutters
  - Conical
  - Spherical
- Input Velocity and Travel of Gas Piston
  - 350, 500, 500 (repeat) and 600 in/sec (0.25”, 0.5”, 0..5” (repeat) and 0.75”)
- Number of Tests
  - 3 rocks x 2 fluid densities x 2 cutters x 3 input energies + 1 repeat = 48 test

Checkout Test Results

- Crab2, Crab Orchard, Conical Cutter, 3000 psi Borehole, 450 psi Gas Pressure, 0.75” Piston Travel and 0.03” to Bottom Piston
- Results
  - 0.08” Indention
  - 0.0122 cu. in. Volume
  - 40.5 ft-lbs (54.9 Joules) Energy
  - 3318 ft-lb/cu. In. Spec. Energy

- Crab3, Crab Orchard, Conical Cutter, 0 psi Borehole, 450 psi Gas Pressure, 0.75” Piston Travel, 0.04” to Bottom Piston
- Results
  - 0.12 Indention
  - 0.0244 cu. In. Volume
  - 57.8 ft-lbs (78.3 Joules Energy
  - 2369 ft-lb/cu. in. Specific Energy

CONCLUSIONS

- Large-scale testing of the optimized and redesigned Smith International fluid hammer at simulated downhole conditions was conducted during April 2004. Smith is hoping to complete another test as they experienced a malfunction during the drilling of the final rock sample. This will be decided later due to possible budgetary constraints.
- Rates of penetration were much improved from Phase 1 benchmarking, in some cases significant improvements compared to baseline roller cone bits and ROPs noted above 10 ft/hr. Industry Advisors had always hoped to exceed the 10 ft/hr drilling rate at high wellbore pressures – in some cases the Smith tool achieved that goal.
- The optimization process that Smith International used included a near doubling of blow energy (increased tool efficiency, more horsepower, and various internal component changes). There were some operational differences including the use of higher flow rates, a successful demonstration of an aggressive bit with chisel shaped cutters, and the use of a servo-control on the torque signal at TerraTek's drilling facility to better operate the hammer.
- At higher borehole pressures (one of the original DOE goals to test mud hammers in harsh environments) craters from cutter impacts are less prominent when compared to lower borehole pressures. This follows from the fact that the rocks will act stronger and the breaking / cutting mechanism changes somewhat.
- 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 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 and during 2Q 2004 final startup was completed with the acquisition of a laser based displacement device. The testing results will be reported next quarter and one of the Industry Advisors plans a review of the data at TerraTek.