Smaller Footprint Drilling System for Deep and Hard Rock Environments; Feasibility of Ultra-High Speed Diamond Drilling

Topical Report

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ABSTRACT

The two phase program addresses long-term developments in deep well and hard rock drilling. TerraTek believes that significant improvements in drilling deep hard rock will be obtained by applying ultra-high (greater than 10,000 rpm) rotational speeds. The work includes a feasibility of concept research effort aimed at development and test results that will ultimately result in the ability to reliably drill 'faster and deeper' possibly with rigs having a smaller footprint to be more mobile. The principle focus is on demonstration testing of diamond bits rotating at speeds in excess of 10,000 rpm to achieve high rate of penetration rock cutting with substantially lower inputs of energy and loads.

The project draws on TerraTek results submitted to NASA's 'Drilling on Mars' program. The objective of that program was to demonstrate miniaturization of a robust and mobile drilling system that expends small amounts of energy. TerraTek successfully tested ultra-high speed (~40,000 rpm) small kerf diamond coring. Adaptation to the oilfield will require innovative bit designs for full hole drilling or continuous coring and the eventual development of downhole ultra-high speed drives.

For domestic operations involving hard rock and deep oil and gas plays, improvements in penetration rates is an opportunity to reduce well costs and make viable certain field developments. An estimate of North American hard rock drilling costs is in excess of $1,200 MM. Thus potential savings of $200 MM to $600 MM are possible if drilling rates are doubled [assuming bit life is reasonable]. The net result for operators is improved profit margin as well as an improved position on reserves.

The significance of the 'ultra-high rotary speed drilling system' is the ability to drill into rock at very low weights on bit and possibly lower energy levels. The drilling and coring industry today does not practice this technology. The highest rotary speed systems in oil field and mining drilling and coring today run less than 10,000 rpm—usually well below 5,000 rpm.

This document details the progress to date on the program entitled SMALLER FOOTPRINT DRILLING SYSTEM FOR DEEP AND HARD ROCK ENVIRONMENTS; FEASIBILITY OF ULTRA-HIGH SPEED DIAMOND DRILLING for the period starting June 23, 2003 through September 30, 2004.

- TerraTek has reviewed applicable literature and documentation and has convened a project kick-off meeting with Industry Advisors in attendance.
- TerraTek has designed and planned Phase I bench scale experiments. Some difficulties in obtaining ultra-high speed motors for this feasibility work were encountered though they were sourced mid 2004.
- TerraTek is progressing through Task 3 "Small-scale cutting performance tests". Some improvements over early NASA experiments have been identified.

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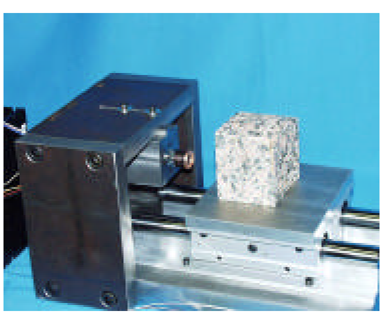
INTRODUCTION

The focus for the Introduction will be the assessment of harder rock drilling environments requiring novel technologies and tools (Task 1) and a view of the equipment being utilized for Phase 1 of the study.

The review of industry practices has shown that in general, rotary speeds above 1000 RPM have not been utilized in the drilling of oil and gas wells. Rotary speeds above 1000 to 50,000 plus RPM have been used successfully to machine or remove hard materials such as ceramics, enamels, and the like. These materials are removed quite efficiently using high RPM and small thrust loads. The most common application is dental work where diamond grit tools are rotated up to 30,000 RPM while being driven by air turbines and cooled by additional mist systems. Mining applications regularly use rotary speeds up to 2,000 RPM coupled to either surface set natural diamond bits or impregnated bits to drill economically.

There have been a few excursions into the higher than normal "mud turbine" rotary speeds, but the concept of driving the bits at high and ultra high RPM has not materialized. An air turbine for downhole applications was operated up to 40,000 RPM but had a gear reduction box coupled to the turbine, which dropped the bit rotary speed back to normal mud motor or rotary drilling range (200 RPM).

The general practice for drilling oil and gas wells uses rotary speeds up to about 150 RPM, mud motors with rotary speeds up to about 400 RPM operating at a preference towards speeds of 200 to 250 RPM, and mud turbine drilling turning bits at a maximum RPM of about 1000. Although it appears that the direction to move in removing harder materials, including rock, might lie in high and ultra high rotary speed systems. There does not appear to be any current or past history that shows a technology direction towards tools or systems that incorporate high or ultra high rotary speed, except for dental or machining industries.



EXECUTIVE SUMMARY

Background

On August 26, 2003, details of the Feasibility of Ultra-High Speed Diamond Drilling Project were presented at a 'kick-off' meeting held at NPTO's offices in Tulsa, Oklahoma. Industry Advisors from Shell Exploration and Production as well as ReedHycalog attended.

- TerraTek has reviewed applicable literature and documentation and has convened a project kick-off meeting with Industry Advisors in attendance.
- TerraTek has designed and planned Phase I bench scale experiments. Some difficulties in obtaining ultra-high speed motors for this feasibility work were encountered though they were sourced mid 2004.
- TerraTek is progressing through Task 3 "Small-scale cutting performance tests". Some improvements over early NASA experiments have been identified.

Current

TerraTek is proceeding with Task 3 experiments even though delays have been encountered.

EXPERIMENTAL

Sept-December 2003

Modified ultra-high speed equipment to accommodate water flow, prepared Berea sandstone, Indiana limestone and Colton sandstone rock samples and prepared some of the blocks with holes and glued in fittings for supplying water to the center of the bits. During this period, the Specific Energy calculations were examined and it was determined that the Specific Energy calculations used in the Mars project had been divided by 2*Pi or 6.2832 by mistake. A calibration error was also found for one data point in the Mars project (Berea, 3 Kgm WOB data) which changed the shape of the curve to be more in line with what might be expected (lower Specific Energy at higher rotational speeds). The Mars project data presented in this report has been corrected. Also, it was decided to report Specific Energy mainly in units of ft-lbs/cu. in. but also shown in Joules/cu. meter units. Confirmation of the correctness of our current Specific Energy calculations was made by Marcel Boucher at Reed-Hycalog and David Curry at Hughes Christensen.

January 2004

Ran several checkout tests with an existing bit used extensively in the Mars project. The intent was to run a series of tests in Berea sandstone and Indiana limestone with nitrogen and water. After starting the testing with nitrogen in Berea sandstone, it was found that the penetration rates achieved in the Mars project could not be duplicated. Penetration rates were 20-60 ft/hr at 5000 to 42000 rpm compared with 110-170 ft/hr at 27000 to 42000 rpm in the Mars project for 3 Kgm WOB. Two things were discovered: 1) the diamonds on the Mars bit had significant wear flats and 2) the ultra-high speed motor bearings were worn. It was decided not to test further until new bits and motors could be obtained.

January-May 2004

Five new bits were fabricated and balanced and three new ultra-high speed motors were obtained. The bit bodies (0.704” OD x 0.624” ID x 0.75” drilling length) were machined at TerraTek and the diamonds attached by Scorpion Engineering of West Jordan, Utah using an electrolis attachment process (same as the Mars project bit) and they had a diamond size of 30 to 40 mesh. With the diamonds attached, the OD and ID were nominally 0.775” and 0.565”, respectively. The bits were balanced at speed between 2000 and 5000 rpm by Rotary Equipment Specialties of Elmhurst, Illinois. The motors were supplied to the project by Korford Engineering of DePlains, Illinois. The motor description includes: 42BD300H Mod 1.6” Halls Effect, 52,000 rpm motor with hollow shaft (0.249” OD x 0.125” ID). While waiting for the bits and motors, an additional checkout test was run with the worn motor and the Mars bit with water to check out the methods developed to keep the motor dry. The concept tested was to blow nitrogen through the bit (through the motor shaft) at the same time the water was introduced through a hole in the rock into the center of the bit. It was felt that the nitrogen flow would keep water out of the motor, however, during the test, water entered into the used motor and it was ruined. It was determined from this failure that for future tests, the center of the bit needed to be plugged to prevent direct movement of the water into the motors hollow shaft.

June 2004

A test was run with a new motor and bit into Indiana limestone with nitrogen flow and the motor stalled and destroyed the new motor. It was determined after the failure that there had not been adequate nitrogen flow to clean the bit resulting in the stalled motor. Also in this time frame, Dennis Tool supplied TerraTek with a bit to be tested on the program. The bit has a saw tooth design. Due to efforts to resolve other issues on the project with the standard diamond bits, we have not attempted as yet to test the Dennis Tool bit.

July-August 2004

No activity

September 2004

A new motor was installed and a series of preliminary tests were planned in Berea sandstone and Indiana limestone with nitrogen and water. Tests were first run at different nitrogen flows to determine its effect on bit cleaning and also the resulting pressure effect to reduce WOB. During these tests, ROP's of 12 to 87 ft/hr for speeds of 17000 to 40000 rpm were achieved, again much less than in the Mars project. The two bits used in these tests (Bit 1 and Bit 4) were relatively heavily set with diamonds compared with the Mars project bit and could explain the lower ROP. Also, Bit 4 experienced extreme vibrations and the hole enlargement at rotational speeds above 25000 rpm. A table of all the results to date includes the calculation of Specific Energy in ft-lbs/cu. in. and Joules/cu. meter. Plots of Specific Energy and versus Rotational Speed and ROP versus Rotational Speed comparing the results of the checkout tests with the worn, light set Mars project bit, the preliminary tests with the two new, heavily set bits and the new, light set Mars project bit drilling in Berea sandstone with nitrogen flow and 3 Kgm WOB is shown. It may be that the nitrogen flow rate is still to low to adequately clean the bits and needs to further investigated or that the heavily set new bits results in the lower ROP's and that WOB needs to be increased. The heavily set new bits will have more contact area with the formation being cut and also less flow area for the cuttings to be removed from. We also ran two test in Indiana limestone and only achieved about 1 ft/hr penetration rate. Again, this might be due to inadequate cleaning. We are considering dropping Indiana limestone as a test rock for now until more is learned about the reason for the very low ROP's and very high Specific Energies in Indiana limestone. In addition, all five of the new bits were mounted on a new motor and rotated from 0 to 50,000 rpm. All of the bits experience what is believed to be a resonant frequency starting between 34,000 to 38,000 rpm. Three of the bits then smoothed out after passing through the resonant zone, but two showed ever increasing bit vibration beyond the on-set of resonant behavior. More effort is needed to get the bits correctly balanced. The next series of tests will be run with Bit 2, which seems to be the best balanced bit. The number of diamonds on Bit #2 is 80, compared with 55 on the 'Mars' bit used in the preliminary tests. In addition, Marcel Boucher at Reed-Hycalog offered to get several bits fabricated from Texas Diamond.

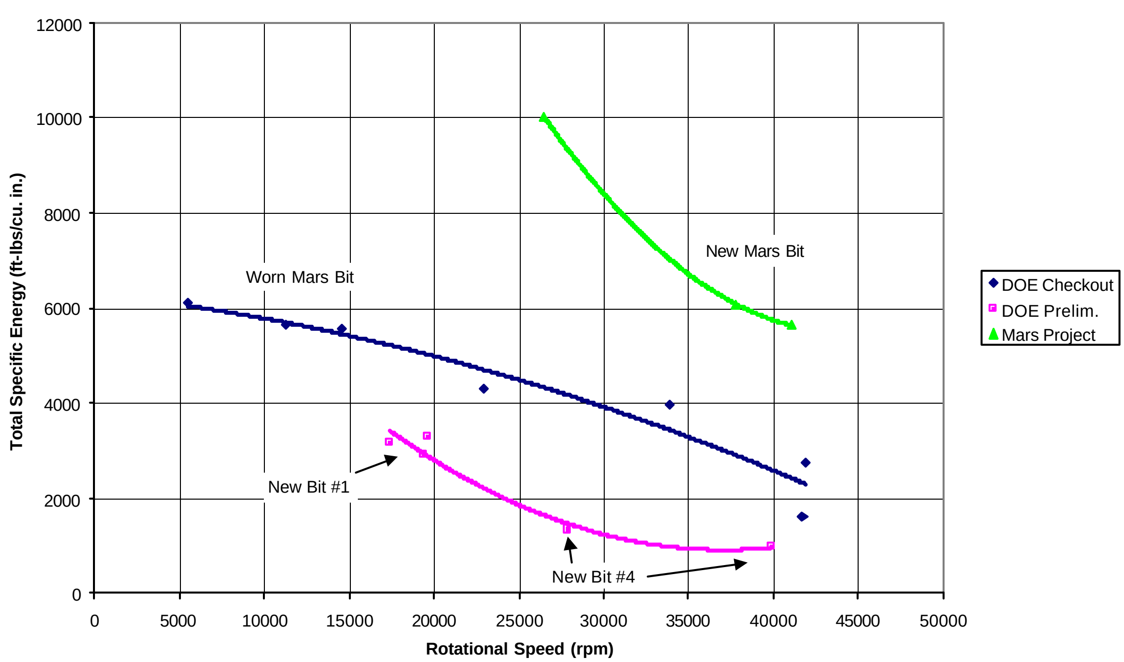
Plans for October-November 2004

Work on getting bits better balanced.
If the existing bits cannot be balanced properly, it may be necessary to fabricate new bits with more precise dimensions, with lighter set diamonds and shorter drilling stroke to reduce gravity effects on the longer bits.
Work on determining the optimum nitrogen flow rate to clean and cool bits.
Test stable bits in Berea sandstone and Colton sandstone with nitrogen and then water flow to establish baseline data for the project.

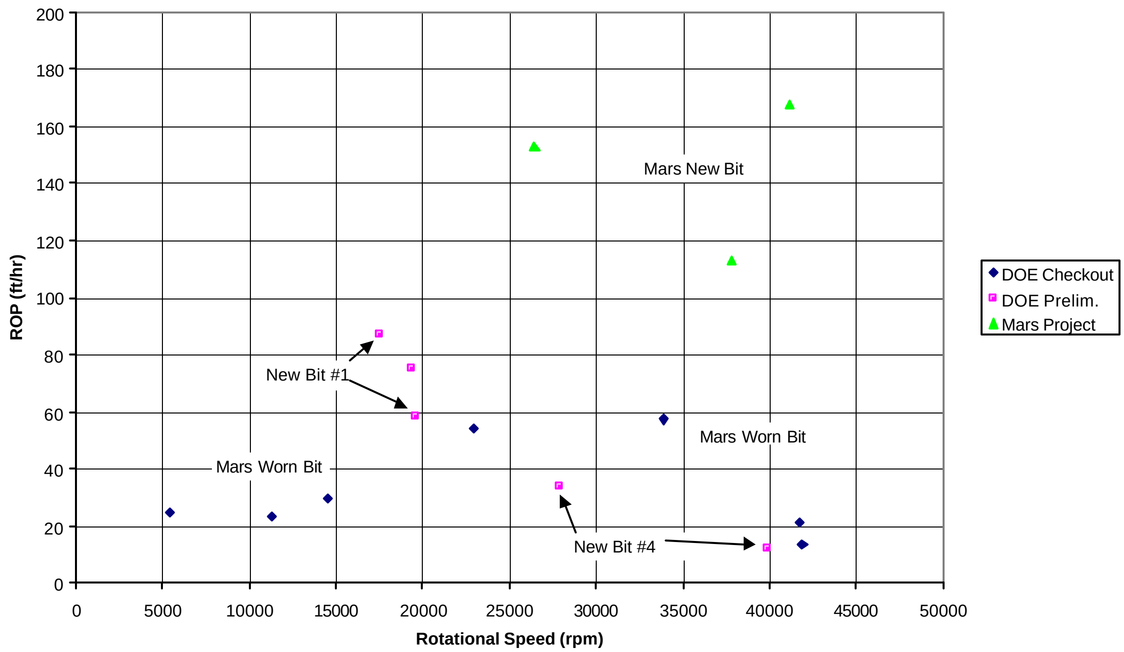
Test Description (nominal values)								Test Results							Calculations				
Test #	Test Date	Bit	Rock	Fluid	WOB (kg)	RPM (rpm)	Travel (in)	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	ROP (in/sec)	S. E. Rotation (ft-lbs/in^3)	S. E. WOB (ft-lbs/in^3)	Total S. E. (ft-lbs/in^3)	Total S. E. (Joules/m^3)	Comments
DOE1a	1/12/04	Mars	Berea	Nitrogen	3	10000	0.750	0.765	0.559	117.0	1.2575	5451.90	3000.0	0.08294	6112.93	2.58	6115.50	5.06E+08	
DOE2a	1/12/04	Mars	Berea	Nitrogen	3	30000	0.750	0.783	0.547	116.8	2.2260	22927.05	3000.0	0.18057	4308.37	2.24	4310.60	3.56E+08	
DOE2c	1/14/04	Mars	Berea	Nitrogen	3	40000	0.750	0.807	0.524	113.6	0.4097	41727.98	3000.0	0.07133	1626.87	1.86	1628.74	1.35E+08	Oversize Hole
DOE3a	1/14/04	Mars	Berea	Nitrogen	3	20000	0.750	0.776	0.560	116.5	1.4350	14566.46	3000.0	0.09817	5542.47	2.43	5544.90	4.58E+08	
DOE3b	1/14/04	Mars	Berea	Nitrogen	3	40000	0.750	0.775	0.558	115.8	2.0098	33889.61	3000.0	0.19085	3957.66	2.43	3960.08	3.27E+08	
DOE3c	1/14/04	Mars	Berea	Nitrogen	3	43000	0.750	0.810	0.524	114.4	0.4408	41915.13	3000.0	0.04527	2741.97	1.84	2743.81	2.27E+08	Oversize Hole
DOE3d	1/14/04	Mars	Berea	Nitrogen	3	15000	0.750	0.780	0.558	117.9	1.1744	11271.84	3000.0	0.07771	5630.98	2.36	5633.34	4.66E+08	
DOE3e	1/14/04	Mars	Berea	Nitrogen	3	25000	0.750	0.778	0.563	117.2	1.5198	19864.48	3000.0	0.07837	7403.80	2.43	7406.23	6.12E+08	Motor Failing
DOE3f	1/14/04	Mars	Berea	Nitrogen	3	35000	0.750	0.780	0.563	116.7	1.6843	29626.76	3000.0	0.07271	8708.53	2.41	8710.94	7.20E+08	Motor Failing
Pre1	9/16/04	1	Berea	15 psi N	2	25000	0.562	0.807	0.509	119.52	3.1842	17464.84	2000.0	0.289886	3144.04	1.19	3145.23	2.60E+08	Oversize Hole
Pre2	9/16/04	1	Berea	50 psi N	2	25000	0.552	0.802	0.516	120.00	2.1465	19628.43	2000.0	0.195500	3282.69	1.24	3283.94	2.71E+08	Oversize Hole
Pre3	9/16/04	1	Berea	100 psi N	3	25000	0.590	0.799	0.522	120.40	2.3585	19363.35	3000.0	0.250731	2906.82	1.92	2908.74	2.40E+08	Oversize Hole
Pre4	9/16/04	4	Berea	100 psi N	3	30000	0.577	0.769	0.544	121.52	0.3899	27849.78	2843.4	0.112922	1331.44	2.25	1333.69	1.10E+08	
Pre5	9/16/04	4	Berea	100 psi N	3	40000	0.433	0.817	0.497	120.87	0.1497	39885.52	2842.1	0.041207	980.81	1.58	982.39	8.12E+07	Oversize Hole
Pre6	9/16/04	4	Berea	100 psi N	3	50000	0.587	0.859	0.454	116.56	0.4690	43138.67	2842.7	0.311468	309.99	1.25	311.24	2.57E+07	Oversized, No Use
Pre7	9/16/04	4	Ind	100 psi N	3	30000	0.357	0.755	0.560	121.95	0.5253	28911.64	2842.4	0.005739	40912.67	2.60	40915.26	3.38E+09	
Pre8	9/16/04	4	Ind	100 psi N	3	40000	0.357	0.757	0.561	121.85	0.5380	28974.24	2839.9	0.004360	54823.02	2.58	54825.60	4.53E+09	

Berea, Mars Light Set Worn Bit, Nitrogen			Berea, New Heavy Set Bits 1 & 4, Nitrogen			Berea, Mars New Light Set Bit, Nitrogen		
RPM	**Total S. E.**	**ROP (ft/hr)**	**RPM**	**Total S. E.**	**ROP (ft/hr)**	**RPM**	**Total S. E.**	**ROP (ft/hr)**
5451.90	6115.50	24.88	17464.84	3145.23	86.97	26458.00	10033.02	152.70
22927.05	4310.60	54.17	19628.43	3283.94	58.65	37793.00	6080.62	113.00
41727.98	1628.74	21.40	19363.35	2908.74	75.22	41117.00	5624.57	167.90
14566.46	5544.90	29.45	27849.78	1333.69	33.88			
33889.61	3960.08	57.26	39885.52	982.39	12.36			
41915.13	2743.81	13.58						
11271.84	5633.34	23.31				`		

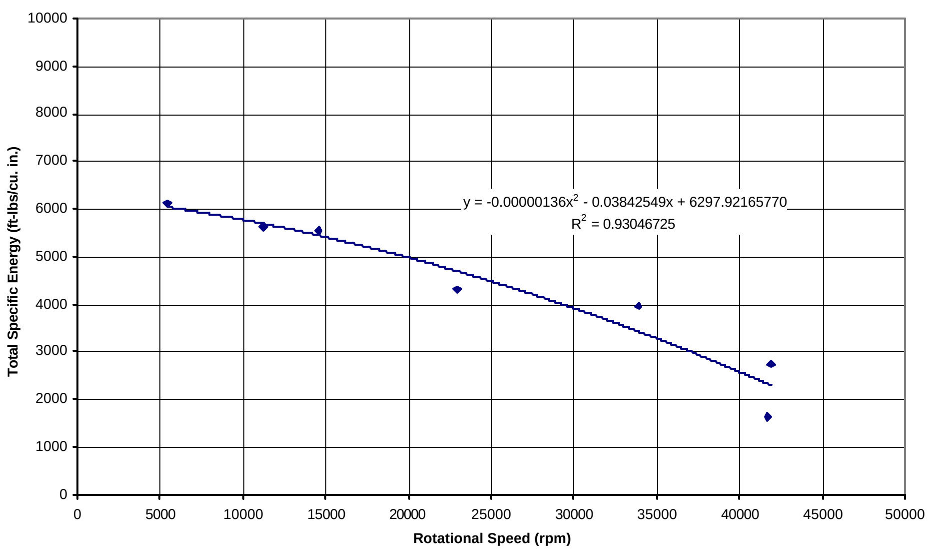
Comparison of Data From DOE Checkout, DOE Prelim. and Mars Project with Berea Sandstone and Nitrogen



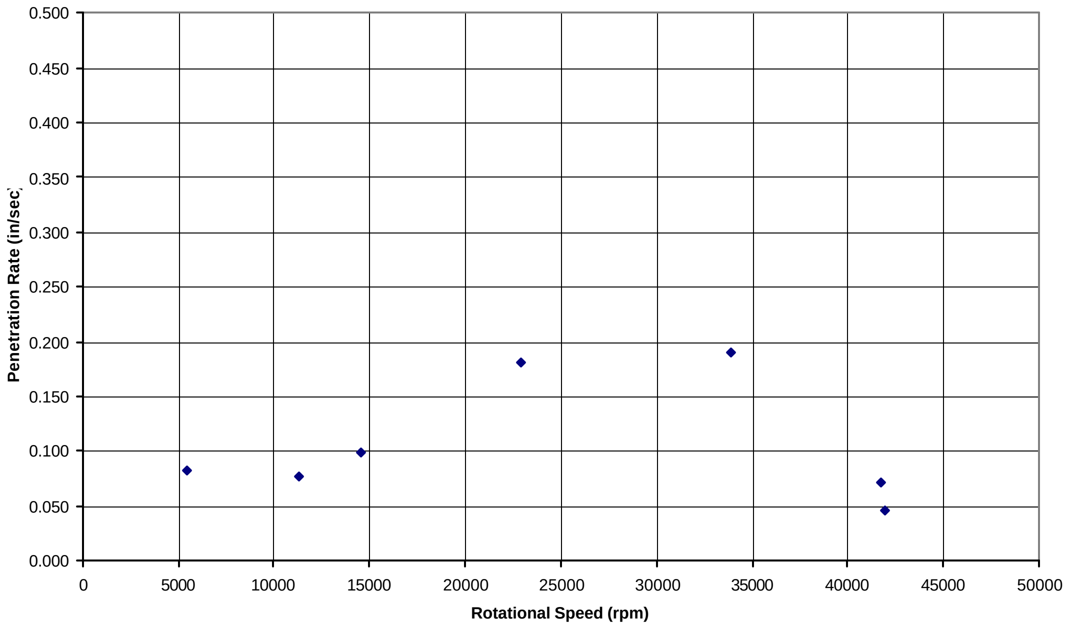
Comparison of Data From DOE Checkout, DOE Prelim. and Mars Project with Berea Sandstone and Nitrogen



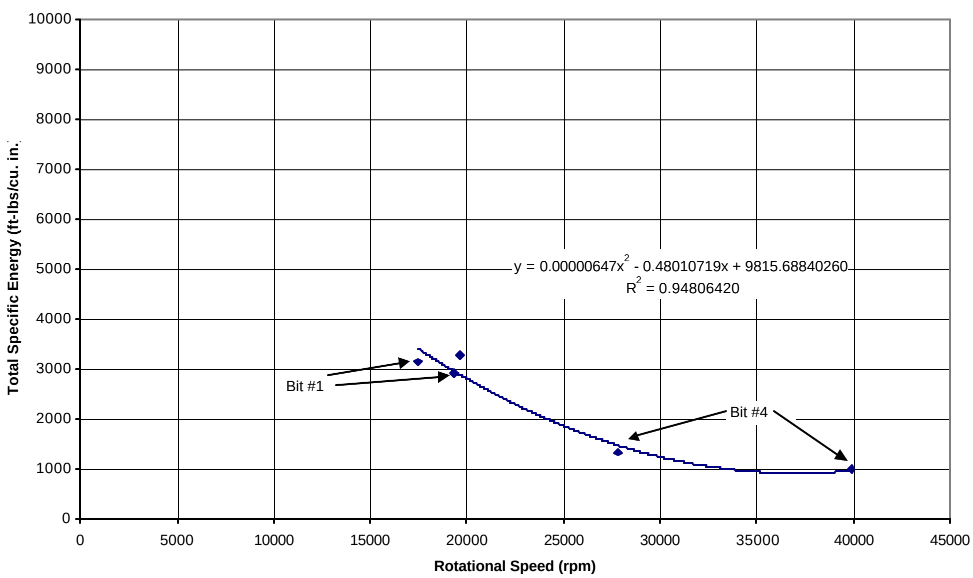
Early Check Out Test Results using Mars Worn Light Set Bit with Berea Sandstone at 3 Kgm WOB and Nitrogen Flow



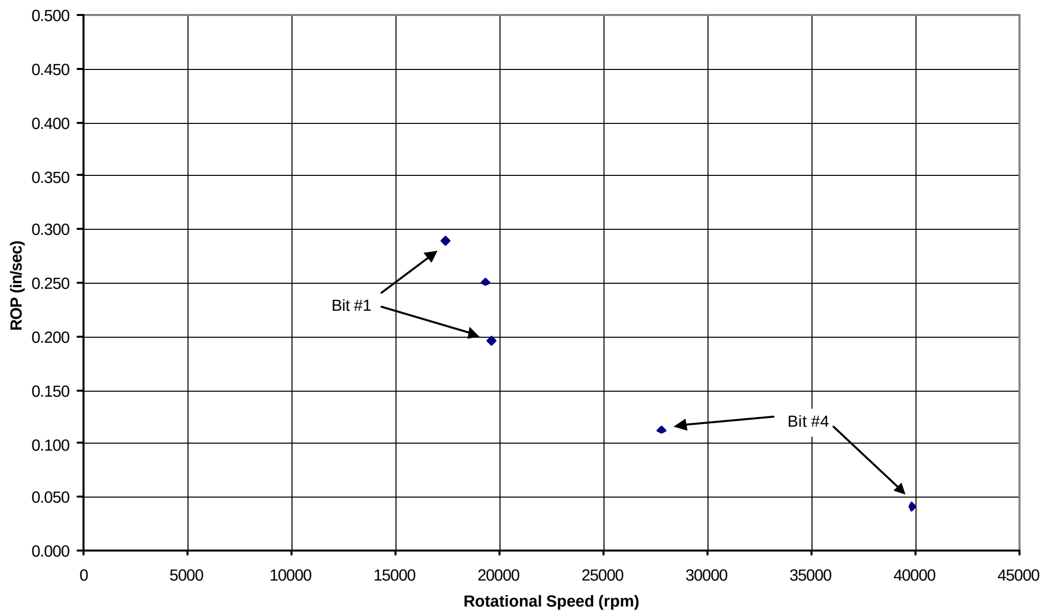
Early Check Out Test Results using Mars Worn Light Set Bit with Berea Sandstone at 3 Kgm WOB and Nitrogen Flow



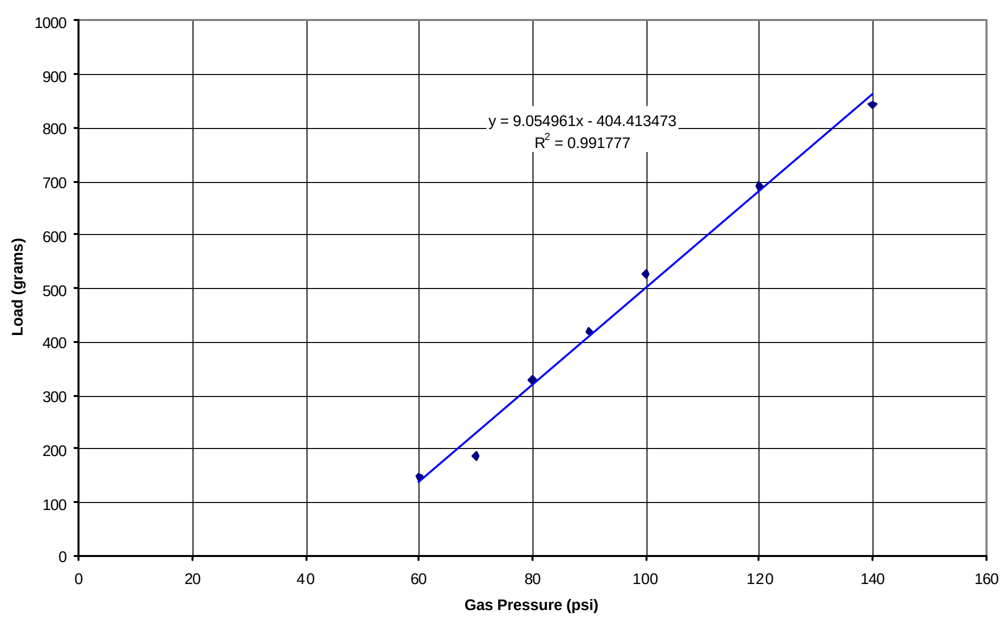
Preliminary Test Results using New Heavy Set Bits #1 and #4 with Berea Sandstone at 3 Kgm WOB and Nitrogen Flow

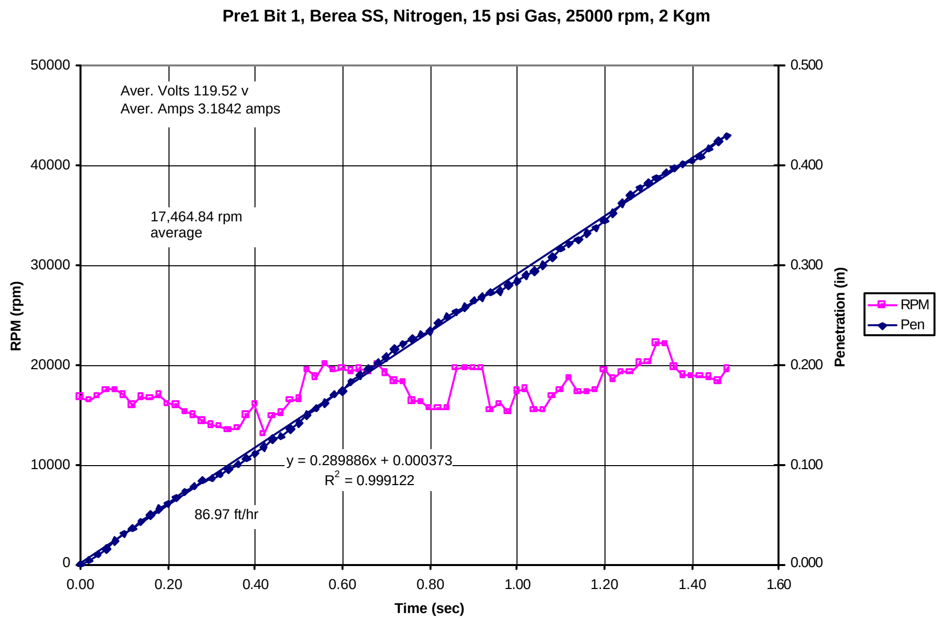


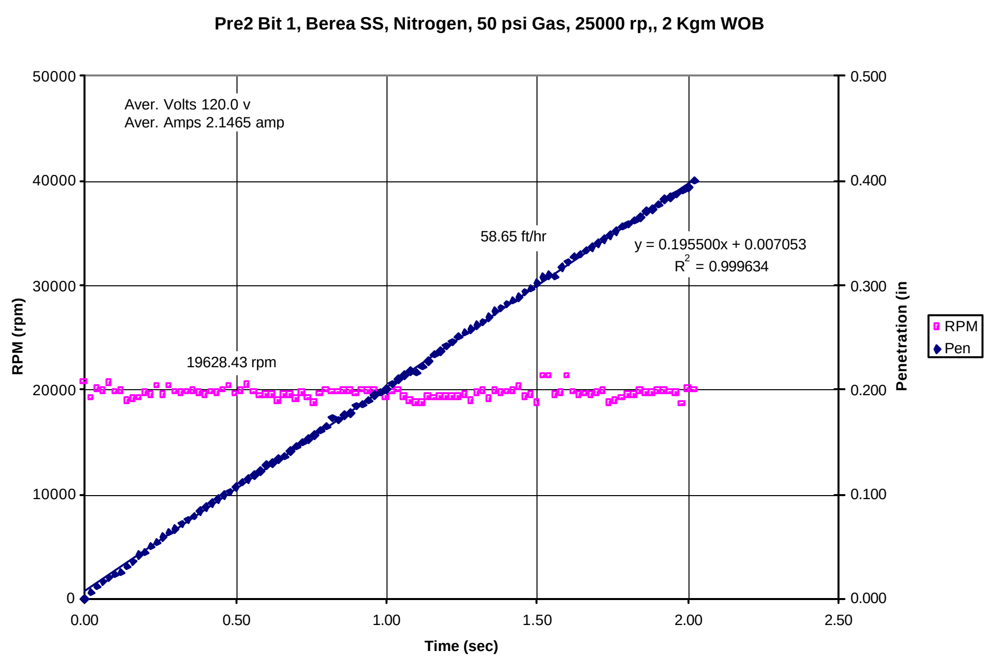
Preliminary Test Results using New Heavy Set Bits #1 and #4 with Berea Sandstone at 3 Kgm WOB and Nitrogen Flow

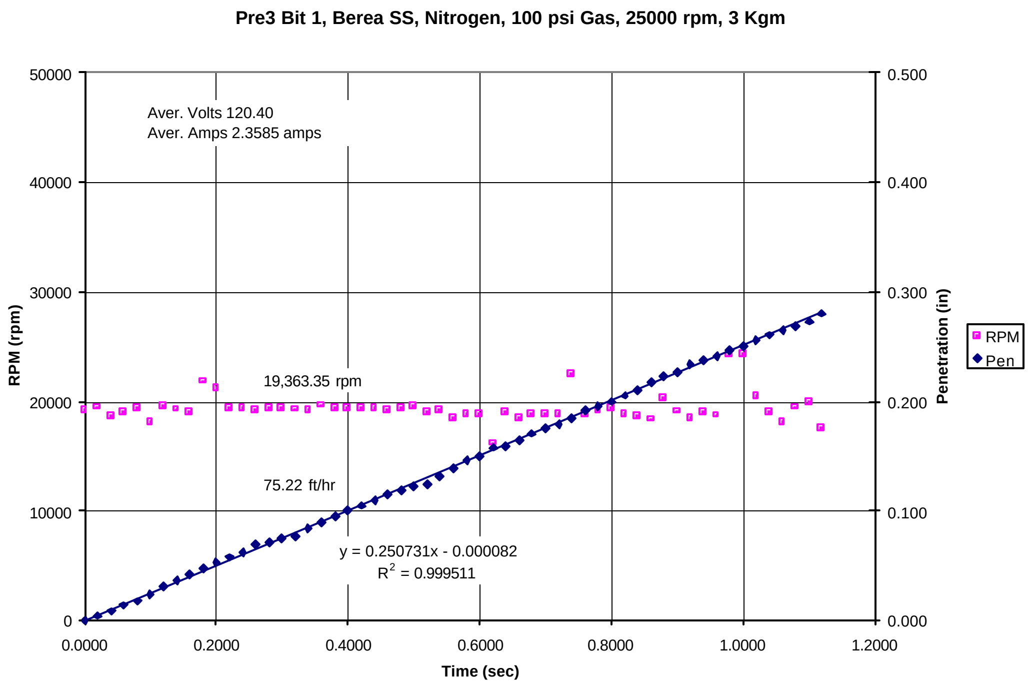


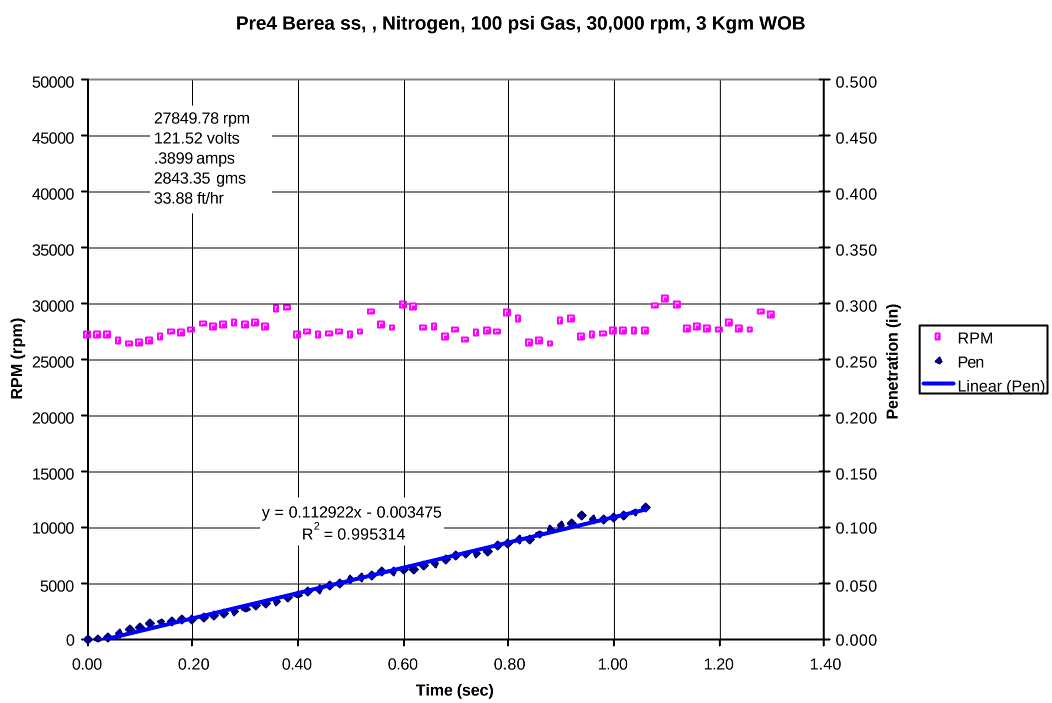
DOE HS Gas Pressure Effect on Load

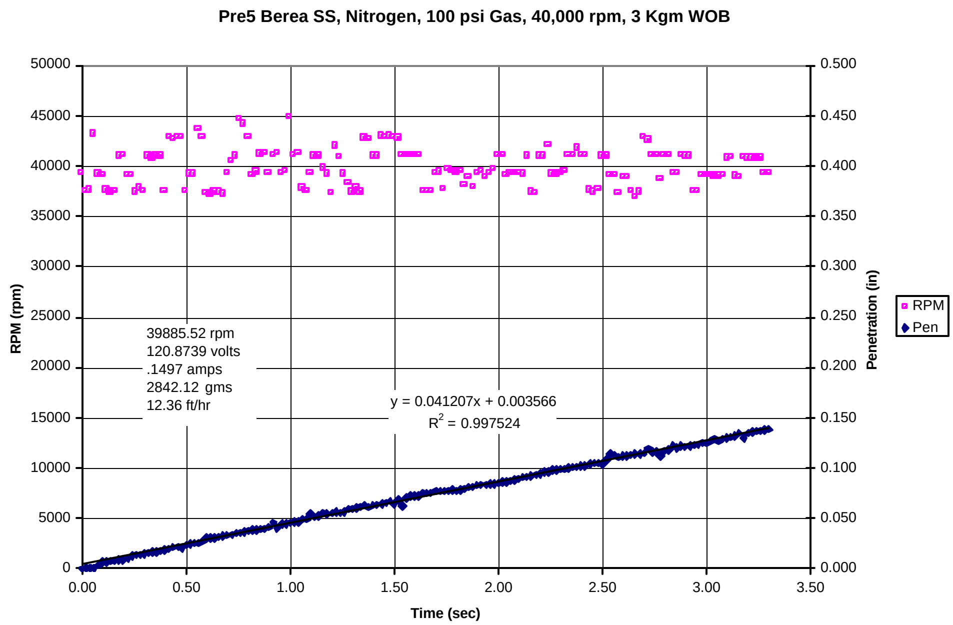


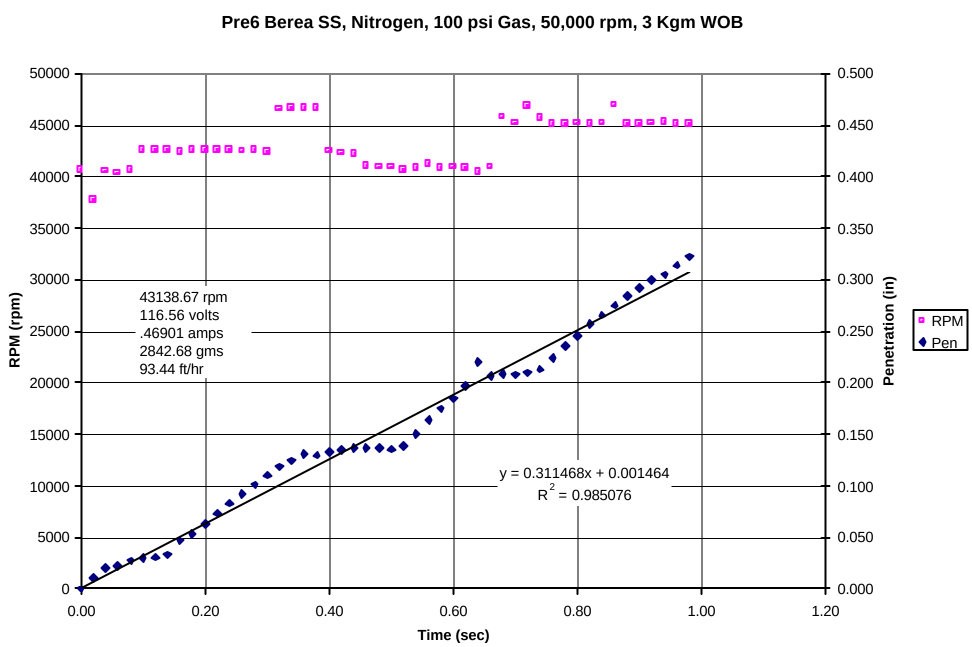

Pre1 Bit 1, Berea SS, Nitrogen, 15 psi Gas, 25000 rpm, 2 Kgm
Aver. Volts 119.52 v
Aver. Amps 3.1842 amps
17,464.84 rpm
average
y = 0.289886x + 0.000373
R2 = 0.999122
86.97 ft/hr
RPM (rpm)
Penetration (in)
Time (sec)
RPM
Pen

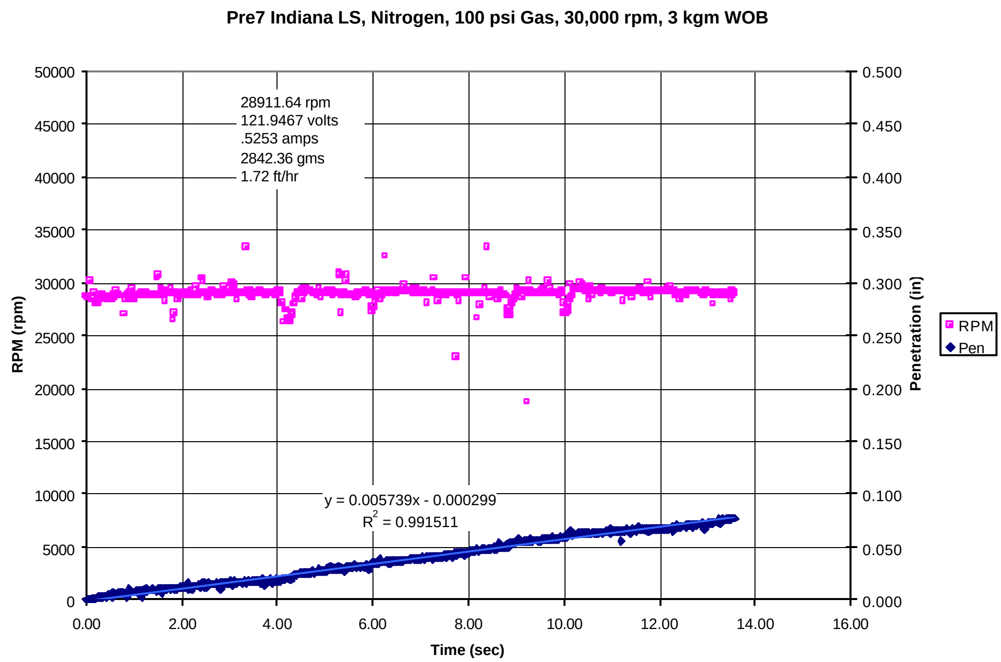

Pre2 Bit 1, Berea SS, Nitrogen, 50 psi Gas, 25000 rp,, 2 Kgm WOB
Aver. Volts 120.0 v
Aver. Amps 2.1465 amp
58.65 ft/hr
y = 0.195500x + 0.007053
R2 = 0.999634
19628.43 rpm
RPM (rpm)
Penetration (in
Time (sec)
RPM
Pen

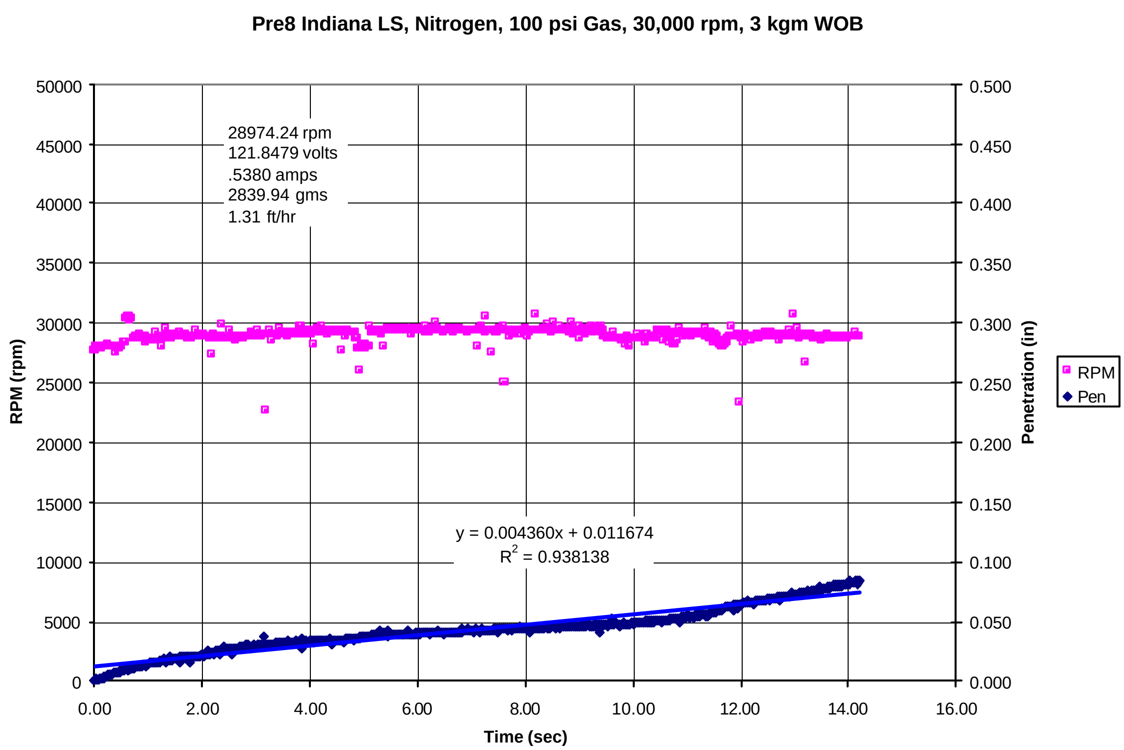

Pre3 Bit 1, Berea SS, Nitrogen, 100 psi Gas, 25000 rpm, 3 Kgm
Aver. Volts 120.40
Aver. Amps 2.3585 amps
19,363.35 rpm
75.22 ft/hr
y = 0.250731x - 0.000082
R2 = 0.999511
RPM (rpm)
Penetration (in)
Time (sec)
RPM
Pen
50000
40000
30000
20000
10000
0
0.500
0.400
0.300
0.200
0.100
0.000
0.0000
0.2000
0.4000
0.6000
0.8000
1.0000
1.2000


Pre4 Berea ss, , Nitrogen, 100 psi Gas, 30,000 rpm, 3 Kgm WOB
27849.78 rpm
121.52 volts
.3899 amps
2843.35 gms
33.88 ft/hr
y = 0.112922x - 0.003475
R2 = 0.995314
RPM (rpm)
Penetration (in)
Time (sec)
RPM
Pen
Linear (Pen)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40

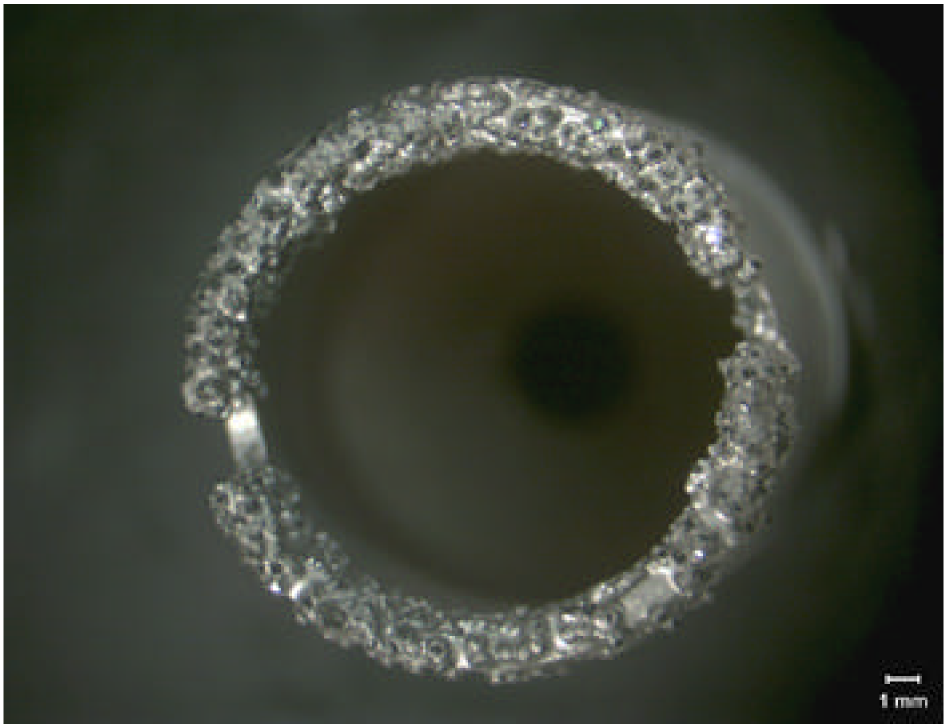

Pre5 Berea SS, Nitrogen, 100 psi Gas, 40,000 rpm, 3 Kgm WOB
RPM (rpm)
Penetration (in)
Time (sec)
RPM
Pen
39885.52 rpm
120.8739 volts
.1497 amps
2842.12 gms
12.36 ft/hr
y = 0.041207x + 0.003566
R2 = 0.997524
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.350
0.400
0.450
0.500
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50


Pre6 Berea SS, Nitrogen, 100 psi Gas, 50,000 rpm, 3 Kgm WOB
RPM (rpm)
Penetration (in)
Time (sec)
RPM
Pen
43138.67 rpm
116.56 volts
.46901 amps
2842.68 gms
93.44 ft/hr
y = 0.311468x + 0.001464
R2 = 0.985076
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.350
0.400
0.450
0.500
0.00
0.20
0.40
0.60
0.80
1.00
1.20

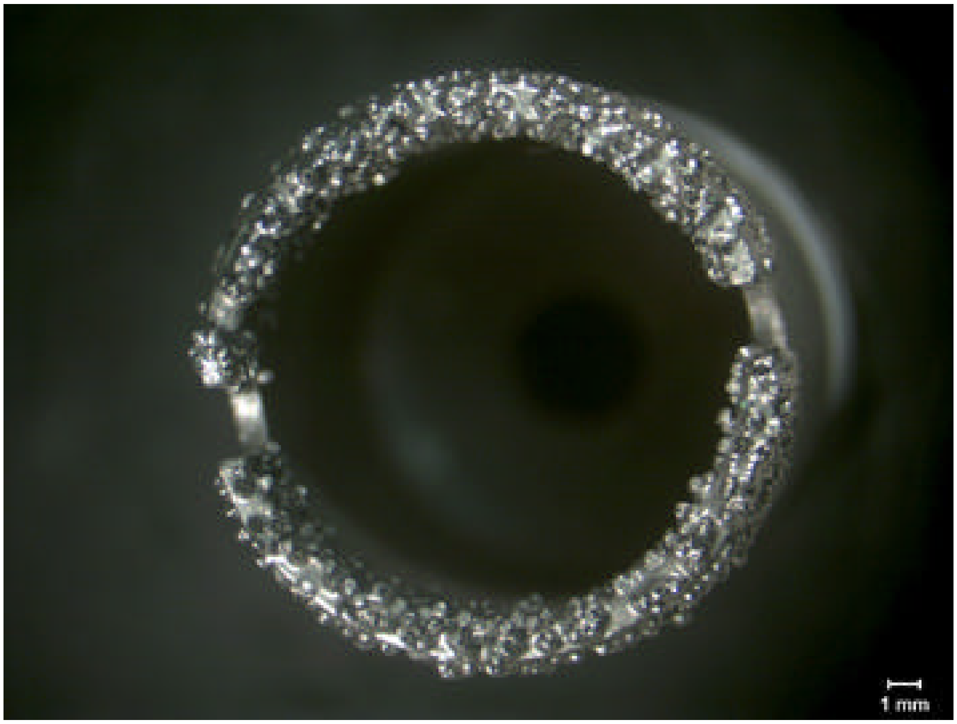

Pre7 Indiana LS, Nitrogen, 100 psi Gas, 30,000 rpm, 3 kgm WOB
28911.64 rpm
121.9467 volts
.5253 amps
2842.36 gms
1.72 ft/hr
y = 0.005739x - 0.000299
R2 = 0.991511
RPM (rpm)
Penetration (in)
Time (sec)
RPM
Pen

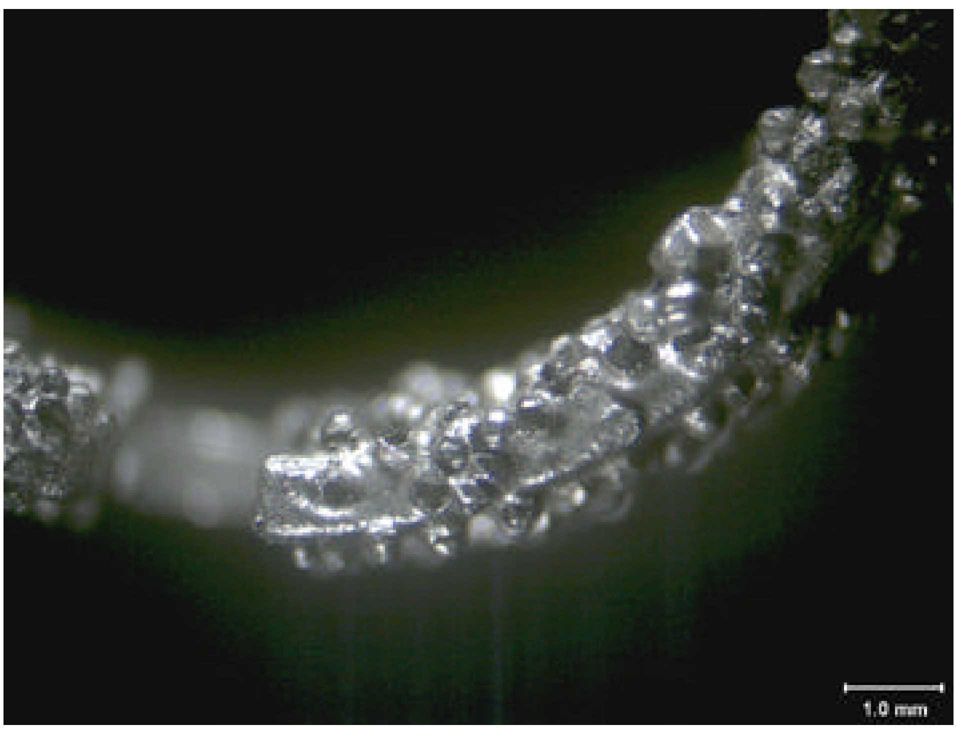

Pre8 Indiana LS, Nitrogen, 100 psi Gas, 30,000 rpm, 3 kgm WOB
28974.24 rpm
121.8479 volts
.5380 amps
2839.94 gms
1.31 ft/hr
y = 0.004360x + 0.011674
R2 = 0.938138
RPM (rpm)
Penetration (in)
Time (sec)
RPM
Pen

Bit #1

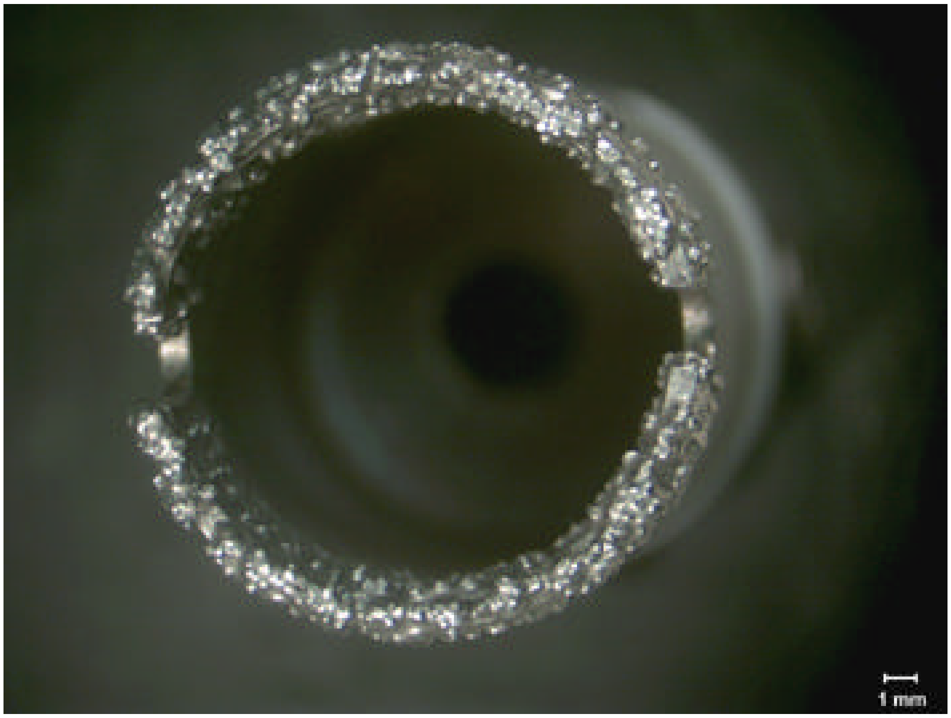


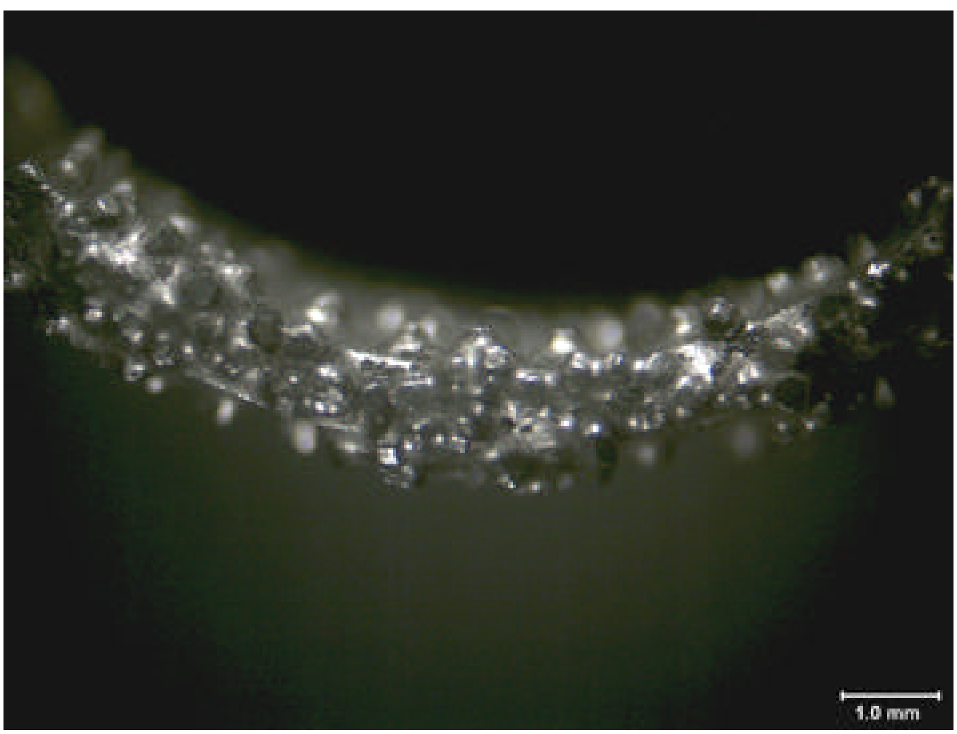
Bit #2





Bit #3





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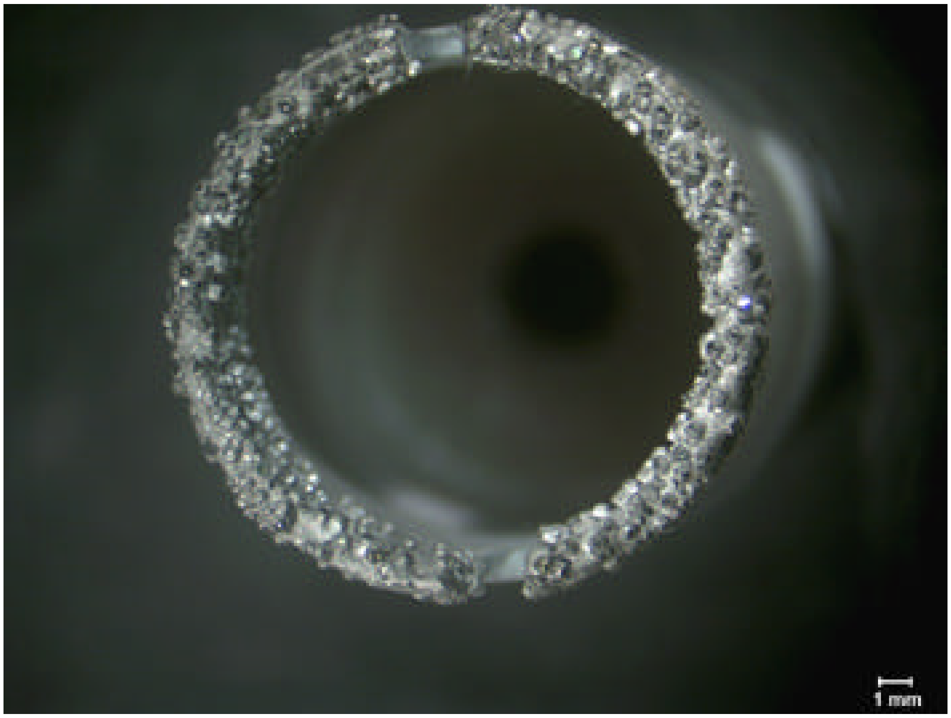

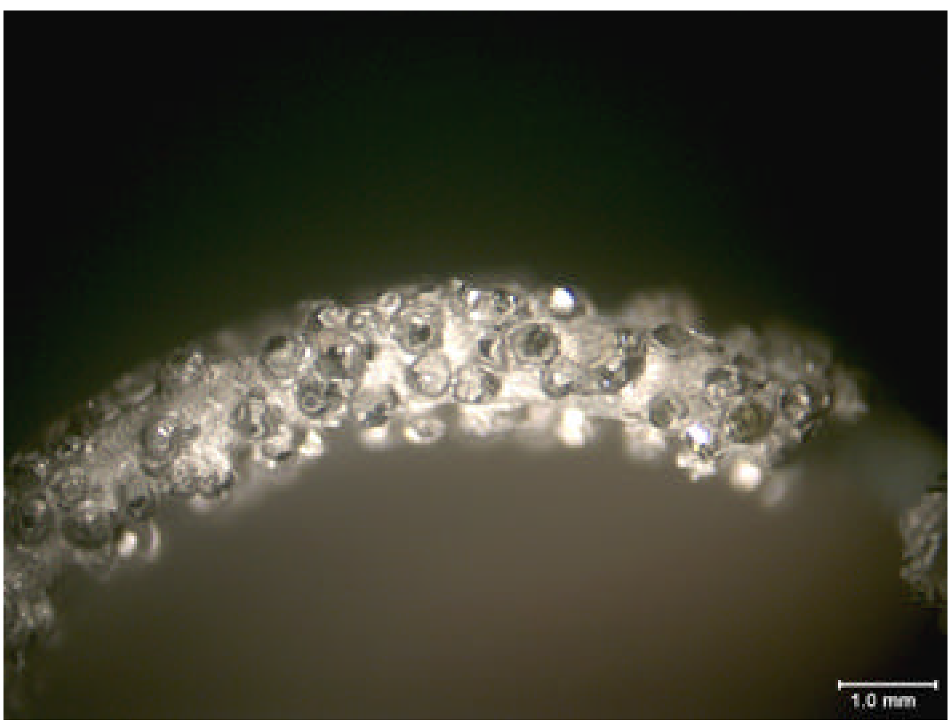

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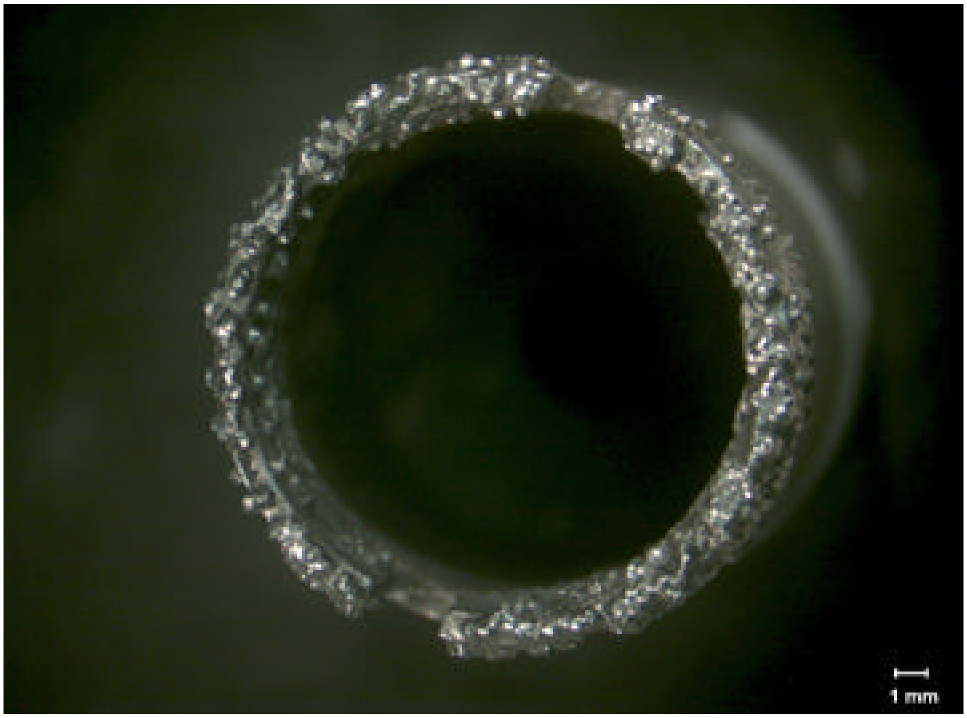
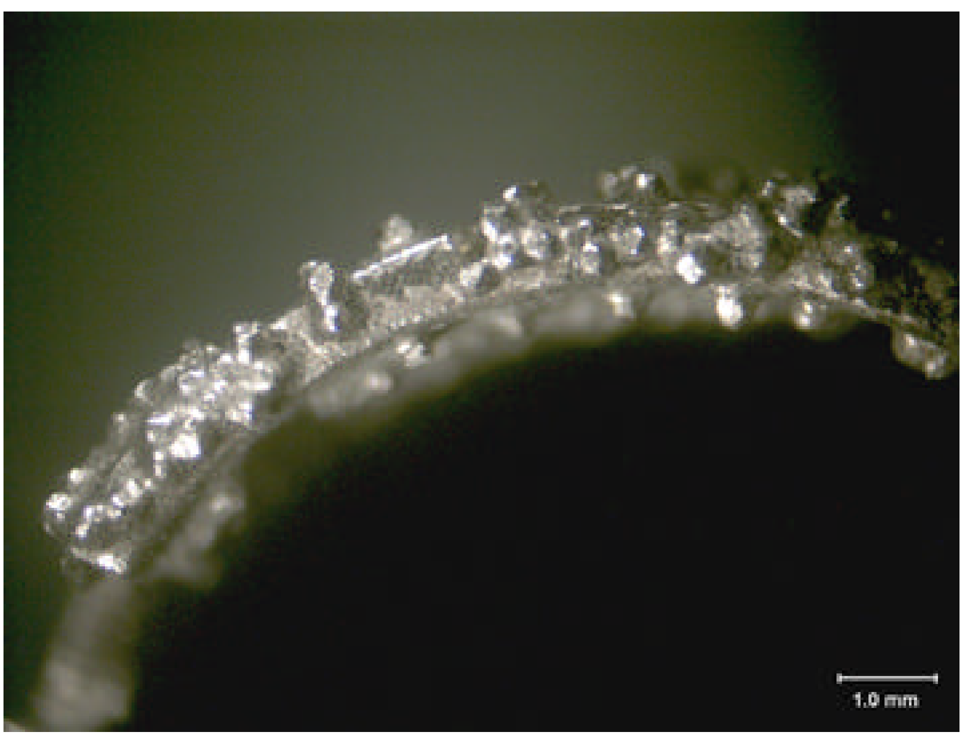




RESULTS AND DISCUSSION

August 26, 2003
Kick-off meeting in Tulsa (Power Point presentations)

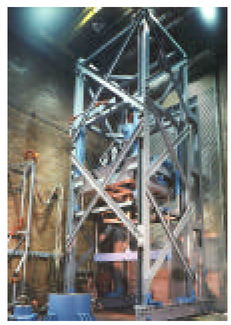
TerraTek

Feasibility of Ultra-High Speed Diamond Drilling

Kick-Off Meeting Team Participants:

Paul West (Department of Energy/NPTO)
Sidney Green, Arnis Judzis, Alan Black (TerraTek)
Marcel Boucher (ReedHycalog)
Brian Tarr (Shell)

Meeting at DOE NPTO Tulsa, August 26, 2003



An Industry / DOE Program "Small Footprint Drilling System for Deep and Hard Rock Environments; Feasibility of Ultra-High Speed Diamond Drilling"

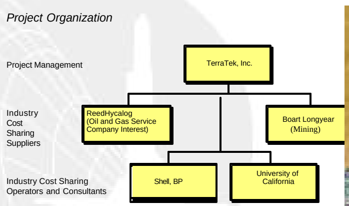
This program aims to address longer term developments in deep and hard rock drilling . Specifically the feasibility of ultra-high speed diamond drilling will be studied to determine if significant improvements in performance are possible

Context
Team Roles & Project Management
Scope of Work
Budget Overview
Looking Forward

Context

- **Economic Benefit**
  - Domestic developments in drilling tools and testing
  - Potential for increased activities in oil and gas plays
- **Drilling Performance**
  - Diamond product bit applications for increased rate of penetration
  - Directional drilling applications
  - Potential for both slim and larger hole sizes
- **Target Markets**
  - Gas, deep gas plays
  - Domestic oil, where drilling performance can be improved
- **Advantages in feasibility study on small scale, followed by slim sizes –**
  - Economics (start-up with high day rates difficult with prototype tools)
  - Ability to study rate of penetration and specific energy effects
  - Bench scale test rig offers easy access to results
  - Drilling conditions are carefully controlled & measured (data acquisition)
  - Equipment can be modified and experiments replicated
  - Provides wide range of experiments - fluids, rock types, rotary speed, etc.

Team Roles and Project Management



Scope of Work

- **Applications and prior art for ultra-high –**
  - Assess drilling applications requiring improvement
  - Access information from available sources
- **Concept development –**
  - Engineer and evaluate concept with bench scale testing*
  - Review progress against plan
- **Demonstration of concept –**
  - Benchmark performance with sizes up to 3” range
  - Prepare final report on ‘Feasibility of Ultra-High Speed Diamond Drilling’

> ****Note that an important aspect of this program will be to evaluate the significance of different phenomenon associated with ultra-high speed diamond drilling - What is the relationship of specific energy with face velocity? We need to do experiments which will validate the concepts of faster drilling with lower loads and with less energy. Perhaps some examination of cuttings, etc. will become necessary.***

Budget Overview

	DOE, $k	Cost Share, $k
• Concept Development	365	125
• Demonstration of Concept	405	125
TOTALS	770	250

Estimates of Operator/Supplier Cost Sharing Details

	Year 1 and details	Year 2 and details	Total, $000
BP	18.8	18.8	37.6
Shell	18.8	18.8	37.6
Boart Longyear	50	50	100
ReedHycalog	50	50	100
Operator 3	Contingency member	Contingency member	
Supplier 2	Contingency member	Contingency member	
TOTAL			275.2
	Operators: Travel $2,000 Meeting & video conf costs $1,800	Operators: Travel $2,000 Meeting & video conf costs $1,800	
$125/hr burdened rate used even though actual rates may be higher; e.g. BP $200/hr	Labor 120 hrs @ $125/hr total $15,000	Labor 120 hrs @ $125/hr total $15,000	
	Boart Longyear: Travel $2,000 Labor 160 hrs @ $125/hr total $20,000 Materials, etc. (Commercial items) $28,000	Boart Longyear: Travel $2,000 Labor 160 hrs @ $125/hr total $20,000 Materials, etc. (Commercial items) $28,000	
	ReedHycalog: Travel $2,000 Labor 160 hrs @ $125/hr total $20,000 Materials, etc. (Commercial items) $28,000	ReedHycalog: Travel $2,000 Labor 160 hrs @ $125/hr total $20,000 Materials, etc. (Commercial items) $28,000	
Summary:			

Cost share labor for Industry Advisory Group meetings, recommendations for bit development and plan and witness tests. Cost share components include operator labor and travel/meeting directs.

Looking Forward

- TerraTek plans to convene team in Houston (probably 4Q 2003) to finalize test conditions and review bit and equipment developments
- Upgrades to bench scale facility will be necessary end 2003.

Closure

Questions and Answers

TerraTek
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Salt Lake City, UT 84108
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Arnis Judzis (801) 5842483, judzis @terratek.com

Test Program and Challenges

Budget Period 1 - Small Bench Testing to Determine High Speed Drilling Phenomenon

Budget Period 2 - Slim-hole Testing to Determine High Speed Drilling Performance

Mars Project Baseline Information

- Berea ss, Indiana ls and some John Day bas.
- Rotational speeds 15,000-45,000 rpm
- WOB 2-4 kg
- Measurements of ROP (ft/hr), torque (amps)
- Calculations of ROP (in/rev) and Specific Energy (joules/cubic meter)

Budget Period 1 Objectives

- Access deep/hard drilling applications
- Design and engineer bits/equipment/matrix
- Determination of high speed/specific energy phenomenon
  - Small bench scale drilling/coring testing
  - Analysis of bench scale results and concept
- Engineering design of scaled up bits
- Transfer technology/lessons learned

Budget Period 2 Objectives

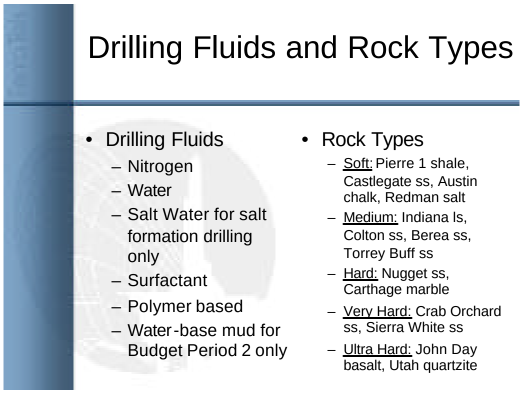
- Job pre-planning advisory meeting
- Prototype bit design and test equipment fabrication
- Determination of drilling performance
  - Slim-hole scale drilling/coring testing
  - Analysis of results and benchmarking results
- Technology transfer-advisors review, recommendations and publications
- Final report to DOE

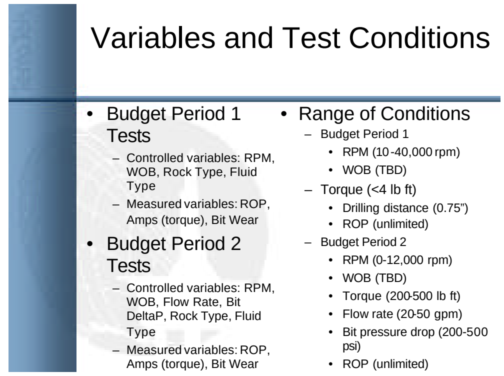
Test Equipment

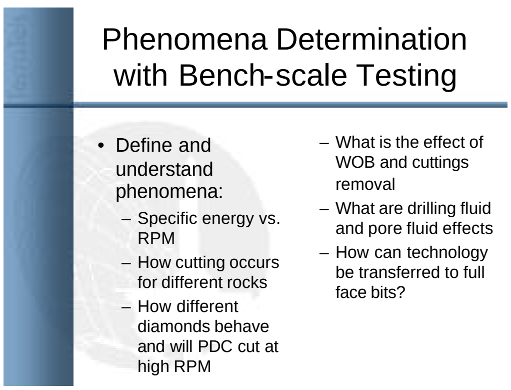
- Budget Period 1
  - Use basic bench set up with Korford 0-51,000 rpm hall effect motor
  - 788 oz in (49.3 lb in or 4.1 lb ft) stall torque
  - set up for nitrogen injection
  - need modification for pumping liquids
- Budget Period 2
  - Large high speed motor TBD with 200 to 500 lb ft stall torque at 12,000 rpm maximum
  - High speed swivel
  - Thrust bearing
  - Shaft and rotary seals
  - Fluid collection can
  - Bit/shaft stabilizer
  - Mounting to existing drill rig

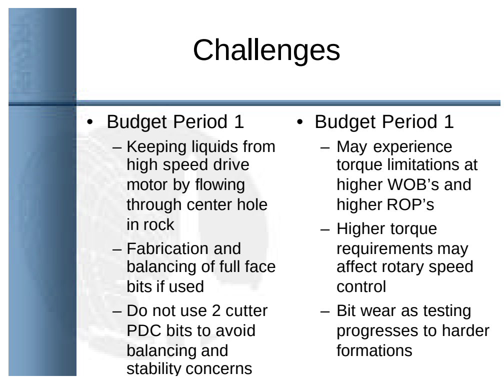
Drilling and Coring Bits

- Budget Period 1
  - 0.75 OD x 0.6 ID core bits
  - Possibly 0.75-1" diameter drill bits (full face)
  - 0.75" drilling stroke
  - Balanced at 50,000 rpm
  - Bits including natural diamond, impregnated or TSP
- Budget Period 2
  - Up to 3" diameter range drill bits (full face)
  - Up to to 3" OD x 2.5" ID range core bits (30% of full face)
  - 6-12" drilling stroke
  - Balanced at 12,000 rpm
  - Bits including natural diamond, impregnated, TSP & PDC









CONCLUSIONS

- TerraTek has reviewed applicable literature and documentation and has convened a project kick-off meeting with Industry Advisors in attendance.
- TerraTek has designed and planned Phase I bench scale experiments. Some difficulties in obtaining ultra-high speed motors for this feasibility work were encountered though they were sourced mid 2004.
- TerraTek is progressing through Task 3 "Small-scale cutting performance tests". Some improvements over early NASA experiments have been identified.