Advanced Mud System
for
Microhole Coiled Tubing Drilling

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ABSTRACT

An advanced mud system is proposed that augments a coiled tubing drilling rig designed to drill microholes. The system is tailored to the hole geometries and rig characteristics required for microholes and is capable of mixing and circulating mud and removing solids while being self contained and having zero discharge capability. Key components of this system are triplex mud pumps and a mud processing unit. The system also includes an additional component of abrasive slurry jetting which allows cutting through most all materials encountered in oil and gas wells including steel, cement, and all rock types. The jetting mechanism does not require rotation of the nozzle or drill string, has small reactive forces acting on the drill pipe, and generates cuttings small enough to be easily cleaned from the well bore. These components and parameters compliment the concepts put forth in microhole coiled tubing drilling and should help insure the reality of drilling small diameter holes quickly and inexpensively with a rig that has a minimal environmental footprint with a mud system that is efficient, compact, and portable.

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INTRODUCTION

Traditionally, the oil and gas industry had drilled large diameter holes with rigs and equipment that are big, heavy, and expensive. Microhole coiled tubing drilling offers the potential to drill wells less expensively thus giving operators a way to acquire geological or geophysical data, or develop reserves that otherwise might go untested. The corresponding CTD rig (Figure 1) will be smaller, lighter, more portable, and have a significantly less environmental footprint than conventional rigs. This will allow access to areas that were previously too environmentally sensitive or remote. Microhole drilling could truly be the quantum shift needed in drilling methods to drill more wells for less investment, access portions of reservoirs that would otherwise never be produced, and move the U.S. toward less dependency on foreign energy.

This project presents the design of an advanced mud system for microhole coiled tubing drilling (MHCTD) within the DOE's Microbore Technology Development Solicitation. The proposed system is designed to be compatible with coiled tubing drilling systems and includes equipment and methodologies to mix drilling fluids, circulate that mixture downhole, clean and store the returned fluids, and will be able to perform these functions in an underbalanced condition with zero discharge and acceptable levels of environmental impact. In addition to performing the above functions, the project was granted the latitude to investigate and develop abrasive slurry jetting (ASJ) as a drilling mechanism to be applied with MHCTD and logically tied ASJ to the mud system.

As with any emerging technology, design and implementation is an iterative process. It will take a systems approach and merging of traditional and new concepts. This report is the culmination of Budget Phase I of this project which was only the design and concept development phase. Progress is on target and results are favorable to applying the current developments and advances to MHCTD in Budget Phase II of the project.

EXECUTIVE SUMMARY

Bandera Petroleum Exploration LLC and Impact Technologies LLC, as joint investigators, have developed an advanced mud system for microhole coiled tubing drilling as part of the DOE's Microhole Technology Development Solicitation. This report presents the basic design(s) and concepts for the system as a conclusion of Budget Phase I. Budget Phase II, if approved, will manufacture and test prototypes of the designs and concepts.

The system as conceived and presented herein includes the following components: pump(s) to convey drilling fluids downhole; a sub-system to process the returned well fluids; and a method to drill a hole in rock with an abrasive laden fluid. The system is compact, portable, and readily adaptable to a microhole coil tubing rig. The ability to drill rock with an abrasive laden fluid represents a significant shift in drilling methods and has numerous congruencies with CTD and microhole drilling.

This research defined operating parameters for the entire mud system considering the intended movement toward microholes, coiled tubing rigs, and the anticipated shifts in drilling technology. This included investigating mud properties for microholes and confirming drilling hydraulics through computer modeling. The resulting predicted performance then allowed setting specifications in terms of flow rates and pressures which ultimately determined types and sizes of equipment to be considered. Needed and appropriate answers were obtained though this work, and no impediments to the ability to drill small holes with coiled tubing and a functioning mud system were found.

Abrasive slurry jet drilling (ASJ) is a logical adjunct to MHCTD but is a technology unto itself. Through a university research sub contract, significant progress was made toward applying ASJ. An extensive literature search provided a springboard to focus ASJ to drilling wells. Laboratory tests demonstrated the feasibility to cut a hole in rock larger than the nozzle diameter and without rotating the nozzle or drill string. A new method of metering and delivering abrasives to the drilling fluid was developed and proved. These are milestones in the scope of ASJ and have direct applicability to MHCTD.

Mud pumps are a key component of MHCTD and have some unique specifications resulting from the defined operating parameters. After

investigating various pump manufacturers and models, and applying the MHCTD parameters, one pump model became a clear choice due to its smaller size, weight and cost. It is applicable with only minor modifications and has sufficient capacity to be used in ASJ. Developing a true high pressure slurry pump (HPSPP) is still a goal of this project which will have to be addressed in Budget Phase II. Thus, we now have several options available for delivering abrasives at high pressures for drilling.

After searching inside and outside of the oil and gas industry there are several mud processing units available that meet the project specifications. There is however room for significant improvement to tailor a unit to true MHCTD. When this is combined with the use of non-traditional tankage materials it would provide another significant step towards the rig of the future. Another potential development for advanced mud processing is a compact 3-phase (gas-liquid-solid) separator that can concentrate the solids stream under backpressure for more compact processing. This work is contemplated for Budget Phase II.

As the industry pushes harder to find more barrels per dollar all methods and equipment need to be continually optimized. It is clear that this is a work in progress and several emerging technologies could find an application in MHCDT. At this juncture, this report lays out the components, sizes, and specifications to fully perform with a MHCT rig. As designed this proposed mud system is a workable solution for MHCTD, but more work will be needed to optimize it

EXPERIMENTAL

Experiments in this project were limited to the testing and development performed by University of Missouri at Rolla related to Abrasive Slurry Jetting. Discussion of these experiments are given in Task 2 of the Results and Discussion section below.

RESULTS AND DISCUSSION

Task 1 -Review of the Overall Mud System (Drilling Synergy)

The synergy of the overall drilling process was reviewed to better define the overall microhole drilling mud system and determine its characteristics. This process consisted of first identifying the mud type, fluid and physical properties. The range of wellbore and hole geometries were next determined that were most likely to be utilized in MHT drilling systems. Pump rates and the resulting standpipe/pump pressures were then modeled to determine conditions needed to clean the hole. Lastly gas injection was evaluated to model underbalanced drilling conditions. All work was consistent with current CTD operations and ASJ practices.

Basic DOE hole specifications for Microhole Technology were a 8.89 cm (3.5 in) hole at a 1524 m (5000 ft) TVD with a possible 305 m (1000 ft) lateral at that TVD. Pump flow rate and pressure modified specifications were: 18.9 lps (300 gpm) @ 6895 KPa (1000 psia) and 0.63 lps (10 gpm) @ 34.4 MPa (5000 psia). Flow Back processing specifications were 31.5 lps (500 gpm) water or oil based and gasified fluids. Other parameters required were that the system mixes, circulates, cleans, and stores 31.8 m^3 (200 bbls) water / diesel muds with Zero Discharge (defined by investigators and industry as –no fluids hit the ground" and that solids and liquids can be hauled off location). Of course, all health, safety and environmental considerations were included in this evaluation. Not included in this project were the generation and transmission of electrical power, the physical mud, any well control equipment, transport & staging equipment, gas storage and injection equipment. Figure 2 shows the sections included in this project in yellow. The blue section has overlap to the mud system but includes a well control component that which is not considered part of the mud system.

Mud properties types and characteristic ranges were determined by knowledge of the investigators and discussions with mud engineers[1] and mud company scientists. From these discussions it was determined that a premium mud system would be desireable, if not required, for proper hole cleaning in the narrow clearances as seen in MHT drilling. Premium mud in this definition would be a water or oil based system with good rheological properties for drilling- namely a low viscosity during flow and good gel strength when flow stops. Two or three percent KCL water based polymer muds and some oil based muds would meet this requirement. Poor muds (poor base and/or poor mud processing) would cause too high a stand pressure for pumping or would allow settling of cuttings during any brief flow stoppage or areas of low velocities. Excellent mud processing would be required to keep the beneficial flow characteristics of these muds from degenerating with solids generation and buildup. These premium muds would also protect from solids settling during periods of no flow. Environmental concerns force strong consideration of water based muds..

In the later hydraulic modeling studies, the Power Law was used to define the muds as a water, spud mud or a premium type mud. A premium type mud had an N =0.31 and a K=0.017974. The poorer spud muds evaluated had an N=0.61 and a K=0.007315 values. Water has an N=1.0 and K=1.0.

Wellbore geometries were determined based on TD bit sizes for MHT (8.89 cm (3.5in) and smaller bit size) and slimhole (12.07 cm (4.75in) to 8.89 cm (3.5 in) and smaller bit size) drilling. Required casing and hole sizes were worked back up the well to the surface. The ranges of hole, CT and casing sizes can be seen in Figure 3 as represented in similar fashion to the DOE's format. Common casing sizes of 11.43 cm (4.5in), 13.97 cm (5.5 in) and 17.78 cm (7 in) were also included in the investigation. Largest hole size considered was 25.08 cm (9.875 in) for setting 19.37 cm (7-5/8 in) casing in the surface section. Coiled tubing sizes considered were 3.175 cm (1.25 in) up to 7.30 cm (2.875 in).

Maurer Engineering's HYMOD and MudLite modeling programs were used to estimate the system hydraulics. These runs helped define the range of operating parameters for MHT drilling. A full HYMOD run is given in Appendix B.

Limitations set in the program include ensuring that cuttings are lifted out of the hole at a minimum rate of 2.13 mpm (7 ft/ min) and that no turbulent flow (non gaseous) occurs in any openhole section. Maximum standpipe pressure allowed was 34.5 MPa (5000 psia). All runs with a CT spool length of 3048 m (10,000 ft). Standpipe pressures were found for each rate and geometry.

The table shown in Figure 4 gives a summary of the HYMOD runs with graphical presentations shown in Figures 5 and 6. In this table, each case is described, red signifies that turbulent flow exists and yellow indicates that insufficient hole cleaning is occurring. In Figure 5, turbulent flow regions are not plotted as are areas of insufficient hole cleaning or standpipe pressures in excess of 34.5 MPa (5000 psia).

From these studies it was determined that the rate-pressure systems of MHT systems are possible but the operating range becomes very narrow in these smaller systems. Maximum flow rates required were only 18.9 lps (300 gpm) to clean cuttings out of any of the identified hole geometries. Minimum flow rates were found to be down to 0.63 lps (10 gpm) for the smaller geometries with very tight control required due to the narrow operating range- between hole cleaning, turbulence and pressure limits. Also of concern are changes from MHT hole diameters to larger diameters where fluid/mud velocity slows and hole cleaning becomes insufficient.

From this hydraulic modeling work, the maximum rate specification of the system was revised with DOE approval from 0.94 – 31.5 lps (15- 500gpm) to 0.63 – 18.9 lps (10-300gpm) ranges, while maintaining the same pressure requirements.

Figure 6 graphically shows the results of the various cases used to evaluate gas/ air injection to create underbalanced or near balanced systems. In this figure cases are described by 'largest casing size or hole diameter X coiled tubing size'. As can be seen in this figure, a maximum of 0.71 – 0.94 m^3/s (1500 to 2000 SCFM) are estimated needed for UBD in MHT. A full MudLite model run is given in Appendix C. Erosional limits were not considered in these cases, but should be carefully considered.

Figure 7 shows the full operating range of MHT pump requirements as defined earlier. This graph shows the full flow ranges and pressures to be encountered and the required equipment to be designed based on that analysis. The investigators contend that most of the CTD rig time will be spent in the 1.3 – 4.7 lps (20 – 75 gpm) range and little time will be spend in the 9.46 – 18.9 lps (150 – 300 gpm) rate ranges. The only time greater than 4.7 lps (75 gpm) will be needed is while drilling the surface hole sections. Such shallow sections (surface to 152 m (500 ft) estimated) normally can be drilled fairly quickly. In this figure, true microhole drilling occurs only in a small region as will conditions where ASJ can occur. Most of the operating area is really slimhole sizes. What the investigators see needed in this system are highly portable, light weight, compact modular components. Twin pumps for redundancy, portability and selection. Mud cleaning system tailored to these smaller flow rates and rig scale while all meeting DOE specifications.

The Mud System was also investigated for Evolving Technologies to improve the CTD operation. These technologies included- Abrasive Slurry Jetting (ASJ) with required methods to pump slurries at high pressures, including a High Pressure Slurry Pump; Modular non-steel tank & piping; Composite Coiled Tubing; Sintered Carbide Surfacing; Grind, Slurry & re-inject fluids & cuttings; Clear water only discharge; compact gas-liquid-solids separation (GLCC plus); Horizontal, Directional Drilling and Trenchless systems; and ground level liners.

Task 2 – Abrasive Slurry System Design

Jet drilling, jet assisted drilling, abrasive cutting/drilling and abrasive slurry cutting/drilling have all had a long history of being considered in oil and gas drilling[2]. The literature search (Appendix D) conducted as part of Task 2 proves this out but also demonstrated that there have historically been some limitations to getting a method commercialized. Several times the limitation has been business cycles or oil and gas product price fluctuations that start and stop the R&D cycles abruptly causing a valid idea or approach to be stopped mid-stream, never to be resurrected. Other limitations have been technical or mechanical in the form of tubular or metallurgical limitations or pump limitations. This solicitation's current combined technologies of coil tubing having working pressures of 34.5 MPa (5000 psia), a conceptually working ASJ system, and the urgent need to develop oil and gas reserves outside of old methods all come together to finally push the concept of ASJ drilling to commercialization. Having recognized the ability of abrasive laden fluid to cut virtually any materials, particularly the steel, cement, and rock formations found in oil and gas drilling, work proceeded to find specific ways to merge abrasive jetting with micro hole coiled tubing drilling (MHCTD).

This work was performed under a subcontract with the University of Missouri-Rolla (UMR) at their Rock Mechanics and Explosives Research Center under the supervision of Dr. D. A. Summers.

That review of applicable published literature in the area of high pressure water jetting and abrasive jetting with submerged jets found that while some work in this area had occurred, it had not progressed enough for direct application to MHCTD. However it was promising enough that it should be further investigated in an attempt to integrate ASJ into MHCTD. A summary of this literature review is also included in Appendix D.

To be applicable to MHCTD, abrasive slurry jetting (ASJ) must be able to: 1) drill (jet) through all materials encountered in oil and gas operations 2) drill (jet) a hole with sufficient diameter to allow the jet and drill string to advance within the cut hole 3) have a nozzle life that is consistent with the operational and economic functions of a drilling rig 4) efficiently operate while submerged in fluids.

UMR laboratory tests demonstrated that a 5.08 cm (2.0 in) diameter hole can be jetted abrasively in rock and the resulting hole is larger than the 0.11 cm (0.043 in) nozzle diameter and upto 4.45 cm (1 ¾ inch) diameter drill string. And, this can be done without rotating the nozzle or drill string. These are both key issues and accomplishments for CT drilling since the drill string cannot be rotated. Testing showed that the system can work under water although additional testing and component development is warranted. Additionally, the performance of the ASJ system was improved by developing an abrasive injection circuit that allows more continuous and metered delivery of abrasives into the flow stream.

The specific energy required to cut a hole in a sandstone test block was measured and calculated to be approximately 670 j/cc. This equates to 3.4 KW (4.6 HP) from 0.15 lps (2.3 gpm) at 20.7 MPa (3000 psia) which are well within limits and consistent with mechanical components of MHCTD. Rate of penetration (ROP) then becomes a function of specific energy to cut a hole in rock, and again, the relative magnitudes of pressure, rate, time, hole and pipe geometries, and fluid/abrasive type(s) are all within the scope of MHCTD. [2] UMR measured ROP at 15.2 cm/ min (6 inches per minute) without advancing the nozzle. By doubling the horsepower and advancing the nozzle, the ROP could conceivably be quadrupled which points toward an ROP of 36.6 m/hr (120 ft/hr). This rate starts to be competitive in drilling operations particularly considering that the ASJ method is indifferent to the type of material being drilled.

The abrasive slurry system was and still is an iterative process. There are only a few key variables needed to be identified and controlled -fluid type and properties, abrasive type and properties, flow rate, pressure, and nozzle configuration. But there are numerous combinations and permutations of how these variables interact in a given system. Dr. Summers' extensive experience in the combined fields of jetting, abrasive jetting, rock mechanics, and mining/petroleum engineering resulted in a very effective way of developing, testing, and proving ASJ for MHCTD. The UMR work has demonstrated a ASJ workable model for MHCTD.

There are safety issues and operational protocols associated with ASJ dealing primarily with high pressure fluids. These have become well defined primarily from the water jetting industry and its trade associations. UMR conducted a 2 day safety course as part of this solicitation for all personnel involved with lab or field testing in this project. Although self-evident once identified, the basic safety rules are: 1) inspect all components for mechanical and pressure integrity 2) stay away from the jet nozzle while operating—if the system can cut rock or steel, human parts have no defense 3) wear hearing protection—jet nozzles emit damaging levels of frequencies beyond hearing limits 4) if injuries from injected fluids occur, convey that fact to medical personnel so that appropriate treatment can be administered 5) consider reactive forces of a jet and secure the equipment accordingly.

Nozzle life could be approaching 2.4 kilominutes (40 hours) from initial tests which is adequate when placed in the context of drilling operations. Other component wear from abrasive flow is minimal as long as flow remains laminar. Tubular wear is expected to be negligible with fluid velocities below 40 m/sec (131 fps) . The UMR newly developed abrasive batch mixing system injects abrasives down stream of the high pressure pump and eliminates the pump's exposure to abrasives and consequent wear. This abrasive delivery system may be more cost effective than the HPSPP originally proposed, allowing multiple options for abrasive delivery for drilling.

The work at UMR resulted in a "currently workable" ASJ design utilizing filtered water, 100-400 u garnet abrasive, 20.7 MPa (3000 psi) and 0.15 lps (2.6 gpm), and an inexpensively machined and hardened nozzle. These parameters are validated when considering ASJ's application in an oilfield environment. Water is generally available and inexpensive and environmentally friendly. Relative to some other abrasives, garnet is reasonably priced, has known handling properties, and is environmentally benign. Other fluid/abrasive combinations were considered and could be evaluated in the future but from all ASJ experience, water/garnet has become a standard. Sand, steel shot or other abrasives should be evaluated for particular formations or target material.

UMR's work has developed a basic nozzle design that creates the desired hole size in a submerged condition, without rotating the nozzle or drillstring, under operating pressures/rates and hole/tubular geometries anticipated in MHCTD conditions. Nozzle, abrasive, and mixing optimization need to part of Budget Phase II of this solicitation.

Task 3 deleted

Task 4 - Pump Sub-system

To identify available industry pumps and any modifications required, the investigators met with several pump manufacturers, including National [3,4], White Star[14], Kerr [7,8], Tulsa Triplex[13] , Gardner Denver [5,6] and others [15,16,17]. The set system requirements were: dual pumps with minor/ no fluid end change for the range of operation, light weight for portability, compact size/ footprint and meet the DOE specifications. In our review of the available pumps we investigated any modifications as needed to meet the specifications. The available pumps identified were:

Kerr 3500 series
National JWS185
Gardner Denver TEE series
Tulsa Triplex TT series

Figure 8 shows available pumps by manufacturer with the MHT operating area shown in black. As can be seen in this Pump Performance Matrix figure, most pumps are for higher rate or pressure ranges than required for MHT. This is due to market demands of current large hole drilling rigs. The closest pump to meeting the specifications required is the Kerr 3500 series with the National JWS 185 next in line. However, for the Kerr 3500 pump to better meet the requirements, some modifications must be made, as seen in Figure 9. This plot shows the required operating performance of a single pump (one of dual pumps) for MHT system and the Ideal pump for this MHT system versus the Kerr 3500 pump performance. As can be seen , the Kerr 3500 can be pressure degraded and bored larger (along with other changes) to obtain the ideal performance. Service life can be adjusted with material changes. The National JWS185 is already bigger than needed for the ideal performance.

Figure 10 shows a table of available and nearest pump equipment summary showing weight and cost for various manufacturers of the closest pumps. Portability dictates that weight and size/ footprint be considered in this MHT system. Based on size, weight and cost considerations, the Kerr pump is best suited for this application. Pictures of these pumps can be seen in Figures 11 and 12.

Handling solids at any pressure in any piston or centrifugal pump is a problem. Pump experts do not like pumping solid laden fluids at high pressures due to low performance, shorten component life and reduced overall pump life. Operators do not like the wear problems and extra cost encountered. For Abrasive Slurry Jet (ASJ) drilling, even higher modifications are required and this study investigated modification to existing triplex pumps listed above, a new High Pressure Slurry Pump, UMR modified DIAjet batch mixing / pumping systems. The HPSPP system has not been developed and the cost of such are unknown. Discussions with pump manufacturers have not progressed to the state of knowing these factors. However, there are now many options are available for pumping slurries for drilling.

Task 5—Returned Well Fluids Processing Unit Sub-system

A key component of the “Advanced Mud System for MHD” is the returned well fluids processing unit. As specified by DOE, the “system” must be able to mix, circulate, clean, and store 31.8 m^3 (200 bbls) of water or diesel based mud and be able to process 31.5 lps (500 gpm), perform while drilling under balanced, and have zero discharge. The “mud processing unit” or the returned well fluids processing unit discussed herein handles all of these functions except delivering and circulating high pressure drilling fluids which is handled by the mud pump(s).

Mud systems have evolved from earthen pits and no mud property control to portable steel pits and many variants of equipment to remove solids including but not limited to shale shakers, desilters, desanders, and centrifuges. The systems have evolved around large diameter holes, large rigs, and handling large volumes of fluid (although sometimes ineffectively).

MHCTD provides an opportunity and the need to re-think and apply a new system to processing and handling mud. The traditional functions of removing drill solids and building desired physical and chemical properties remain inherent to the "advanced mud system". However, scale, portability, environmental impact, and integration with MHCTD can now be including in the design process.

The horizontal boring industry and its economic boom of the late 1980's and 1990's created mud processing equipment that is very suitable for MHCTD. Interestingly, the underlying source of knowledge and technology for the horizontal boring equipment came from the oil and gas drilling industry which was in a severe down-cycle during that time period.

"Oilfield" portable mud processing systems are large, heavy, and expensive. However, they are a proven design that functions well with conventional sized rigs (See Figure 13 on Swaco equipment). "Horizontal boring" systems are smaller and lighter, perform all of the requisite processing functions, are readily available, and closer to the specifications of MHCTD.

Much of the work in Task 5 consisted of contacting experts and vendors of mud and processing units (in and out of the oil and gas industry) and evaluating products for applicability to MHCTD. For the flow conditions developed by DOE and other tasks of this solicitation, several available components of available mud processors approached the DOE MHCTD specifications. Equipment from Kemtron [9,10](Houston, TX) and Tri-Flo [11,12] (Conroe, TX) meet all of the operating parameters and conditions but vary from each other in how the shakers and tankage are configured. Either can be modified for MHCTD and pricing is relatively similar (See Figure 13). Final selection should be delayed until other contemplated design concepts are matured within Budget Phase II for this solicitation. These contemplated concepts include: 1) making the unit more portable than even existing models; 2) eliminating steel tankage and piping; 3) modularizing unit components, pumps, prime movers, tanks; 4) automating functions such as fluid levels, mud property measurements, screen and cone maintenance, lift systems for packaged mud products; and 5) improved sub-20 micron solids separation.. These concepts also need to be integrated into the CT rig design.

The immediate need of processing MHCT drilling fluids can be accomplished by applying one of the Kemtron or Tri-Flo mud processing units, plumbing in 15.9 m^3 (100 bbls) of additional tankage, and installing a liner with a sump under the processing unit.

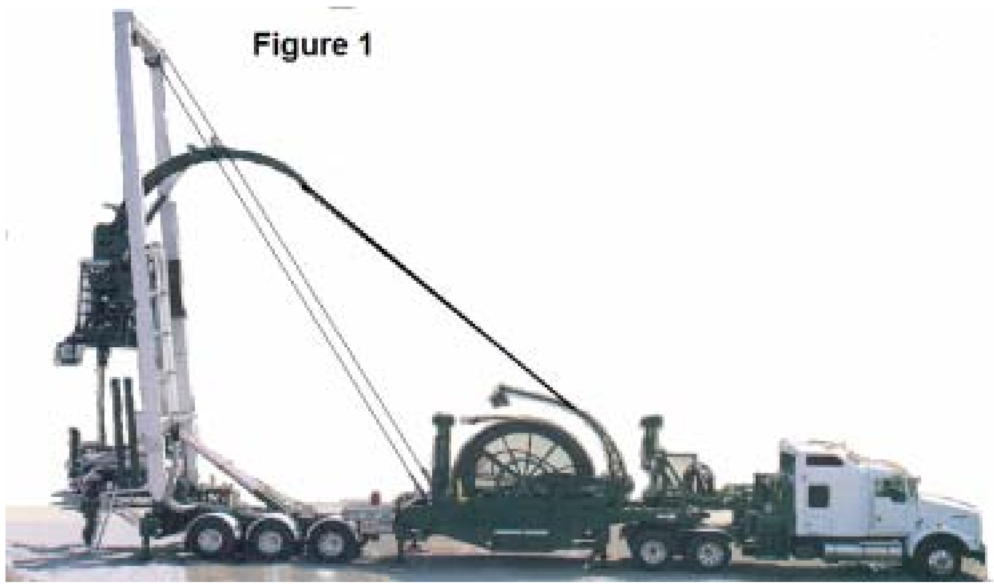
This set up would result in a system capable of routinely cleaning 18.9 lps (300 gpm) of high viscosity mud to the 20 micron level with surges to 31.5 lps (500 gpm), mixing new mud and additives, creating dry handlable cuttings, and containing any spills. A unit or components from either manufacturer would have multiple vibratory shakers with easily selectable and changeable screens and hydrocyclone desilters/desanders. Screen selection becomes a function of mud viscosity and pump rate, and cutting characteristics. Cutting characteristics are a function of rock type, bit type, ROP, WOB, and RPM. Returned fluids and mud properties must be continuously monitored and evaluated to properly adjust the operation of the processing unit for optimum performance. Training of the MHCTD personnel by the mud processing unit vendor is essential. It is not extremely high tech but proper solids control and mud property maintenance is critical for maximum ROP, minimum wear on drilling assemblies, and maintaining hole integrity.

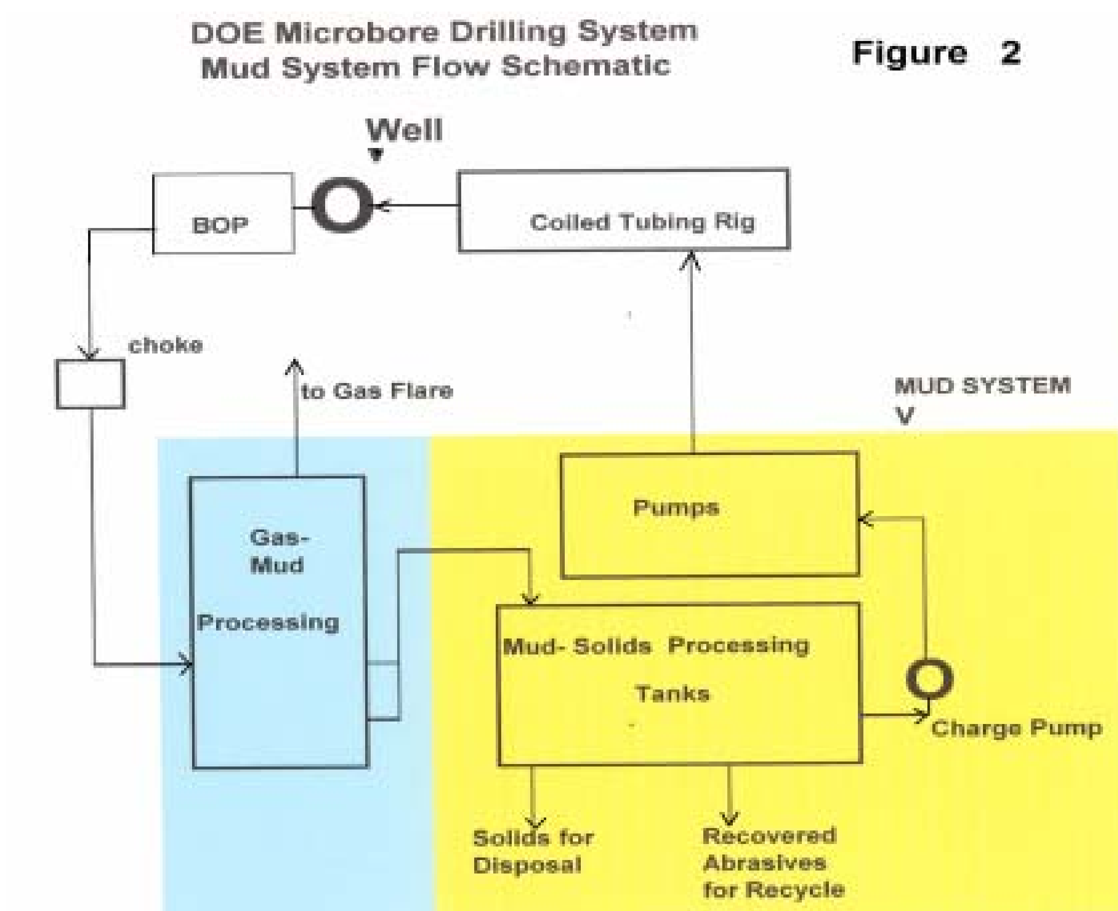
Cleaning below the 20 micron particle size range must be accomplished with a centrifuge, ultra-small hydrocyclones. Centrifuges are heavy, expensive to buy and operate and hard to maintain. They are difficult to justify for the fast drilled wells envisioned for MHCTD. Hole and mud volumes for MHD are relatively small as are the rotating hours per hole. Plugging concerns of the small cones might be remedied with an automated hole cleaner. Automated filter presses using stainless steel filters with an air backwash systems may be developed for removing these small diameter particles.

The concept of “zero discharge” must be kept in perspective. The “closed” or “haul off” mud system model is the most applicable to MHCTD. As a hole is created, the removed rock must go somewhere. Ideally these cuttings are “shaken” out of the mud into a dry enough form to be scooped, piled, or hauled. In many (most) drilling operations, these cuttings are benign or inert enough to not endanger the environment. There are unique situations where the cuttings might be ground finer and re injected into the well or hauled off to a fill area. The liquid component of the mud can be “cleaned” down to clear water with enough time and money. However, practical limits usually result in a suspension with 10-20 u and smaller particles consisting of clays and ground rock. As the mud is circulated, the solids are ground finer and finer during the drilling and pumping processes. This is a problem because the mud gets heavier and more viscous with each circulation and it loses some of its beneficial properties. Thus, it is prudent to remove the solids as soon as possible in the drilling process. The resulting “cleaned” mud at the completion of drilling can be used to drill another well, injected into the just drilled well, or hauled to a disposal facility. Small total system volumes for MHCTD of 31.8 m^3 (200 bbls) make hauling or re use viable options.

The recommended mud processing equipment is well suited to removing solids and tankage can be designed and plumbed to allow continuous mud processing included times while not drilling.

GRAPHIC MATERIALS AND TABLES





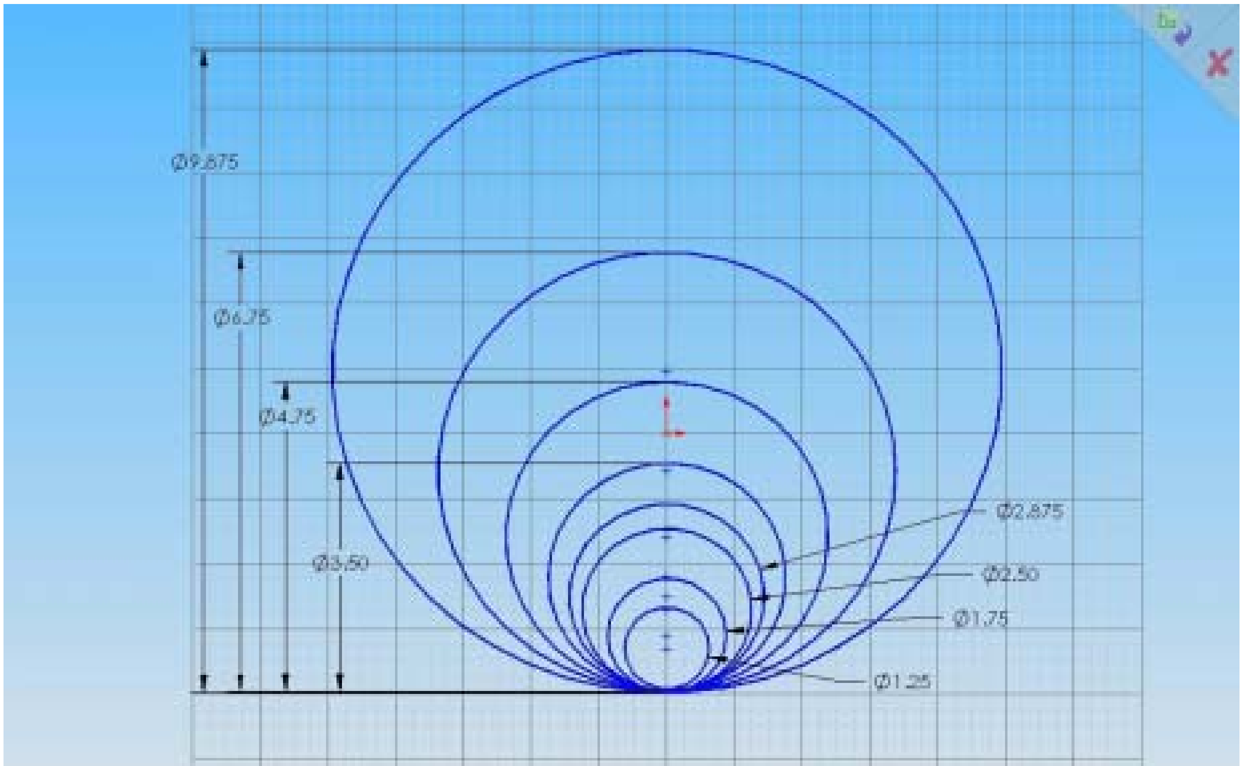


Figure 3
MHT Wellbore Geometries

Figure 4

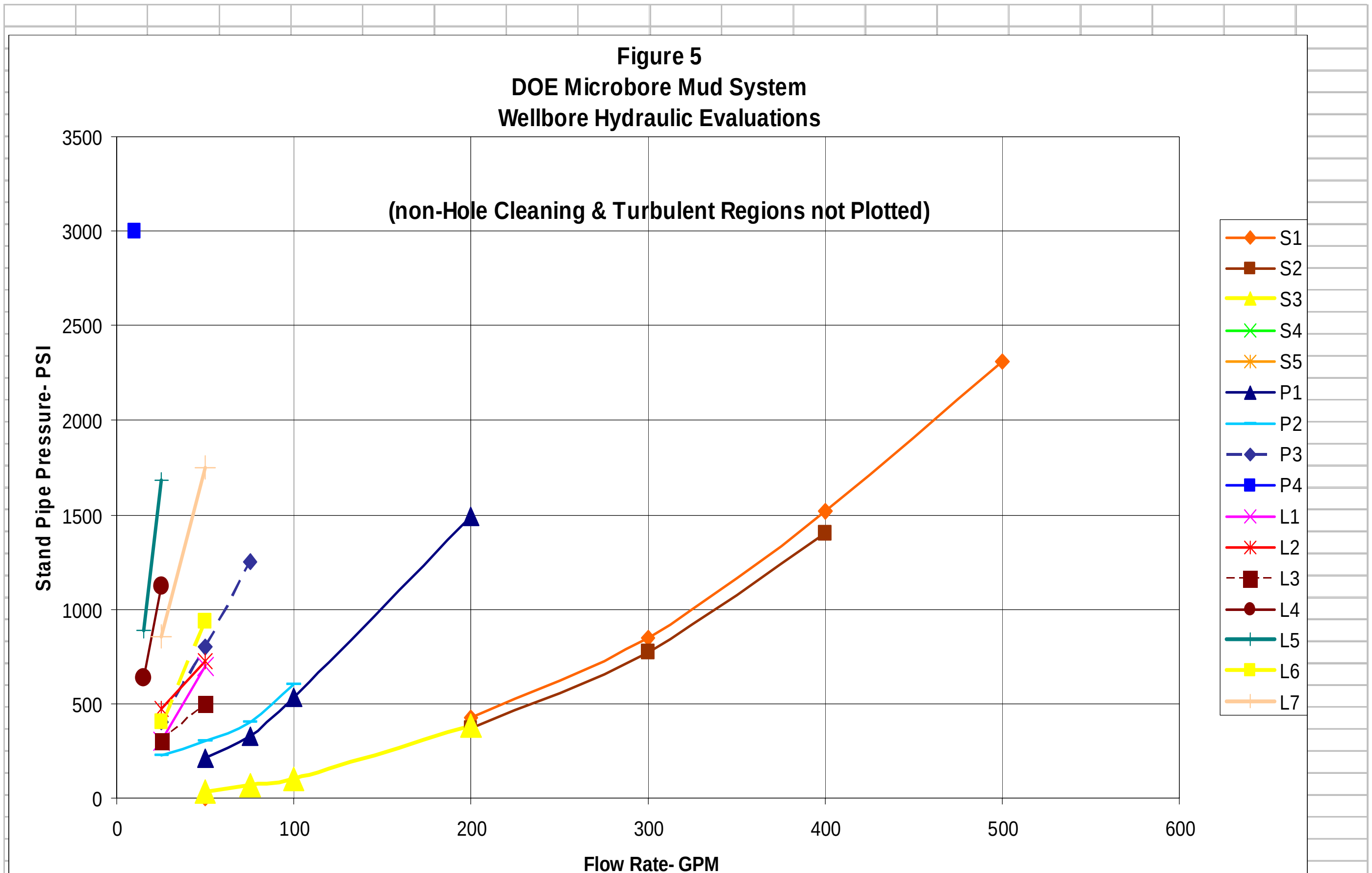
DOE - Advanced Mud System for Microhole Coiled Tubing Drilling

Pump Pressures Required for Selected Wellbore Configurations and Flow Rates

Case	Descrp	TVD	Casing Size-TVD	Hole Size	DP Size	Mud Type	Lateral Length	Flow Rates - GPM 10	15	25	50	75	100	200	300	400	500
S5	surface	500	none	9.875	3.5 JT	water								355	788	1425	2151
S1	surface	500	none	9.875	3.5 JT	spud								425	850	1520	2308
S2	surface	500	none	9.875	3.5 JT	premium								370	775	1400	2120
S4	surface	500	none	6.75	3.5 JT	water							85	350	780	1350	2162
S3	surface	500	none	6.75	3.5 JT	premium					31	70	100	380	780	1370	2135
P1	production	5000	7.875" @ 500'	6.75	2.875	premium					210	325	533	1493	2838	4543	
P2	slimhole ve	5000	5.5" @ 500'	4.75	2.875	premium				225	300	400	600	1480	2500	4225	
P3	microbore	5000	5.5" @ 500'	3.5	2.375	premium				400	800	1250	1701	5036			
P4	microbore	5000	3.5" @ 500'	2.5	1.75	premium		3000	4939								
L3	microbore	5000	5.5" @ 5000'	3.5	2.375	premium	1000			300	500	800	1400				
L1	microbore	5000	5.5" @ 5000'	3.5	1.75	premium	1000			300	700	1300	2000	5000			
L6	microbore	5000	4.5" @ 5000'	3.5	1.75	premium	1000			400	934	1643					
L2	microbore	5000	5.5" @ 5000'	2.5	1.75	premium	1000			475	725	2005	3300				
L7	microbore	5000	4.5" @ 5000'	2.5	1.75	premium	1000			856	1750	3000					
L4	microbore	5000	3.5" @ 5000'	2.5	1.5	premium	1000		636	1118	3000						
L5	microbore	5000	3.5" @ 5000'	2.5	1.25	premium	1000		887	1681	3800						

No hole cleaning

Turbulent Flow in Open Hole Section



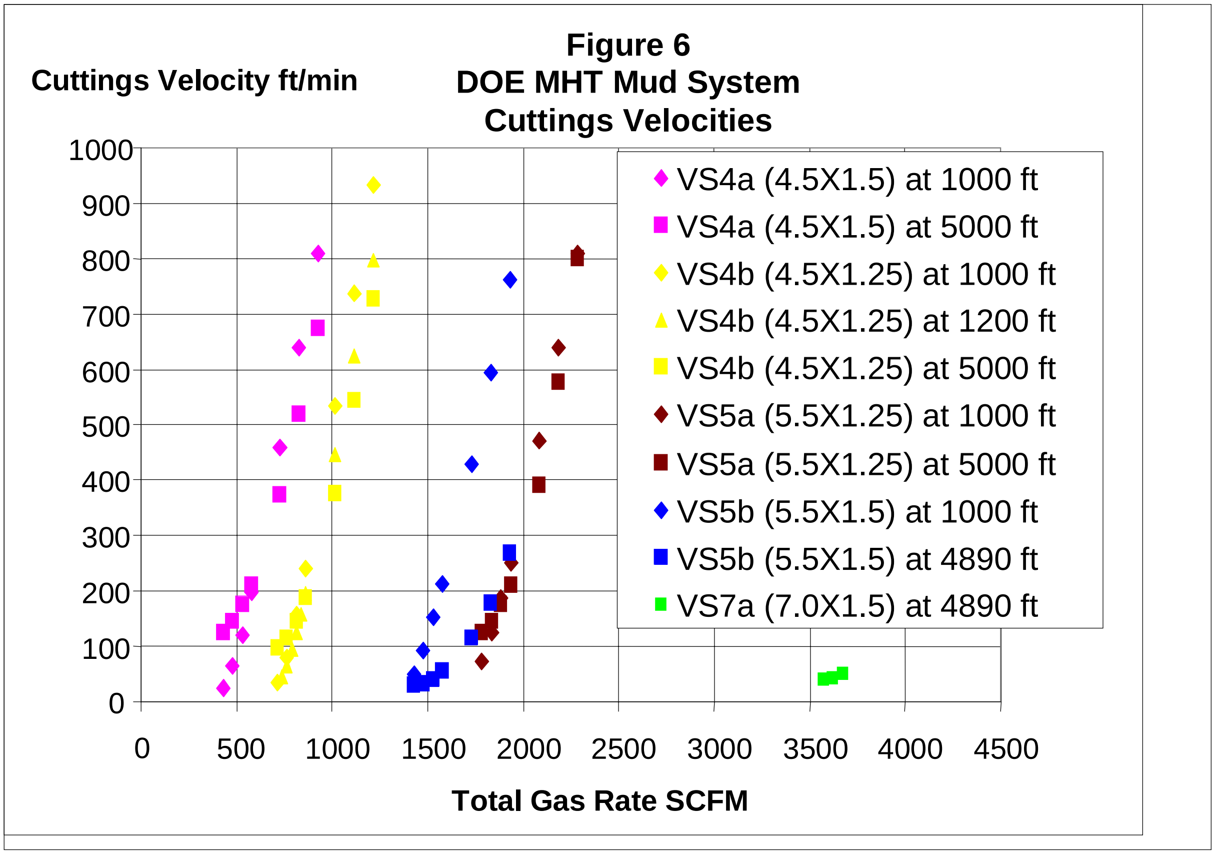


Figure 6
DOE MHT Mud System
Cuttings Velocities
Cuttings Velocity ft/min
1000
900
800
700
600
500
400
300
200
100
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Total Gas Rate SCFM
VS4a (4.5X1.5) at 1000 ft
VS4a (4.5X1.5) at 5000 ft
VS4b (4.5X1.25) at 1000 ft
VS4b (4.5X1.25) at 1200 ft
VS4b (4.5X1.25) at 5000 ft
VS5a (5.5X1.25) at 1000 ft
VS5a (5.5X1.25) at 5000 ft
VS5b (5.5X1.5) at 1000 ft
VS5b (5.5X1.5) at 4890 ft
VS7a (7.0X1.5) at 4890 ft

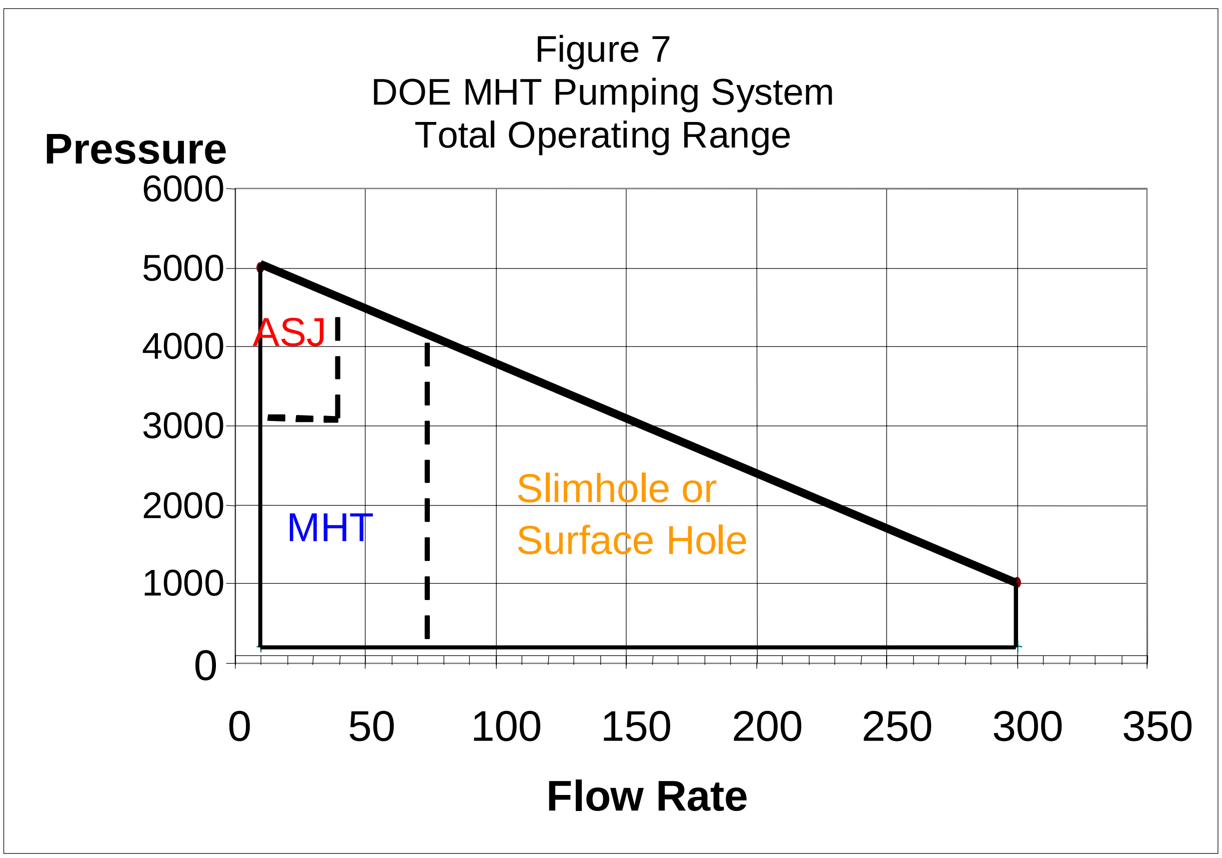


Figure 7
DOE MHT Pumping System
Total Operating Range
Pressure
6000
5000
4000
3000
2000
1000
0
0
50
100
150
200
250
300
350
Flow Rate
ASJ
MHT
Slimhole or
Surface Hole

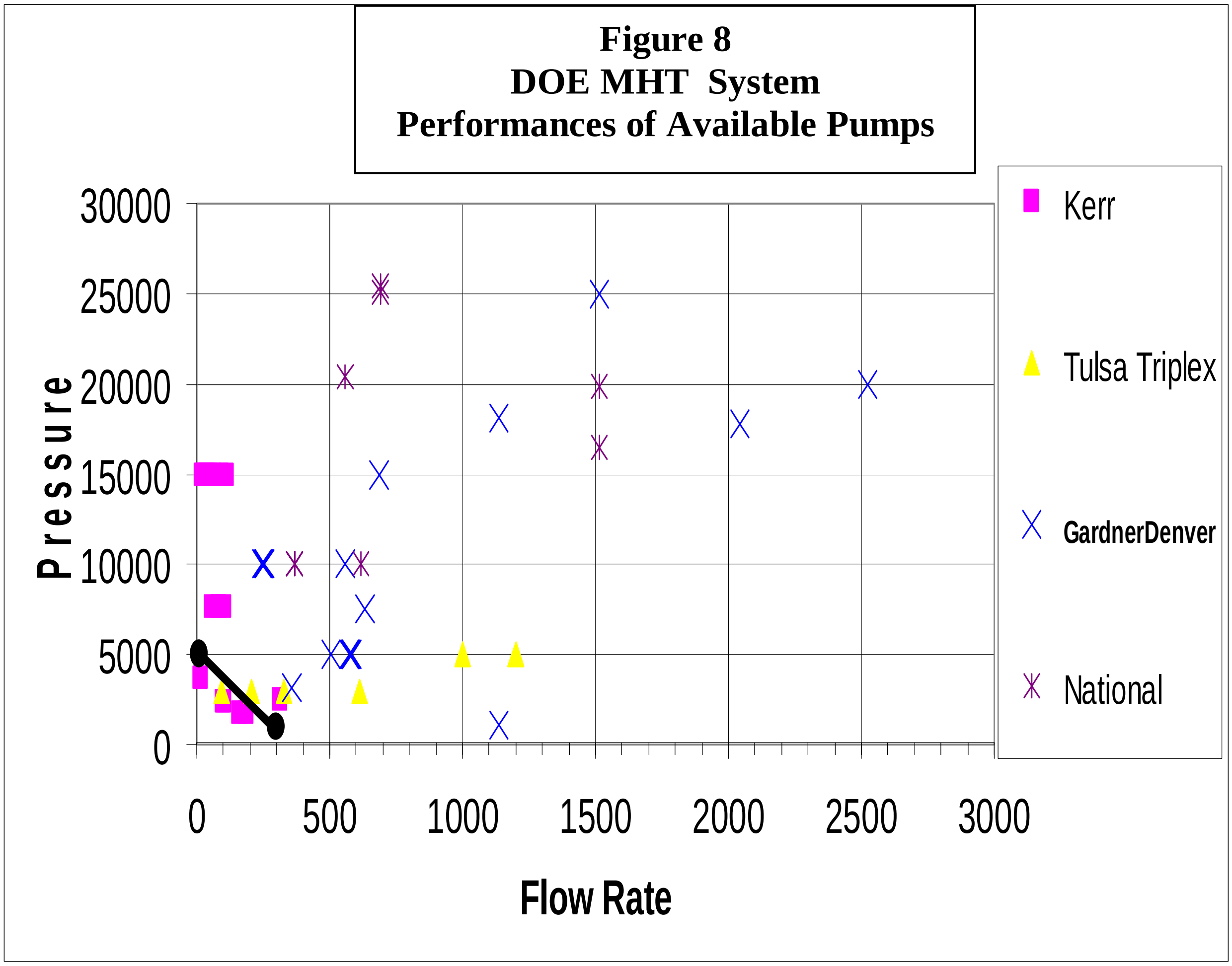


Figure 8
DOE MHT System
Performances of Available Pumps
Pressure
30000
25000
20000
15000
10000
5000
0
0
500
1000
1500
2000
2500
3000
Flow Rate
Kerr
Tulsa Triplex
GardnerDenver
National

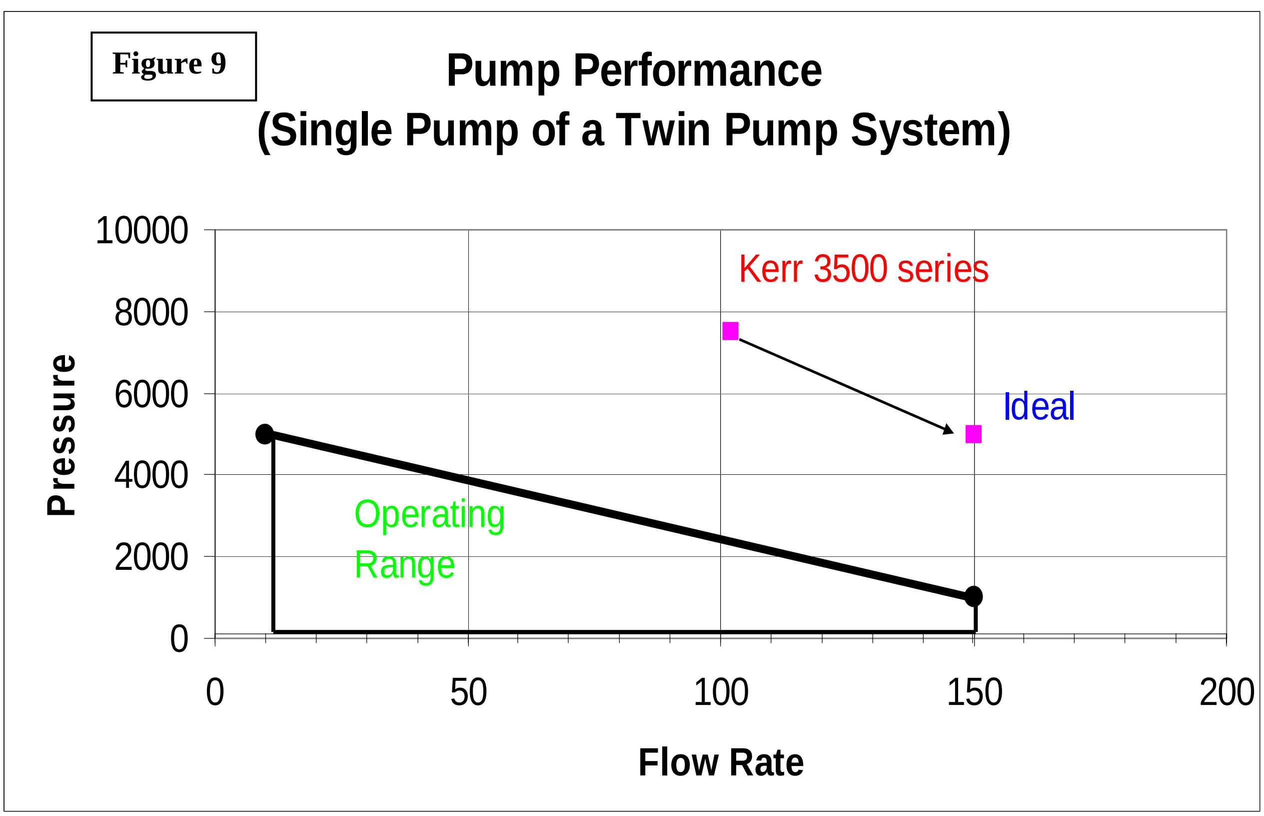


Figure 9
Pump Performance
(Single Pump of a Twin Pump System)
Pressure
10000
8000
6000
4000
2000
0
0
50
100
150
200
Flow Rate
Kerr 3500 series
Ideal
Operating
Range

Figure 10 DOE MHT Available Processing Equipment

Pump Equipment Summary

MFG	Req # and Model	Pump Wgt #	Pump Cost $	Pkg Total Wgt #	Pkg Total Cost $
Kerr	Two-K3500 series	2.1K	10K	8K	50K
National	One-JWS 185	20K	47.5K	38K	96K

Figure 11

Kerr Pumps

Since 1946

Fluid Ends: Steel, Stainless Steel. Side Ports Threaded. Bolted Valve Covers. Right or Left Hand Drive.

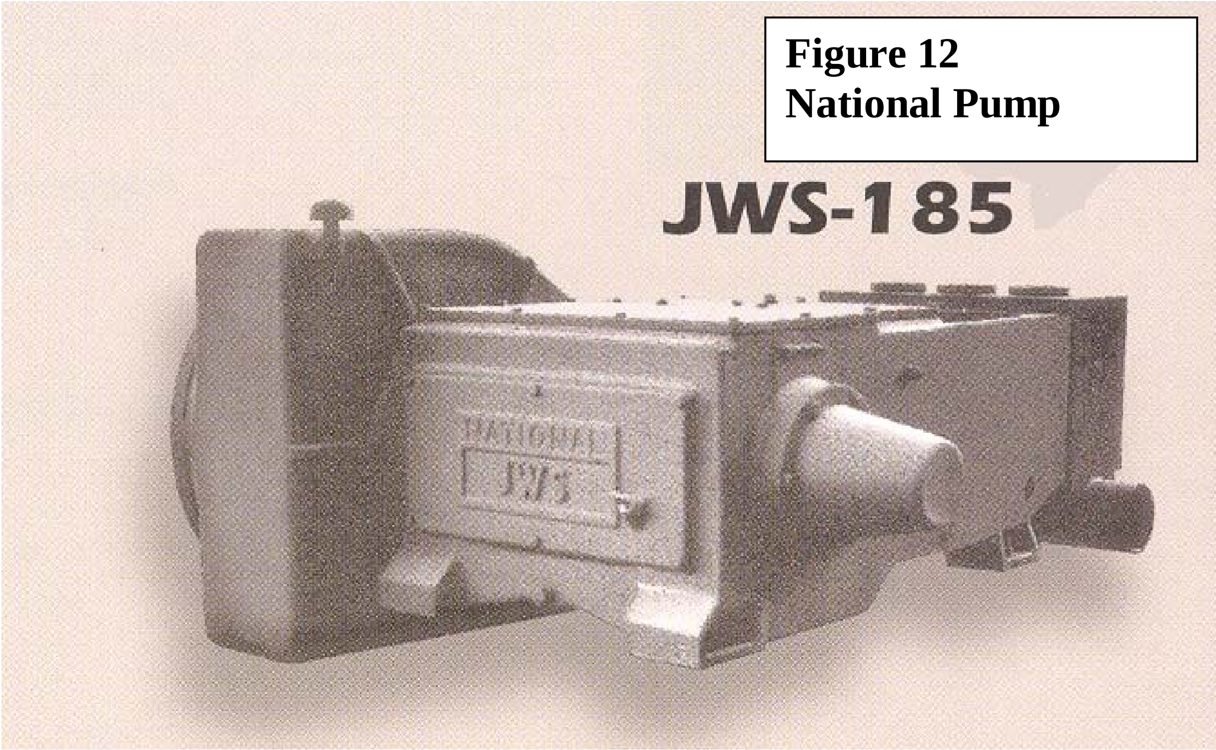


Figure 12
National Pump

Processing Equipment Summary

MFG	Model	Wgt #	Cost $	Pkg Total Wgt #	Pkg Total Cost $
Kemtron	T350 20micron	7K	75K - 100K	16K	120K
Tri-Flo	126/20-2 10micron	9K	120K	25K	150K
Swaco					251K

Figure 13 Summary of Processing

Figure 14 Kemtron Basic Unit for mud processing

Figure 15- Triflo 20-2" cones for mud processing

PROJECT MILESTONES Summary

●Drilling Synergy-Task 1
▪Defined Mud System Characteristics/ hydraulics
▪Investigated Mud properties for MHD
▪Confirm UBD hydraulics for MHD
▪Defined operating parameters for entire mud system
▪Presented status report of above to DOE on 13Dec04
▪Defined composition of returned fluids
▪Achieved DOE change in pump flow rate specifications
▪Submitted abstract to SPE Fall meeting for reporting hydraulic study

●Abrasive Slurry Jet Drilling- Task 2
▪Performed literature review of previous work
▪Developed new nozzle design
▪Demonstrated feasibility of cutting holes in rock that are larger than the nozzle and performed without rotating the pipe or nozzle
▪Developed new HP slurry delivery system
▪Demonstrated feasibility to continuously deliver abrasives to downhole tools
▪Safety training at UMR

●Task 3- Deleted by DOE

●Pump System- Task 4
▪Met with pump design and manufacturing representatives
▪Identified existing pump performance, specifications, availability and cost
▪Addressed possible modifications to existing pumps
Project Milestones- continued

●Processing System – Task 5
▪Identified mud system manufacturers inside and outside the oil & gas industry
▪Met with technical vendors and manufacturers of existing systems
▪Identified specifications and availability of existing systems
▪Addressed possible modifications to existing systems
▪Considered non-traditional tankage materials and configurations
▪Addressed sub-20micron particle processing
▪Investigated 3 phase separation for more compact processing systems

QUESTIONS ORIGINALLY POSED- now answered

- Does each of the technologies meet the requirements to move forward? Yes. ASJ, slurry pumping, pumping system, and the processing systems are all within DOE specifications and should perform well in MHCTD based on engineering estimates and practices.
- Have all safety concerns been met and have safety plans and procedures been prepared for further work and field testing? Yes, ASJ safety has been reviewed. All other safety concerns follow standard industry practices.
- Will abrasive slurry nozzle meet the requirements of hole size, penetration rate, hole cleaning at the limits of pressure and rates? Based on tests so far, yes.
- Is ASJ feasible ? Based on experience and tests,Yes from a technical and economic basis.
- Is ASJ economical compared to current methods? Yes, increased penetration rate should offset any increased cost.
- Will the fluids and abrasives mixtures achieve the desired drilling performance while being economical and compatible with all system components? Yes. The limited combinations of fluids and abrasive tested performed well and are compatible with current drilling components. Fluids and abrasives are fairly low cost items.
- Will each drilling component survive the abrasive fluids coursing through them? Yes, UMR has seen that if velocities are kept below 40meters per second erosion is not a concern. Also rapid direction changes of the slurries should be avoided. These are all known in the water jet industry.
- Are all ASJ connections compatible and interchangeable if needed? Yes. No problem with components are anticipated at the pressures specified. ASJ can be utilized or not without change in the overall design.
- Will the HPSSP meet the system requirements? Yes existing triplex pumps can be modified to meet these requirements. New designs are also possible to gain increased efficiency. Also, other options for delivering slurries may be more cost effective than the HPSPP.
- Will the HPSSP provide adequate service life? Unknown at this time, but still appears reasonable.
- Will the return processing fluid unit provide adequate fluid cleaning within acceptable environmental parameters? Yes. Nothing has been seen otherwise. This system should prove environmentally more secure than existing systems.

CONCLUSIONS

Satisfactory hydraulics are possible within true MHT systems in both mud and gasified systems. Pump operating range required for these MHT systems are 0.63 – 18.9 lps (10-300 gpm) with 6.9 – 34.5 MPa (1000 - 5000 psi) capabilities with those respective rates. Gas injection of 0- 0.94 m^3/s (0-2000 scfm) allows underbalanced drilling operations. Processing of returned fluids at a 31.5 lps (500gpm) specified rate is possible. Nodal analysis / modeling should be strongly considered for each specific application in both the planning and execution phases since each well and rig configuration is different and the operating ranges are so narrow in MHT systems.

An Abrasive Slurry Jetting (ASJ) should be applicable to MHCTD after demonstrating a nozzle prototype that is capable of jetting a hole larger than itself without rotating and submerged in water. Also a low cost batch abrasive slurry mixing and deliverability method was demonstated, but still requiring optimization..

Compact, light weight and modular components with twin pumps are desired for redundancy, portability, and flexibility. Two such pumps were identified that suit this application with only minor modifications.

A compact mud processing system is possible. Through contacts with experts- mud engineer, mud companies and mud processing companies, both inside and outside the oil & gas industry, trenchless systems, and other industries, two system were identified as approaching the specifications of rate and processing. Modifications are needed for weight, size, ASJ processing, sub-20micron solids removal. Modular systems and non-metal tankage and plumbing are anticipated in high savings in size and weight-ie portability.

If implemented, these processes can greatly benefit MHCTD.

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Contract no. FI1D-0069; reference no. EUR 12684; working period July 1987 - March 1989; contractor(s) University of Hanover, Germany.
A special cutting head for underwater use was designed and built. Tests were carried out to find out useful parameters for submerged cutting. With regard to the production of secondary waste the abrasive flow rate had to be minimized. It seems to be useful to realize this demand by using a small water jet nozzle (up to 0.4 mm diameter) and a high pressure (up to 4000 bar) with an optimal abrasive flow rate of about 5 g/s. In case of a higher ambient pressure a decrease of the cutting performance was measured. But this decrease is not important regarding decommissioning because the ambient pressure is less than 2 bar. An air mantle nozzle was adapted to the cutting head to improve the working distance under water. The air mantle surrounding the abrasive jet lowers the friction between jet and surrounding water and increases the cutting efficiency in case of greater working distances.

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LIST OF ACRONYMS AND ABBREVIATIONS

MHT- Microhole Technology
MHCT- Microhole Coiled Tubing
MHCT D- Microhole Coiled Tubing Drilling
ASJ- Abrasive Slurry Jetting
CT- Coiled Tubing
CTD- Coiled Tubing Drilling
CCT- Composite Coiled Tubing
UMR- University of Missouri at Rolla
DOE- Department of Energy
TVD- True vertical depth
UBD- underbalanced drilling

Gpm- gallons per minute
Scfm –standard cubic foot per minute
Psi- pounds per square inch pressure
Fpm- feet per minute
Ft- foot
In- inch
N- Power Law exponent for mud rheology
K- Power Law constant for mud rheology
Pa- Pascals
KPa- Kilo Pascals
MPa- Mega Pascals
m- meter
m^3- cubic meter
lps- liters per second

APPENDIX LIST

A. Contact Information for Investigators
B. HYMOD Modeling run- full input and output
C. MUDLite Modeling run- full input and output
D. UMR Literature Search and Review
E. UMR BP1 Final Presentation to DOE

APPENDIX A
CONTACT INFORMATION

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APPENDIX B

HYMOD Modeling run-full input and output

Wellbore Hydraulics Model (HYDMOD)

Table - Hydraulics Details

Data File	V:\Documents and Settings\Ken Oglesby\My Documents\L1-Hymod 1000 horiz 3.hy4
Well Name	Production Casing Point 1 with CT
Project	Microbore Drilling
Company	BPX / Impact
Field	Test
Location	location
Date	30Nov04
Comments	Hydraulics evaluation for 1000' lateral with CT, premium mud, 3.5" hole, 1.75CT@@@@@at 5000' TVD in 5.5" casing

Flow Rate (gpm)	50.00
Pump Output Hydraulic Power (HP)	26.66
Circulation System HP Loss (w/o bit) (HP)	26.66
Bit Hydraulic HP (HP)	0.00
Pump Pressure (psi)	913.9
Surface Equipment Pressure Loss (psi)	249.9
Circulation System Pressure Loss (w/o bit) (psi)	913.9
Nozzle Pressure Loss (psi)	0.0
Jet Impact Force (lbf)	0
Jet Pressure (psi)	0.0
Nozzle Area (in2)	0.331
Nozzle Velocity (ft/s)	0.00
Required Flow Rate w/o Ctgs (gpm)	246.16

Frictional Pressure Drop Inside the Drill Strings, etc.:

Drill Strings	Press. Drop (psi)	Flow Type	Velocity (ft/min)
Surface	249.9	NA	NA
CT	583.3	Turbulent	678.44
DC	1.9	Turbulent	544.66
BHA	1.9	Turbulent	544.66

Bit Information:

Bit Press. Loss (psi) = 0.0	Jet Velocity (ft/s) = 0.00

Frictional Pressure Drop in the Annulus:

Inner	Outer	P. Drop (psi)	Flow Type	Velocity (ft/min)
Open Hole	BHA	4.5	Turbulent	307.57
Open Hole	DC	4.5	Turbulent	307.57
Open Hole	CT	25.1	Laminar	133.39
Prod casing	CT	42.7	Laminar	55.86

Volume Information:

Pipe Volume (bbl)	10.64
Annulus Volume (bbl)	115.62
Total Volume (bbl)	126.26

Nozzle Selection - Max. Hydraulic Horsepower

Optimum Flow Rate (gpm)	74.08
Optimum Total Flow Area (in2)	0.037
Optimum System Pressure Drop (psi)	1818.2
Optimum Bit Pressure Drop (psi)	3181.8
Optimum Bit HHP (HP)	137.51

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HYDMOD - Wellbore Hydraulics Model

Project Input Data

Project File Name	V:\Documents and Settings\Ken Oglesby\My Documents\L1-Hymod 1000 horiz 3.hy4

Well	Production Casing Point 1 with CT
Project	Microbore Drilling
Company	BPX / Impact
Field	Test
Location	location
Date	30Nov04
Comments	Hydraulics evaluation for 1000' lateral with CT, premium mud, 3.5" hole, 1.75CT@@@@@at 5000' TVD in 5.5" casing

Survey Data

Total measured depth	6050.0 (ft)

Drill Strings/Collars (from bit):

Casing shoe depth (ft) = 0.0	Rig Type: Coiled-Tubing Unit	Bit Depth (ft) = 6050.0

#	Description	Length (ft)	O.D. (in)	Wall Thick. (in)	BHA	TJ OD (in)	TJ Contact %	P.Drop (psi)
1	BHA	30.0	2.875	0.688	No	4.750	4.2	DC

Coiled-tubing total length (ft) = 10000.0	Length of remaining tubing on the reel (ft) = 3950.0

Nozzle Data (nozzle ID unit: (1/32in)):

No nozzle or TFA

Well Interval

#	Description	Bottom (ft)	I.D. (in)
1	Prod casing	5000.0	5.000
2	Open Hole	6050.0	3.500

Mud Properties

Mud Weight (ppg)	N' (-)	K' (lbf-s^n/ft2)
8.50	0.30	0.01797

Flow Rate (gpm) = 50.00

Surge/Swab Condition

Pipe Running Speed (ft/min) = 20.00	Closed Pipe End

Cuttings Properties

Drilling rate (ft/h) = 600.0	Cuttings slip calculation: Moore method
Cuttings Diameter (in) = 0.250	Cuttings Density (ppg) = 21.60

Well Planning and Nozzle Selection: Maximum hydraulic HP

Max. pump pressure (psi) = 5000.0	Max. pump horsepower (HP) = 300.00
Pump efficiency = .9	Flow rate index = 1.75
Minimum flow rate (gpm) = 15.00	

Formation Pore/Frac. Data

Show pore/frac. pressures in output graphs? Yes.

Trip margin (psi/ft) = 0.100	Kill margin (psi/ft) = 0.100

#	Description	Bottom (TVD)(ft)	Pore (psi/ft)	Fracture (psi/ft)
1	shale	1000.0	0.400	0.800

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2	gold	2000.0	0.400	0.900
3	silver	3000.0	0.400	0.900
4	coal	4000.0	0.400	0.800
5	bottom	6000.0	0.400	0.850

HYDMOD - Wellbore Hydraulics Model
Table - Hydraulics Details

Data file: V:\Documents and Settings\Ken Oglesby\My Documents\L1-Hymod 1000 horiz 3.hy4
Well name: Production Casing Point 1 with CT
Project: Microbore Drilling
Company: BPX / Impact
Field: Test
Location: location
Date: 30Nov04
Comments: Hydraulics evaluation for 1000' lateral with CT, premium mud, 3.5" hole, 1.75CT@@@@@at 5000' TVD in 5.5" casing

	MD (ft)	TVD (ft)	Pore Pressure (psi)	Frac Pressure (psi)	Hydrostatic (psi)	Static Mud Wt. (ppg)	Pipe Pressure (psi)	Pipe Velocity (ft/min)	Pipe Flow	Annulus Pressure (psi)	Annulus Velocity (ft/min)	Annulus Flow	Annulus ECD (ppg)	Annulus Eff Density (ppg)	Ctgs Concentration (%)	Ctgs Flow Velocity (ft/min)	Ctgs Slip Velocity (ft/min)	Ctgs Trans Ratio	Flow Rate w/o Ctgs (gpm)
1	0.0	0.0	0.0	0.0	0.0	8.50	663.9	678.44	Turbulent	0.0	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
2	100.0	100.0	40.0	80.0	44.2	8.50	698.4	678.44	Turbulent	45.0	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
3	200.0	200.0	80.0	160.0	88.3	8.50	732.8	678.44	Turbulent	90.0	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
4	300.0	300.0	120.0	240.0	132.5	8.50	767.2	678.44	Turbulent	135.0	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
5	400.0	400.0	160.0	320.0	176.6	8.50	801.6	678.44	Turbulent	180.0	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
6	500.0	500.0	200.0	400.0	220.8	8.50	836.0	678.44	Turbulent	225.1	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
7	600.0	600.0	240.0	480.0	264.9	8.50	870.5	678.44	Turbulent	270.1	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
8	700.0	700.0	280.0	560.0	309.1	8.50	904.9	678.44	Turbulent	315.1	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
9	800.0	800.0	320.0	640.0	353.3	8.50	939.3	678.44	Turbulent	360.1	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
10	900.0	900.0	360.0	720.0	397.4	8.50	973.7	678.44	Turbulent	405.1	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
11	1000.0	1000.0	400.0	800.0	441.6	8.50	1008.1	678.44	Turbulent	450.1	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
12	1100.0	1100.0	440.0	990.0	485.7	8.50	1042.6	678.44	Turbulent	495.1	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
13	1200.0	1200.0	480.0	1080.0	529.9	8.50	1077.0	678.44	Turbulent	540.1	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
14	1300.0	1300.0	520.0	1170.0	574.0	8.50	1111.4	678.44	Turbulent	585.1	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
15	1400.0	1400.0	560.0	1260.0	618.2	8.50	1145.8	678.44	Turbulent	630.2	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
16	1500.0	1500.0	600.0	1350.0	662.4	8.50	1180.2	678.44	Turbulent	675.2	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
17	1600.0	1600.0	640.0	1440.0	706.5	8.50	1214.7	678.44	Turbulent	720.2	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
18	1700.0	1700.0	680.0	1530.0	750.7	8.50	1249.1	678.44	Turbulent	765.2	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
19	1800.0	1800.0	720.0	1620.0	794.8	8.50	1283.5	678.44	Turbulent	810.2	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
20	1900.0	1900.0	760.0	1710.0	839.0	8.50	1317.9	678.44	Turbulent	855.2	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
21	2000.0	2000.0	800.0	1800.0	883.1	8.50	1352.3	678.44	Turbulent	900.2	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
22	2100.0	2100.0	840.0	1890.0	927.3	8.50	1386.8	678.44	Turbulent	945.2	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
23	2200.0	2200.0	880.0	1980.0	971.5	8.50	1421.2	678.44	Turbulent	990.3	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
24	2300.0	2300.0	920.0	2070.0	1015.6	8.50	1455.6	678.44	Turbulent	1035.3	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
25	2400.0	2400.0	960.0	2160.0	1059.8	8.50	1490.0	678.44	Turbulent	1080.3	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
26	2500.0	2500.0	1000.0	2250.0	1103.9	8.50	1524.4	678.44	Turbulent	1125.3	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
27	2600.0	2600.0	1040.0	2340.0	1148.1	8.50	1558.9	678.44	Turbulent	1170.3	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
28	2700.0	2700.0	1080.0	2430.0	1192.3	8.50	1593.3	678.44	Turbulent	1215.3	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
29	2800.0	2800.0	1120.0	2520.0	1236.4	8.50	1627.7	678.44	Turbulent	1260.3	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
30	2900.0	2900.0	1160.0	2610.0	1280.6	8.50	1662.1	678.44	Turbulent	1305.3	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
31	3000.0	3000.0	1200.0	2700.0	1324.7	8.50	1696.5	678.44	Turbulent	1350.3	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
32	3100.0	3100.0	1240.0	2480.0	1368.9	8.50	1730.9	678.44	Turbulent	1395.4	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
33	3200.0	3200.0	1280.0	2560.0	1413.0	8.50	1765.4	678.44	Turbulent	1440.4	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
34	3300.0	3300.0	1320.0	2640.0	1457.2	8.50	1799.8	678.44	Turbulent	1485.4	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
35	3400.0	3400.0	1360.0	2720.0	1501.4	8.50	1834.2	678.44	Turbulent	1530.4	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
36	3500.0	3500.0	1400.0	2800.0	1545.5	8.50	1868.6	678.44	Turbulent	1575.4	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
37	3600.0	3600.0	1440.0	2880.0	1589.7	8.50	1903.0	678.44	Turbulent	1620.4	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
38	3700.0	3700.0	1480.0	2960.0	1633.8	8.50	1937.5	678.44	Turbulent	1665.4	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
39	3800.0	3800.0	1520.0	3040.0	1678.0	8.50	1971.9	678.44	Turbulent	1710.4	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
40	3900.0	3900.0	1560.0	3120.0	1722.1	8.50	2006.3	678.44	Turbulent	1755.4	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
41	4000.0	4000.0	1600.0	3200.0	1766.3	8.50	2040.7	678.44	Turbulent	1800.5	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72

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HYDMOD - Wellbore Hydraulics Model
Table - Hydraulics Details

Data file: V:\Documents and Settings\Ken Oglesby\My Documents\6.1 Hymod 1000 horiz 3.hy4
Well name: Production Casing Point 1 with CT
Project: Microbore Drilling
Company: BPX / Impact
Field: Test
Location: location
Date: 30Nov04
Comments: Hydraulics evaluation for 1000' lateral with CT, premium mud, 3.5" hole, 1.75CT@@@@@at 5000' TVD in 5.5" casing

	MD (ft)	TVD (ft)	Pore Pressure (psi)	Frac Pressure (psi)	Hydrostatic (psi)	Static Mud Wt (ppg)	Pipe Pressure (psi)	Pipe Velocity (ft/min)	Pipe Flow	Annulus Pressure (psi)	Annulus Velocity (ft/min)	Annulus Flow	Annulus ECD (ppg)	Annulus Eff. Density (ppg)	Ctgs Concentration (%)	Ctgs Flow Velocity (ft/min)	Ctgs Slip Velocity (ft/min)	Ctgs Trans. Ratio	Flow Rate w/o Ctgs (gpm)
42	4100.0	4100.0	1640.0	3485.0	1910.5	8.50	2075.1	678.44	Turbulent	1945.5	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
43	4200.0	4200.0	1680.0	3570.0	1954.6	8.50	2109.6	678.44	Turbulent	1990.5	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
44	4300.0	4300.0	1720.0	3655.0	1998.8	8.50	2144.0	678.44	Turbulent	1935.5	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
45	4400.0	4400.0	1760.0	3740.0	1942.9	8.50	2178.4	678.44	Turbulent	1980.5	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
46	4500.0	4500.0	1800.0	3825.0	1987.1	8.50	2212.8	678.44	Turbulent	2025.5	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
47	4600.0	4600.0	1840.0	3910.0	2031.2	8.50	2247.2	678.44	Turbulent	2070.5	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
48	4700.0	4700.0	1880.0	3995.0	2075.4	8.50	2281.7	678.44	Turbulent	2115.5	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
49	4800.0	4800.0	1920.0	4080.0	2119.6	8.50	2316.1	678.44	Turbulent	2160.5	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
50	4900.0	4900.0	1960.0	4165.0	2163.7	8.50	2350.5	678.44	Turbulent	2205.6	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	88.72
51	5000.0	4993.9	1997.6	4244.8	2205.2	8.50	2382.2	678.44	Turbulent	2247.9	55.86	Laminar	8.66	10.69	16.736	27.78	28.08	0.50	248.18
52	5100.0	5008.2	2003.3	4256.9	2211.5	8.50	2378.8	678.44	Turbulent	2256.7	133.39	Laminar	8.67	10.13	12.463	93.65	39.74	0.70	114.30
53	5200.0	5008.2	2003.3	4256.9	2211.5	8.50	2368.0	678.44	Turbulent	2259.3	133.39	Laminar	8.68	10.13	12.463	93.65	39.74	0.70	114.30
54	5300.0	5008.2	2003.3	4256.9	2211.5	8.50	2359.3	678.44	Turbulent	2261.8	133.39	Laminar	8.69	10.13	12.463	93.65	39.74	0.70	114.30
55	5400.0	5008.2	2003.3	4256.9	2211.5	8.50	2349.6	678.44	Turbulent	2264.3	133.39	Laminar	8.70	10.13	12.463	93.65	39.74	0.70	114.30
56	5500.0	5008.2	2003.3	4256.9	2211.5	8.50	2339.8	678.44	Turbulent	2266.9	133.39	Laminar	8.71	10.13	12.463	93.65	39.74	0.70	114.30
57	5600.0	5008.2	2003.3	4256.9	2211.5	8.50	2330.1	678.44	Turbulent	2269.4	133.39	Laminar	8.72	10.13	12.463	93.65	39.74	0.70	114.30
58	5700.0	5008.2	2003.3	4256.9	2211.5	8.50	2320.4	678.44	Turbulent	2272.0	133.39	Laminar	8.73	10.13	12.463	93.65	39.74	0.70	114.30
59	5800.0	5008.2	2003.3	4256.9	2211.5	8.50	2310.6	678.44	Turbulent	2274.5	133.39	Laminar	8.74	10.13	12.463	93.65	39.74	0.70	114.30
60	5900.0	5008.2	2003.3	4256.9	2211.5	8.50	2300.9	678.44	Turbulent	2277.0	133.39	Laminar	8.75	10.13	12.463	93.65	39.74	0.70	114.30
61	5990.0	5008.2	2003.3	4256.9	2211.5	8.50	2292.1	678.44	Turbulent	2279.3	133.39	Laminar	8.76	10.13	12.463	93.65	39.74	0.70	114.30
62	6000.0	5008.2	2003.3	4256.9	2211.5	8.50	2291.5	544.66	Turbulent	2280.8	307.57	Turbulent	8.77	9.95	11.102	246.20	61.38	0.80	74.43
63	6020.0	5008.2	2003.3	4256.9	2211.5	8.50	2290.2	544.66	Turbulent	2283.8	307.57	Turbulent	8.78	9.95	11.102	246.20	61.38	0.80	74.43
64	6050.0	5008.2	2003.3	4256.9	2211.5	8.50	2288.3	544.66	Turbulent	2288.3	307.57	Turbulent	8.80	9.95	11.102	246.20	61.38	0.80	74.43

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Optimum Nozzle Velocity (ft/s)	646.78
Optimum Jet Impact Force (lbf)	211
Optimum Hole Impact Pressure (psi)	21.9

Optimum Nozzle Selection Variance Analysis:

Assumed Optimum Total Nozzle Area(in2) = 0.037

Two Nozzles (1/32in)	Area Vari. (%)	Three Nozzles (1/32in)	Area Vari. (%)	Four Nozzles (1/32in)	Area Vari. (%)	Five Nozzles (1/32in)	Area Vari. (%)
5+5	4	4+4+4		3+3+4+4	4	2+2+3+4+4	2
3+5	-30	3+4+5	4	3+3+3+4	-11	2+3+3+3+4	-3
4+4	-34	4+4+5	18	2+2+4+4	-17	3+3+3+3+3	-7
		4+5+5	37	3+4+4+4	18	3+3+3+3+4	8
		5+5+5	55	2+3+3+4	-21	3+3+3+4+4	22
				3+3+3+3	-25	3+3+4+4+4	37
				4+4+4+4	33	3+4+4+4+4	51
						4+4+4+4+4	66

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Wellbore Hydraulics Model (HYDMOD)

Hydraulics Sensitivity Analysis

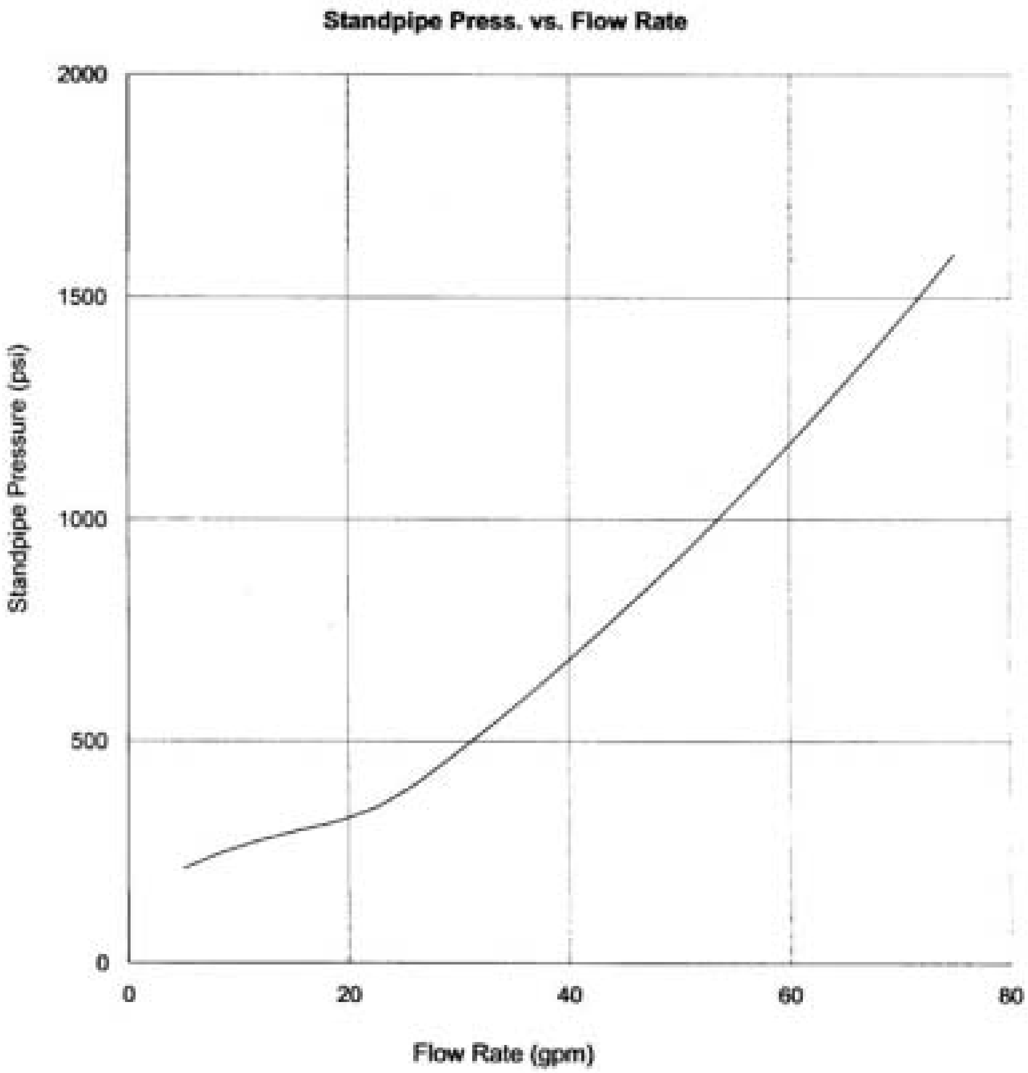
Data File	V:\Documents and Settings\Ken Oglesby\My Documents\L1-Hymod 1000 horiz 3.hy4
Well Name	Production Casing Point 1 with CT
Project	Microbore Drilling
Company	BPX / Impact
Field	Test
Location	location
Date	30Nov04
Comments	Hydraulics evaluation for 1000' lateral with CT, premium mud, 3.5" hole, 1.75CT@@@@@at 5000' TVD in 5.5" casing

Flow Rate (gpm)	Standpipe P (psi)
5.00	213.7
8.50	250.7
12.00	278.1
15.50	300.3
19.00	320.7
22.50	352.4
26.00	403.1
29.50	468.1
33.00	536.5
36.50	608.0
40.00	683.2
43.50	761.1
47.00	842.2
50.50	926.0
54.00	1013.6
57.50	1103.5
61.00	1196.1
64.50	1291.5
68.00	1390.2
71.50	1492.0
75.00	1596.8

Wellbore Hydraulics Model (HYDMOD)

Hydraulics Sensitivity Analysis

Data File	V:\Documents and Settings\Ken Oglesby\My Documents\L1-Hymod 1000 horiz 3.hy4
Well Name	Production Casing Point 1 with CT
Project	Microbore Drilling
Company	BPX / Impact
Field	Test
Location	location
Date	30Nov04
Comments	Hydraulics evaluation for 1000' lateral with CT, premium mud, 3.5" hole, 1.75CT@@@@@at 5000' TVD in 5.5" casing



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Wellbore Hydraulics Model (HYDMOD)

Hydraulics Sensitivity Analysis

Data File	V:\Documents and Settings\Ken Oglesby\My Documents\L1-Hymod 1000 horiz 3.hy4
Well Name	Production Casing Point 1 with CT
Project	Microbore Drilling
Company	BPX / Impact
Field	Test
Location	location
Date	30Nov04
Comments	Hydraulics evaluation for 1000' lateral with CT, premium mud, 3.5" hole, 1.75CT@@@@@at 5000' TVD in 5.5" casing

Flow Rate (gpm)	Fluid Velocity (ft/min)	Ctgs Velocity (ft/min)
5.00	5.59	-5.14
8.50	9.50	-6.05
12.00	13.41	-6.73
15.50	17.32	-4.06
19.00	21.23	-1.18
22.50	25.14	1.83
26.00	29.05	4.94
29.50	32.96	8.13
33.00	36.87	11.38
36.50	40.78	14.68
40.00	44.69	18.03
43.50	48.60	21.42
47.00	52.51	24.83
50.50	56.42	28.27
54.00	60.33	31.74
57.50	64.24	35.23
61.00	68.15	38.74
64.50	72.06	42.26
68.00	75.97	45.80
71.50	79.88	49.36
75.00	83.79	52.93

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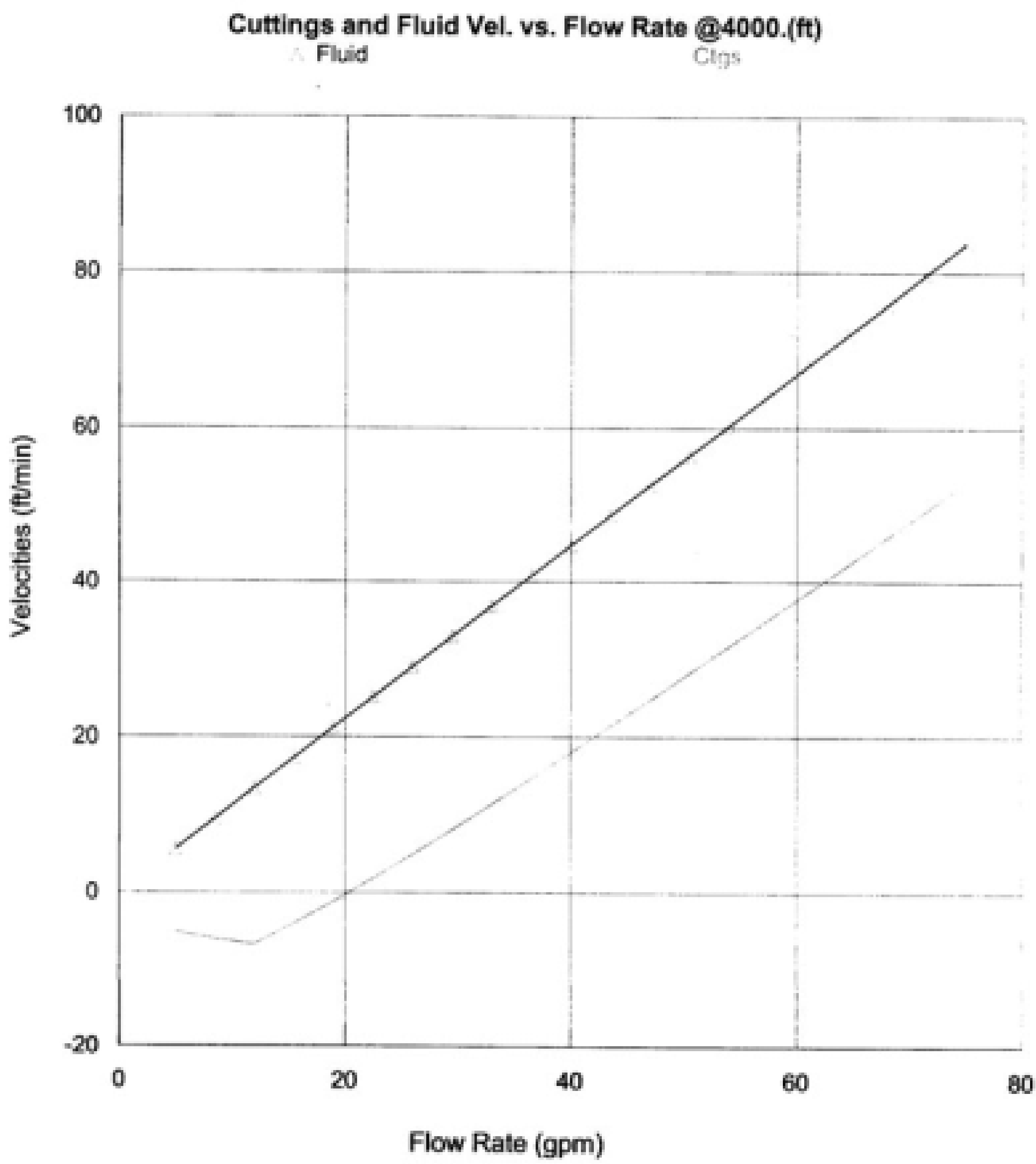
Wellbore Hydraulics Model (HYDMOD)

Hydraulics Sensitivity Analysis

Data File	V:\Documents and Settings\Ken Oglesby\My Documents\L1-Hymod 1000 horiz 3.hy4
Well Name	Production Casing Point 1 with CT
Project	Microbore Drilling
Company	BPX / Impact
Field	Test
Location	location
Date	30Nov04
Comments	Hydraulics evaluation for 1000' lateral with CT, premium mud, 3.5" hole, 1.75CT@@@@@at 5000' TVD in 5.5" casing



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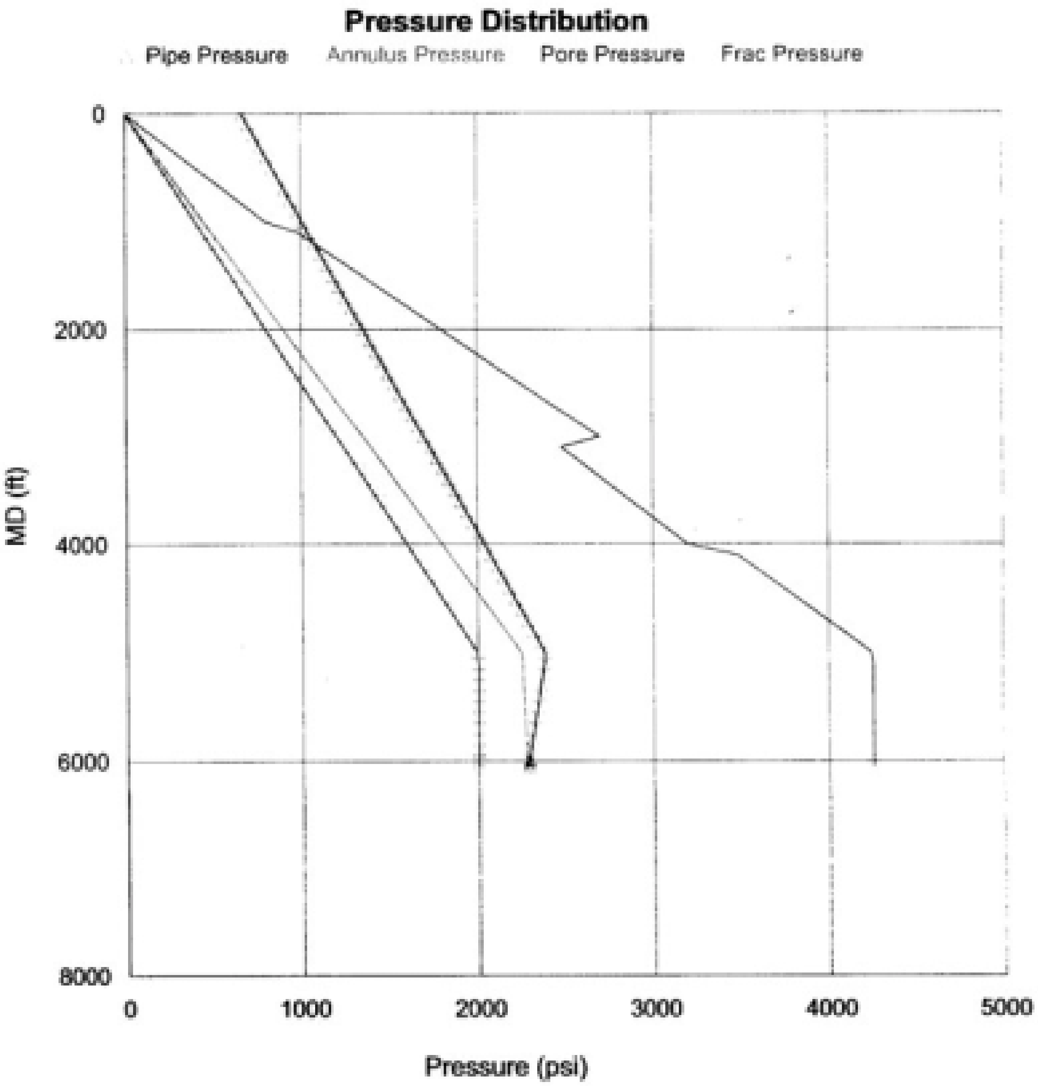
Wellbore Hydraulics Model (HYDMOD)

Pressure Distribution

Data File	V:\Documents and Settings\Ken Oglesby\My Documents\L1-Hymod 1000 horiz 3.hy4
Well Name	Production Casing Point 1 with CT
Project	Microbore Drilling
Company	BPX / Impact
Field	Test
Location	location
Date	30Nov04
Comments	Hydraulics evaluation for 1000' lateral with CT, premium mud, 3.5" hole, 1.75CT@@@@@at 5000' TVD in 5.5" casing



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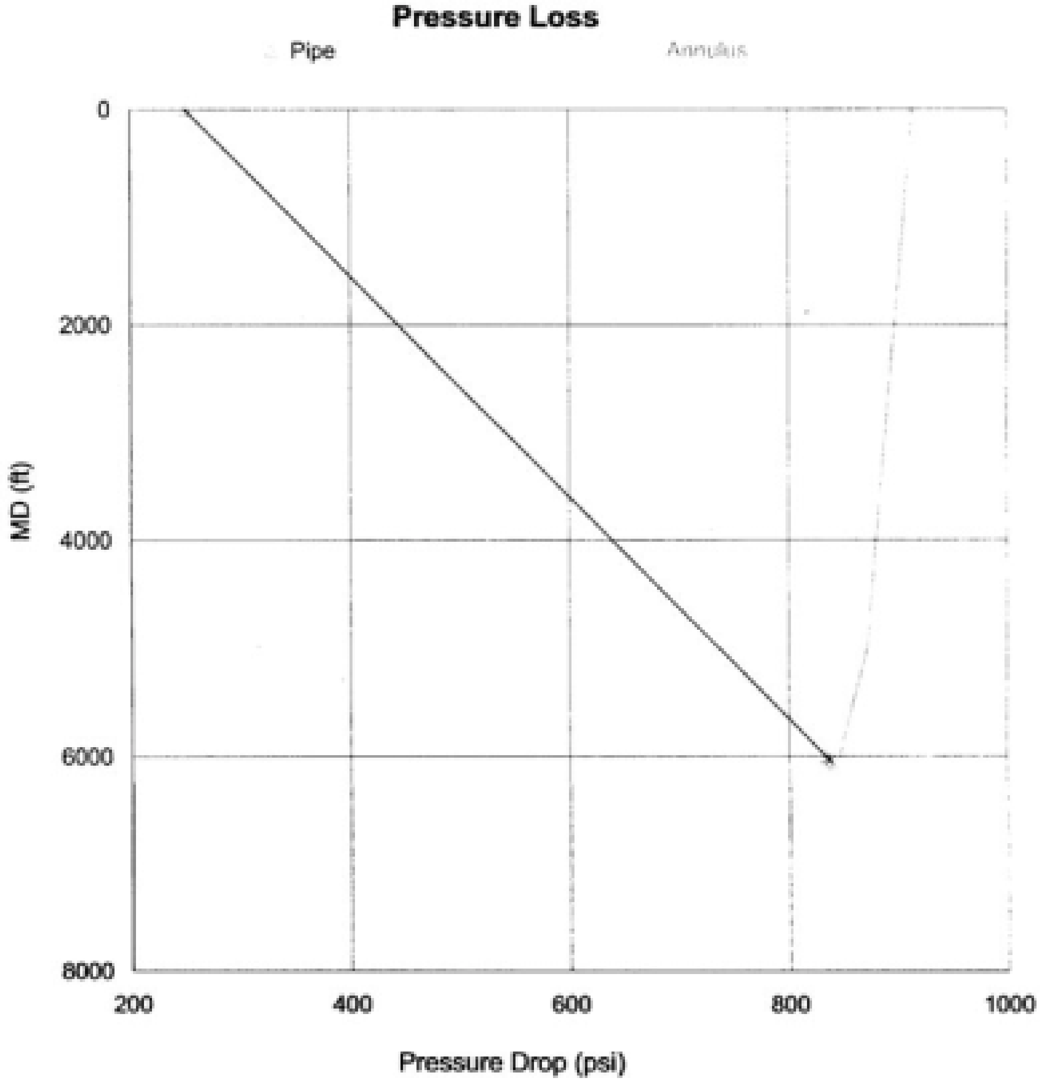
Wellbore Hydraulics Model (HYDMOD)

Pressure Loss

Data File	V:\Documents and Settings\Ken Oglesby\My Documents\L1-Hymod 1000 horiz 3.hy4
Well Name	Production Casing Point 1 with CT
Project	Microbore Drilling
Company	BPX / Impact
Field	Test
Location	location
Date	30Nov04
Comments	Hydraulics evaluation for 1000' lateral with CT, premium mud, 3.5" hole, 1.75CT@@@@@at 5000' TVD in 5.5" casing



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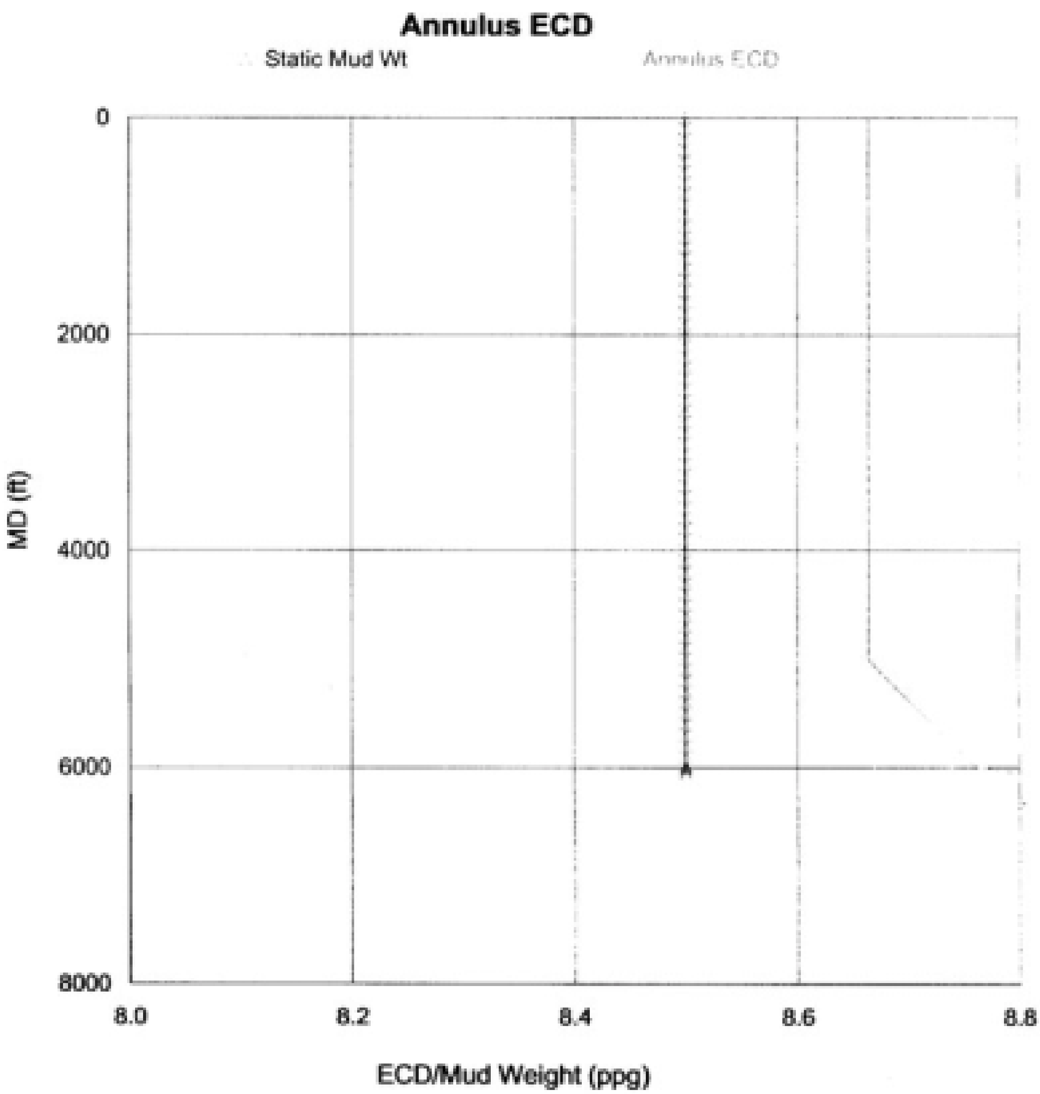
Wellbore Hydraulics Model (HYDMOD)

Annulus ECD

Data File	V:\Documents and Settings\Ken Oglesby\My Documents\L1-Hymod 1000 horiz 3.hy4
Well Name	Production Casing Point 1 with CT
Project	Microbore Drilling
Company	BPX / Impact
Field	Test
Location	location
Date	30Nov04
Comments	Hydraulics evaluation for 1000' lateral with CT, premium mud, 3.5" hole, 1.75CT@@@@@at 5000' TVD in 5.5" casing



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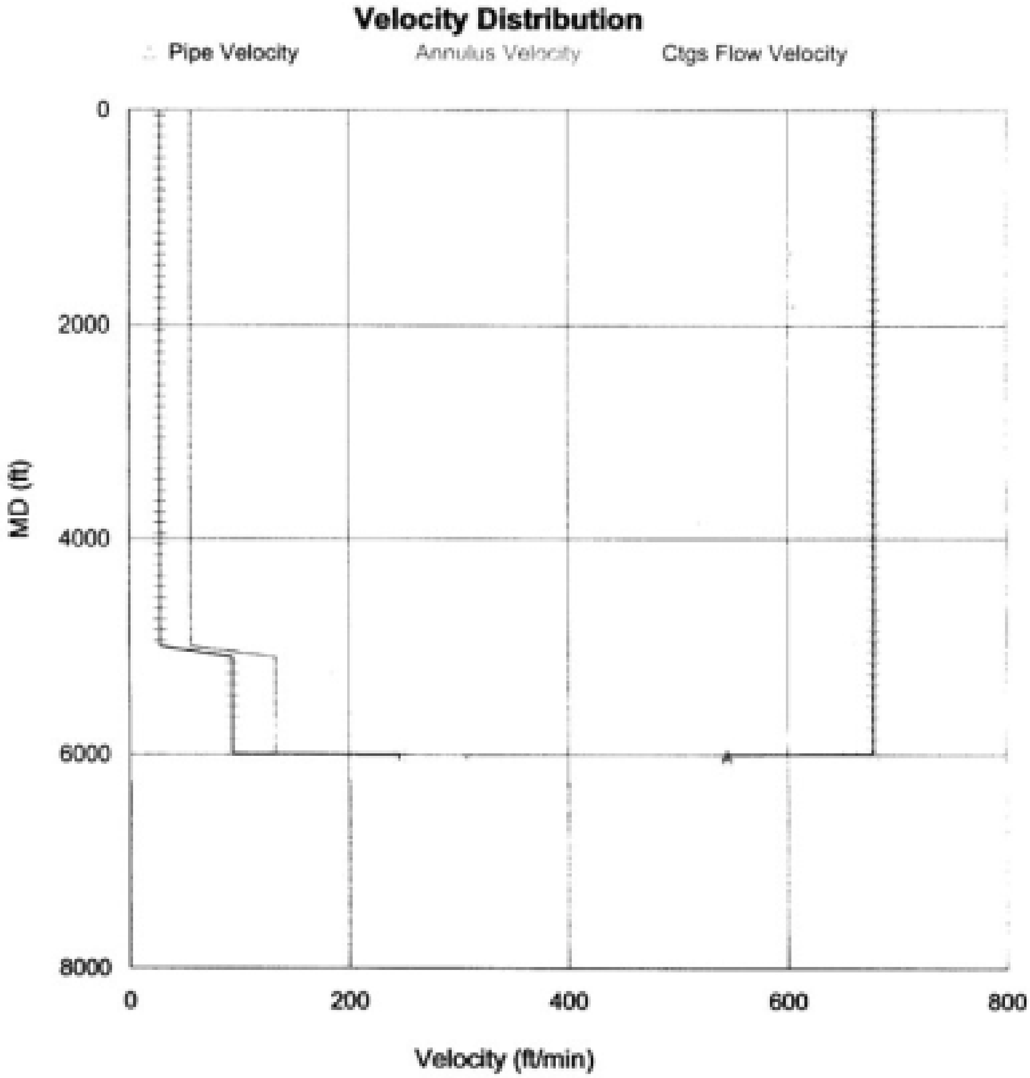
Wellbore Hydraulics Model (HYDMOD)

Velocity Distribution

Data File	V:\Documents and Settings\Ken Oglesby\My Documents\L1-Hymod 1000 horiz 3.hy4
Well Name	Production Casing Point 1 with CT
Project	Microbore Drilling
Company	BPX / Impact
Field	Test
Location	location
Date	30Nov04
Comments	Hydraulics evaluation for 1000' lateral with CT, premium mud, 3.5" hole, 1.75CT@@@@@at 5000' TVD in 5.5" casing



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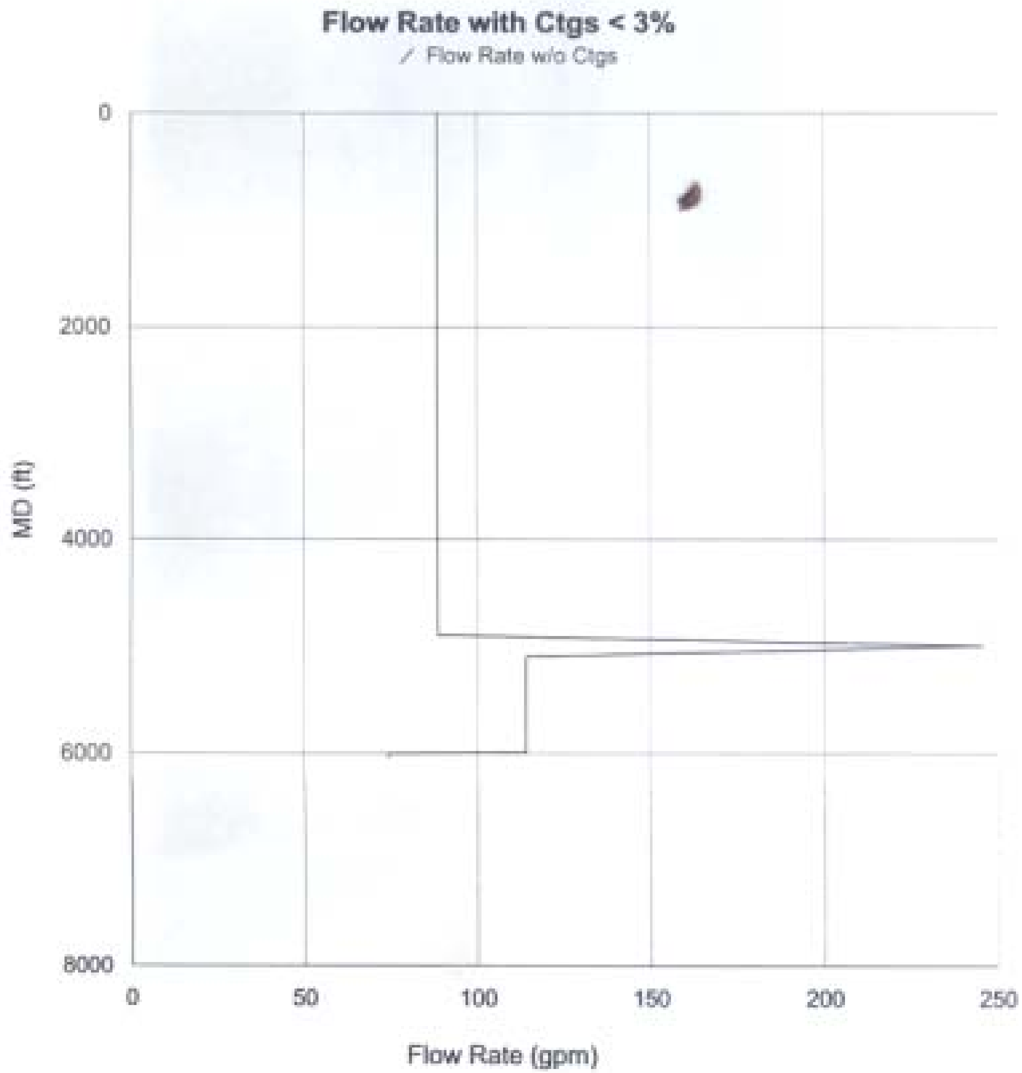
Wellbore Hydraulics Model (HYDMOD)

Flow Rate with Ctgs < 3%

Data File	V:\Documents and Settings\Ken Oglesby\My Documents\L1-Hymod 1000 horiz 3.hy4
Well Name	Production Casing Point 1 with CT
Project	Microbore Drilling
Company	BPX / Impact
Field	Test
Location	location
Date	30Nov04
Comments	Hydraulics evaluation for 1000' lateral with CT, premium mud, 3.5" hole, 1.75CT@@@@@at 5000' TVD in 5.5" casing



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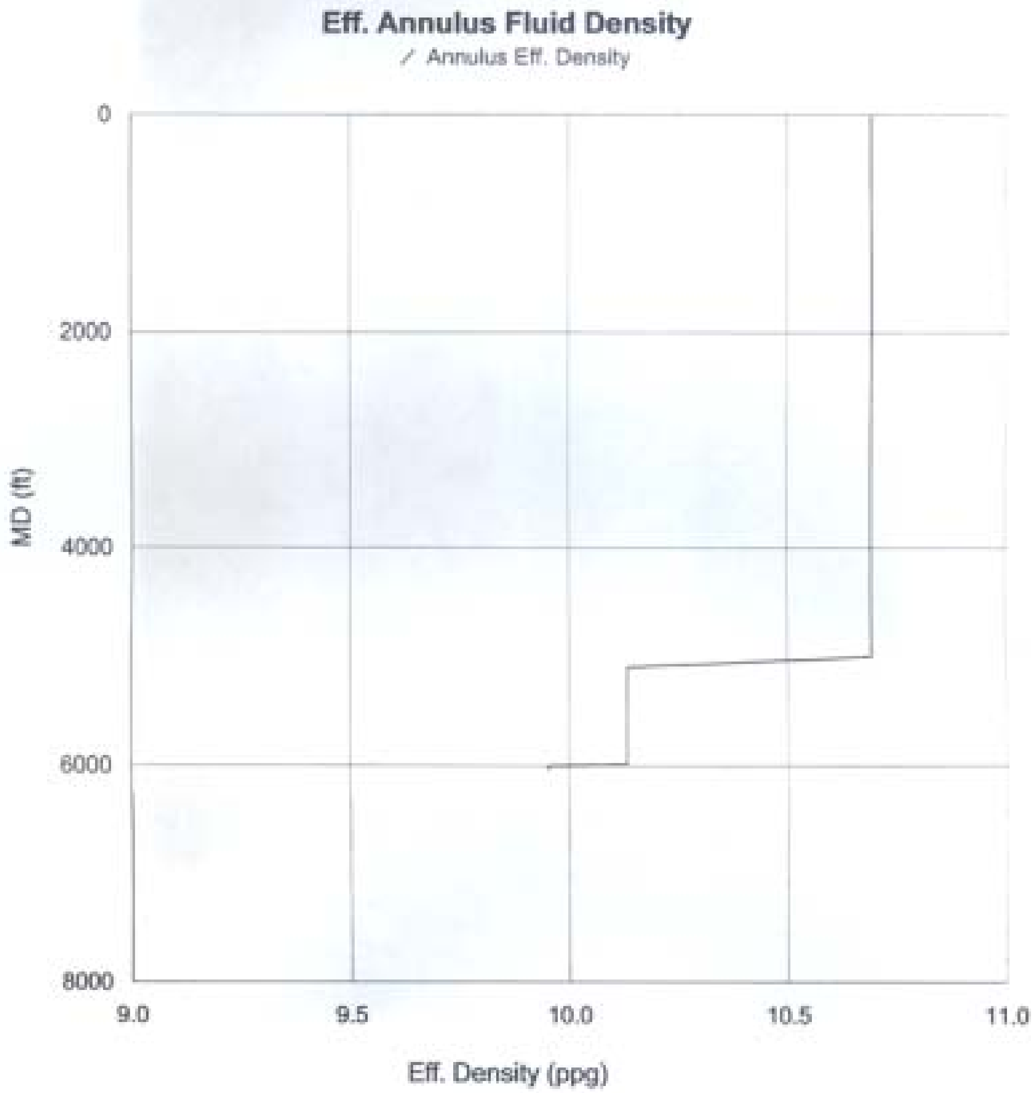
Wellbore Hydraulics Model (HYDMOD)

Eff. Annulus Fluid Density

Data File	V:\Documents and Settings\Ken Oglesby\My Documents\L1-Hymod 1000 horiz 3.hy4
Well Name	Production Casing Point 1 with CT
Project	Microbore Drilling
Company	BPX / Impact
Field	Test
Location	location
Date	30Nov04
Comments	Hydraulics evaluation for 1000' lateral with CT, premium mud, 3.5" hole, 1.75CT@@@@@at 5000' TVD in 5.5" casing



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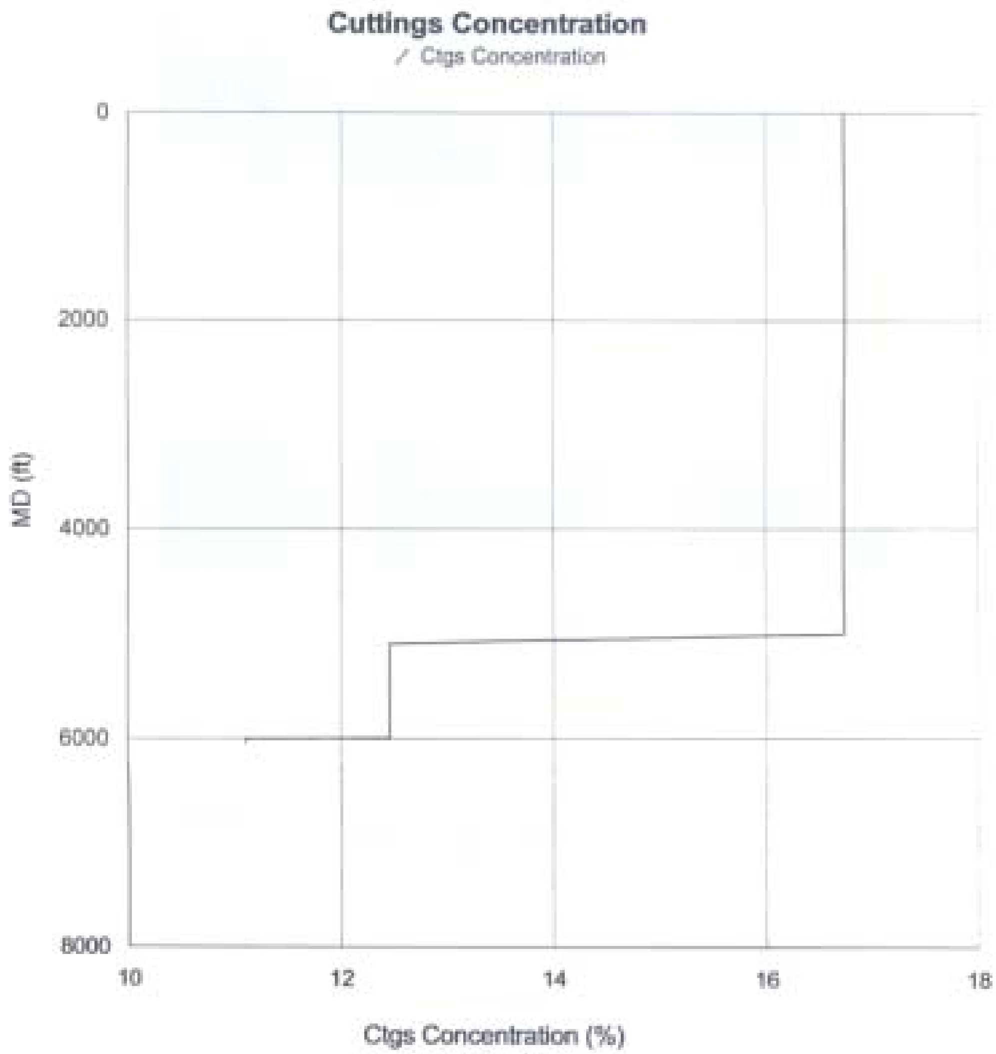
Wellbore Hydraulics Model (HYDMOD)

Cuttings Concentration

Data File	V:\Documents and Settings\Ken Oglesby\My Documents\L1-Hymod 1000 horiz 3.hy4
Well Name	Production Casing Point 1 with CT
Project	Microbore Drilling
Company	BPX / Impact
Field	Test
Location	location
Date	30Nov04
Comments	Hydraulics evaluation for 1000' lateral with CT, premium mud, 3.5" hole, 1.75CT@@@@@at 5000' TVD in 5.5" casing



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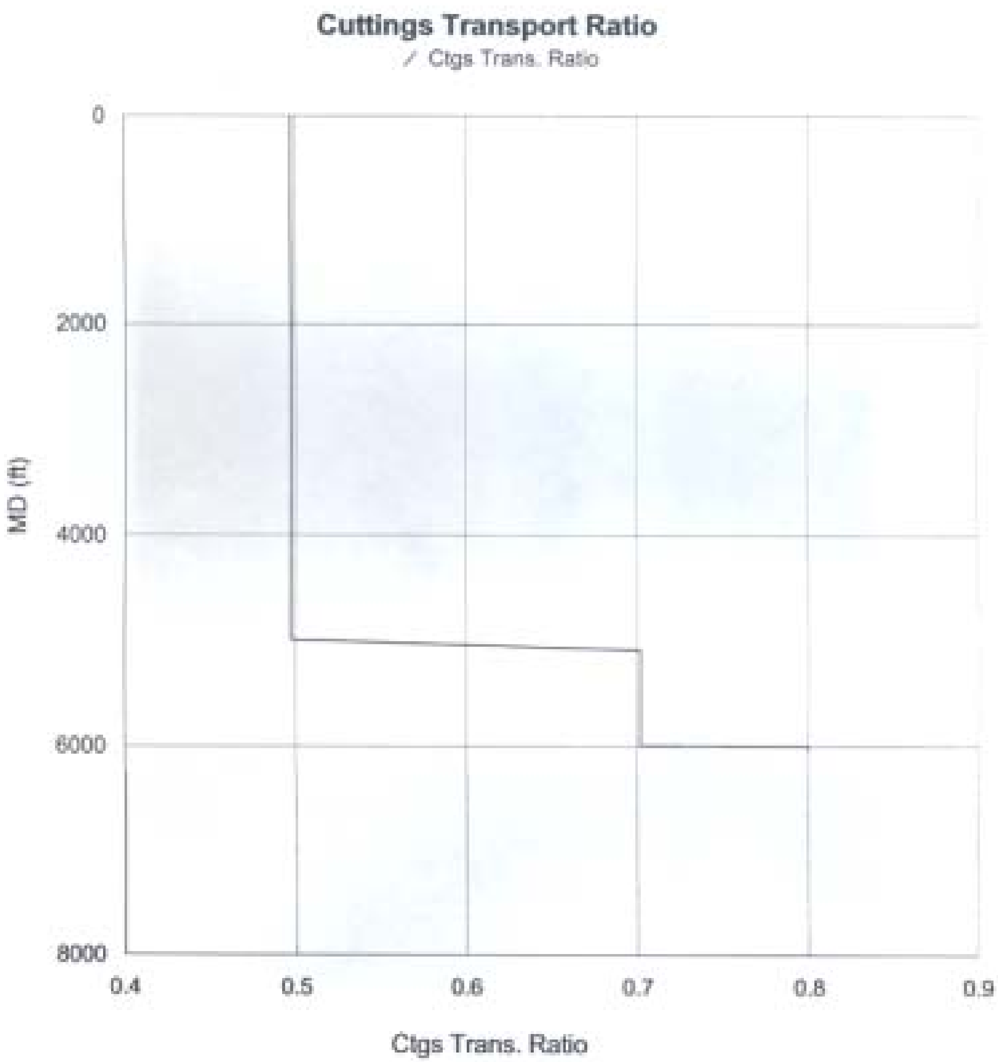
Wellbore Hydraulics Model (HYDMOD)

Cuttings Transport Ratio

Data File	V:\Documents and Settings\Ken Oglesby\My Documents\L1-Hymod 1000 horiz 3.hy4
Well Name	Production Casing Point 1 with CT
Project	Microbore Drilling
Company	BPX / Impact
Field	Test
Location	location
Date	30Nov04
Comments	Hydraulics evaluation for 1000' lateral with CT, premium mud, 3.5" hole, 1.75CT@@@@@at 5000' TVD in 5.5" casing



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APPENDIX C

MUDLite Modeling run – full input and output

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Air/Mist/Foam Hydraulics Model (MUDLITE)

Project Input Data

Project File Name:	V:\Documents and Settings\Ken Oglesby\My Documents\HS7 MHT Test Well.ml3

Well:	Test Well
Project:	Microbore CT Drilling
Company:	Impact Technologies LLC
Field:	Anywhere
Location:	Anywhere
Date:	12/5/03 2:34:51 PM
Comments:	Test for 1000' 3.5" lateral out of 7" casing with 1.75"CT at 5000'TVD

Survey

Total Measured Depth:	6020.0 (ft)

Tubulars

Total Drill String Length:	6020.0 (ft)

#	Description	Length (ft)	OD (in)	ID (in)
1	BHA and DC	30.0	2.875	2.000
2	Drill Pipe	5990.0	1.750	1.443

Rig Type:	Coiled-Tubing
Tubing Total Length:	10000.0 (ft)
Has Jet Sub:	No

Wellbore

Borehole Bottom Depth:	6020.0 (ft)

#	Description	Bottom (ft)	ID (in)
1	Casing	4900.0	6.500
2	OH	6020.0	3.500

Surface Temperature:	28.01 (F)
Thermal Gradient:	5.185 (F/100ft)
Has Influx/Para-String:	Yes

#	Para Str	MD (ft)	Nozzle ID (in)	Para Str ID (in)	Gas Influx (MMscf/d)	Gas Mol Wt	Gas Viscosity (cp)	SH Ratio	Water Influx (STB/d)	Oil Influx (STB/d)	Oil Viscosity (cp)	Oil Wt (ppg)
1	Yes	4900.0	1.000	1.000	0.000	24.	0.010	1.2	0.0	0.0	0.000	0.
2	No	6020.0	0.000	0.000	0.000	28.964	0.018	0.	0.0	2.0	1.000	7.

Formation

Maximum Depth of Pressure Info:	8000.0 (ft)

#	To TVD (ft)	Pore Pressure (psi)	Frac Pressure (psi)
1	5000.0	0.451	0.710
2	8000.0	0.465	0.730

Drilling

Motor/BHA Pressure Drop:	Yes
Motor Pressure Drop:	150.0 (psi)
Motor Speed	1.20 (RPM/GPM)
BHA Pressure Drop:	25.0 (psi)
Cuttings Type:	Shale/Limestone

Rate of Penetration:	600.0 (ft/h)
Cuttings Density:	162.3 (lb/ft3)
Cuttings Diameter:	0.125 (in)
Bit MD:	6020.0 (ft)
Nozzle TFA:	1000000015047470000000000000000.000 (in2)

Operation

Gas Injection Rate:	250.0 (scfm) *
Liquid Injection Rate:	25.00 (gpm)
Injection Temperature:	28.01 (F)
Gas:	Air
Molecular Weight:	28.964
Ratio of Spec.Heats:	1.40
Viscosity:	0.018 (cp)
Base Liquid:	
Density:	8.35 (ppg)
Viscosity:	5.000 (cp)
Choke Pressure:	10.0 (psi)
Blooie ID:	7.000 (in)
Blooie Length:	50.0 (ft)

Fluid

Flow Model:	Multi-Phase Flow, Beggs-Brill

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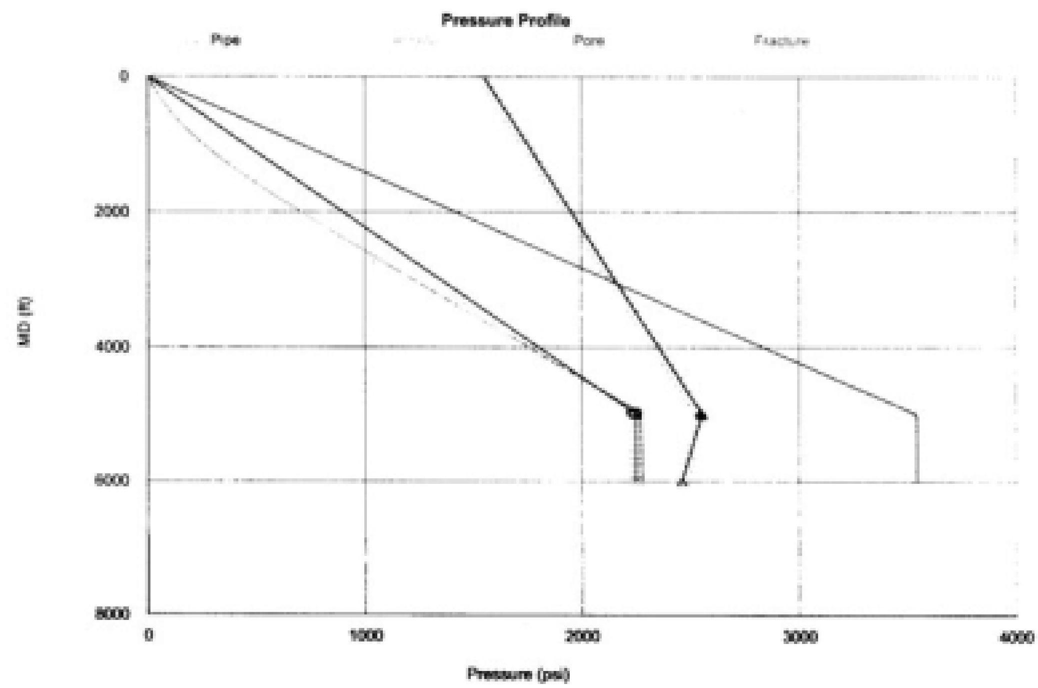
Air/Mist/Foam Hydraulics Model (MUDLITE)

Pressure Profile

Project File	V:\Documents and Settings\Ken Oglesby\My Documents\HS7 MHT Test Well.ml3
Well	Test Well
Project	Microbore CT Drilling
Company	Impact Technologies LLC
Field	Anywhere
Location	Anywhere
Date	12/5/03 2:34:51 PM
Comments	Test for 1000' 3.5" lateral out of 7" casing with 1.75"CT at 5000'TVD
Gas Injection Rate	250.0 (scfm)
Liquid Injection Rate	25.00 (gpm)
Choke Pressure	10.0 (psi)
Rate of Penetration	600.0 (ft/h)
Fluid Rheology Model	Multi-Phase Flow
Gas Type	Air
Equation of Gas State	Engineering Gas Law
OD of Upper Drill String	1.750 (in)
ID of Bottomhole	3.500 (in)
Transition Foam Quality	97.0 (%)
Pump Pressure	1909.2 (psi)
Annular BHP	2286.4 (psi)
Pressure Drop across Bit	0.0 (psi)
Gas Total Circulation Time	298 (min)
Gas Circulation Time in Pipe	54 (min)
Gas Circulation Time in Annulus	244 (min)
Liquid Total Circulation Time	309 (min)
Liquid Circulation Time in Pipe	34 (min)
Liquid Circulation Time in Annulus	274 (min)
Vol. Flow Rate through Motor	41.44 (gpm)
Motor Rotary Speed	49.7 (rpm)
Jet-Sub Present	No
Formation Influx Present	Yes
Parasite String Present	Yes



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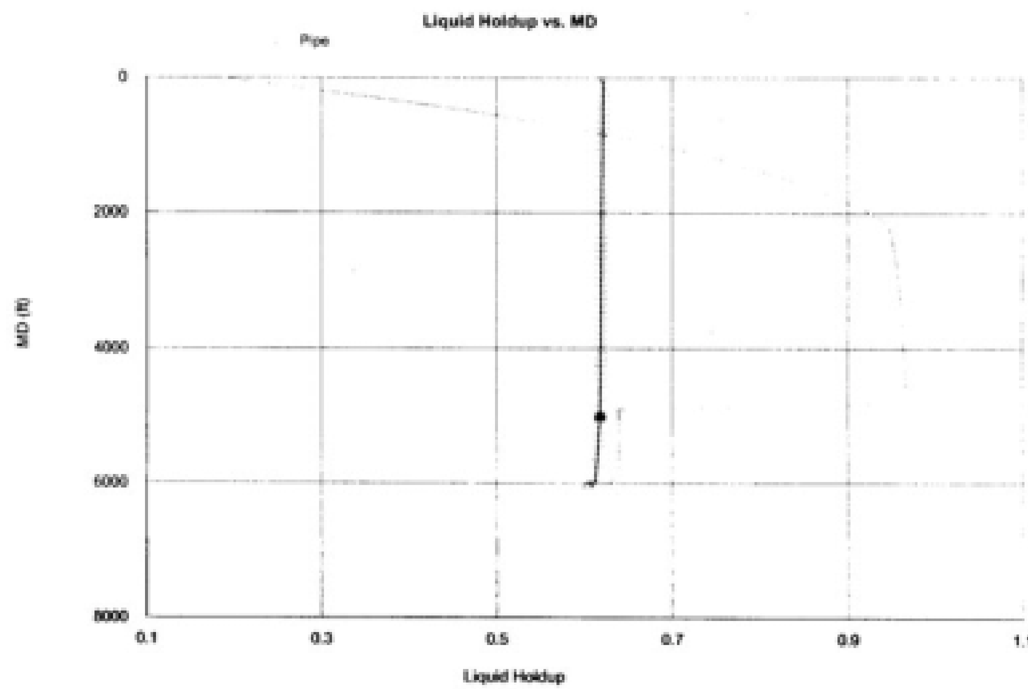
Air/Mist/Foam Hydraulics Model (MUDLITE)

Liquid Holdup vs. MD

Project File	V:\Documents and Settings\Ken Oglesby\My Documents\HS7 MHT Test Well.ml3
Well	Test Well
Project	Microbore CT Drilling
Company	Impact Technologies LLC
Field	Anywhere
Location	Anywhere
Date	12/5/03 2:34:51 PM
Comments	Test for 1000' 3.5" lateral out of 7" casing with 1.75"CT at 5000'TVD
Gas Injection Rate	250.0 (scfm)
Liquid Injection Rate	25.00 (gpm)
Choke Pressure	10.0 (psi)
Rate of Penetration	600.0 (ft/h)
Fluid Rheology Model	Multi-Phase Flow
Gas Type	Air
Equation of Gas State	Engineering Gas Law
OD of Upper Drill String	1.750 (in)
ID of Bottomhole	3.500 (in)
Transition Foam Quality	97.0 (%)
Pump Pressure	1909.2 (psi)
Annular BHP	2286.4 (psi)
Pressure Drop across Bit	0.0 (psi)
Gas Total Circulation Time	298 (min)
Gas Circulation Time in Pipe	54 (min)
Gas Circulation Time in Annulus	244 (min)
Liquid Total Circulation Time	309 (min)
Liquid Circulation Time in Pipe	34 (min)
Liquid Circulation Time in Annulus	274 (min)
Vol. Flow Rate through Motor	41.44 (gpm)
Motor Rotary Speed	49.7 (rpm)
Jet-Sub Present	No
Formation Influx Present	Yes
Parasite String Present	Yes



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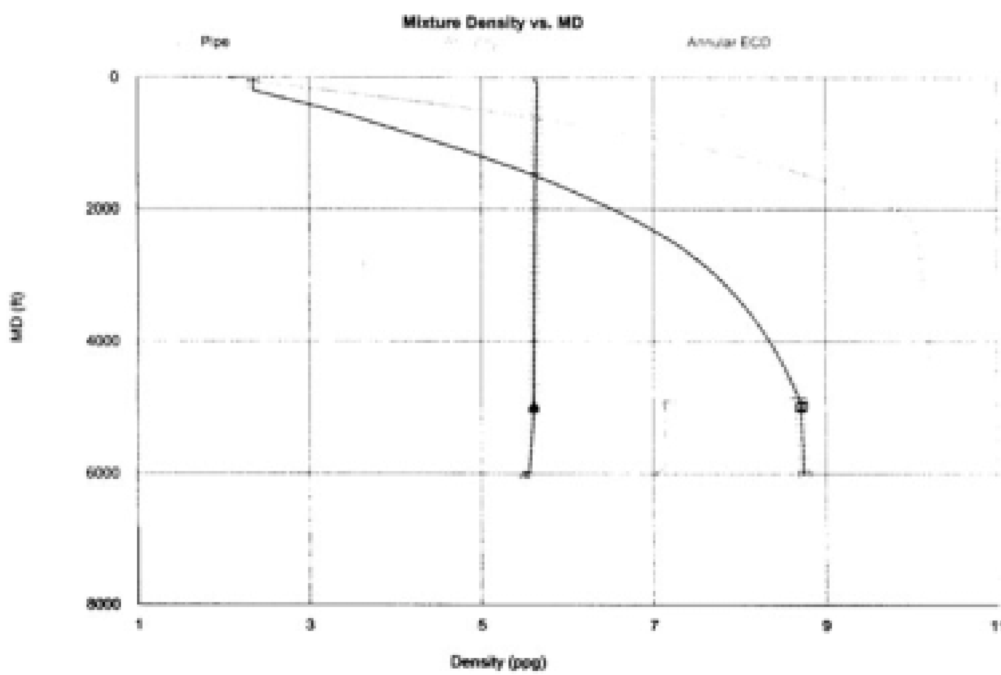
Air/Mist/Foam Hydraulics Model (MUDLITE)

Mixture Density vs. MD

Project File	V:\Documents and Settings\Ken Oglesby\My Documents\HS7 MHT Test Well.ml3
Well	Test Well
Project	Microbore CT Drilling
Company	Impact Technologies LLC
Field	Anywhere
Location	Anywhere
Date	12/5/03 2:34:51 PM
Comments	Test for 1000' 3.5" lateral out of 7" casing with 1.75"CT at 5000'TVD
Gas Injection Rate	250.0 (scfm)
Liquid Injection Rate	25.00 (gpm)
Choke Pressure	10.0 (psi)
Rate of Penetration	600.0 (ft/h)
Fluid Rheology Model	Multi-Phase Flow
Gas Type	Air
Equation of Gas State	Engineering Gas Law
OD of Upper Drill String	1.750 (in)
ID of Bottomhole	3.500 (in)
Transition Foam Quality	97.0 (%)
Pump Pressure	1909.2 (psi)
Annular BHP	2286.4 (psi)
Pressure Drop across Bit	0.0 (psi)
Gas Total Circulation Time	298 (min)
Gas Circulation Time in Pipe	54 (min)
Gas Circulation Time in Annulus	244 (min)
Liquid Total Circulation Time	309 (min)
Liquid Circulation Time in Pipe	34 (min)
Liquid Circulation Time in Annulus	274 (min)
Vol. Flow Rate through Motor	41.44 (gpm)
Motor Rotary Speed	49.7 (rpm)
Jet-Sub Present	No
Formation Influx Present	Yes
Parasite String Present	Yes



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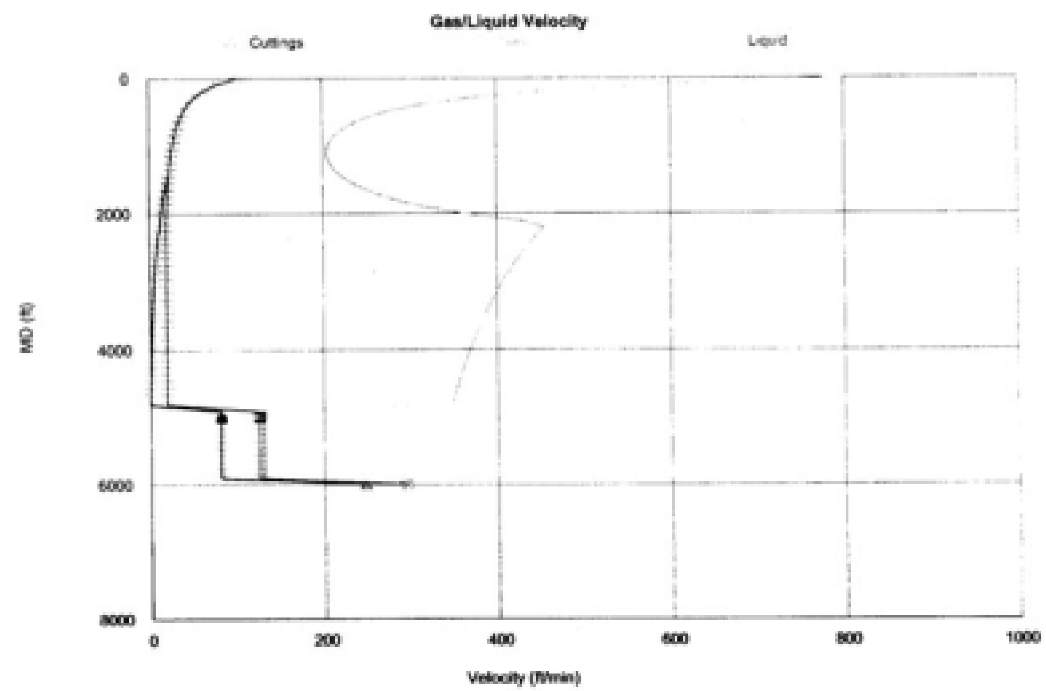
Maurer Technology

Air/Mist/Foam Hydraulics Model (MUDLITE)

Gas/Liquid Velocity

Project File	V:\Documents and Settings\Ken Oglesby\My Documents\HS7 MHT Test Well.ml3
Well	Test Well
Project	Microbore CT Drilling
Company	Impact Technologies LLC
Field	Anywhere
Location	Anywhere
Date	12/5/03 2:34:51 PM
Comments	Test for 1000' 3.5" lateral out of 7" casing with 1.75"CT at 5000'TVD
Gas Injection Rate	250.0 (scfm)
Liquid Injection Rate	25.00 (gpm)
Choke Pressure	10.0 (psi)
Rate of Penetration	600.0 (ft/h)
Fluid Rheology Model	Multi-Phase Flow
Gas Type	Air
Equation of Gas State	Engineering Gas Law
OD of Upper Drill String	1.750 (in)
ID of Bottomhole	3.500 (in)
Transition Foam Quality	97.0 (%)
Pump Pressure	1909.2 (psi)
Annular BHP	2286.4 (psi)
Pressure Drop across Bit	0.0 (psi)
Gas Total Circulation Time	298 (min)
Gas Circulation Time in Pipe	54 (min)
Gas Circulation Time in Annulus	244 (min)
Liquid Total Circulation Time	309 (min)
Liquid Circulation Time in Pipe	34 (min)
Liquid Circulation Time in Annulus	274 (min)
Vol. Flow Rate through Motor	41.44 (gpm)
Motor Rotary Speed	49.7 (rpm)
Jet-Sub Present	No
Formation Influx Present	Yes
Parasite String Present	Yes



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Air/Mist/Foam Hydraulics Model (MUDLITE)

Cuttings Transport Ratio (for Vertical Well)

Project File	V:\Documents and Settings\Ken Oglesby\My Documents\HS7 MHT Test Well.ml3
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Company	Impact Technologies LLC
Field	Anywhere
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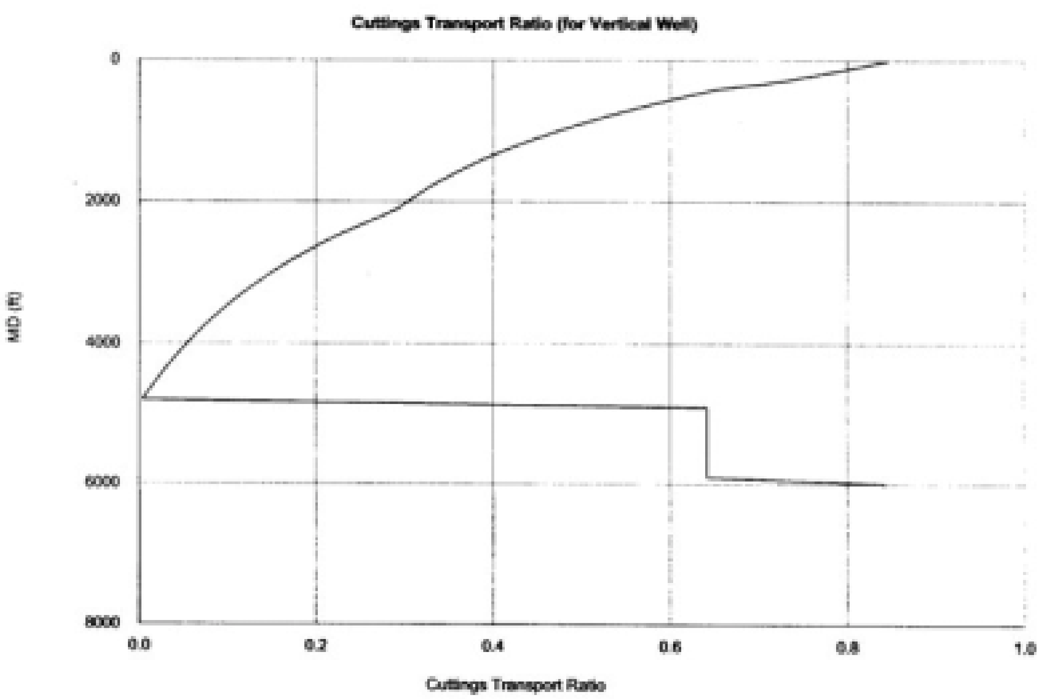

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Maurer Technology

Air/Mist/Foam Hydraulics Model (MUDLITE)

Project Relevant Data

Project File	V:\Documents and Settings\Ken Oglesby\My Documents\HS7 MHT Test Well.ml3

General Infomation

Well	Test Well
Project	Microbore CT Drilling
Company	Impact Technologies LLC
Field	Anywhere
Location	Anywhere
Date	12/5/03 2:34:51 PM
Comments	Test for 1000' 3.5" lateral out of 7" casing with 1.75"CT at 5000'TVD

Key Input Data

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MUDLITE - Air/Mis'oam Hydraulics Model
Cuttings Transport

Data file: V:\Documents and Settings\Ken Oglesby\My Documents\HS7 MHT Test Well.ml3
Well: Test Well
Company: Impact Technologies LLC
Project: Microbore CT Drilling
Field: Anywhere
Location: Anywhere
Date: 12/5/03 2:34:51 PM
Comments: Test for 1000' 3.5" lateral out of 7" casing with 1.75"CT at 5000'TVD

	MD (ft)	TVD (ft)	Pipe Pressure (psi)	Pipe App. Viscosity (cp)	Pipe Friction Factor	Annulus Pressure (psi)	Annulus App. Viscosity (cp)	Annulus Friction Factor	Cuttings Transport Ratio
1	CT Inlet	0.0	1909.2	0.000	0.0000	N/A	N/A	N/A	N/A
2	0.0	0.0	1548.4	3.118	0.0095	10.0	0.945	0.0062	0.8465
3	100.0	100.0	1568.8	3.117	0.0095	22.2	1.236	0.0067	0.8074
4	200.0	200.0	1589.1	3.116	0.0095	37.6	1.528	0.0071	0.7652
5	300.0	300.0	1609.4	3.115	0.0095	56.2	1.818	0.0075	0.7216
6	400.0	400.0	1629.7	3.115	0.0095	77.9	2.099	0.0079	0.6547
7	500.0	500.0	1649.9	3.114	0.0095	101.9	2.362	0.0083	0.6192
8	600.0	600.0	1670.2	3.113	0.0095	128.1	2.604	0.0086	0.5863
9	700.0	700.0	1690.5	3.113	0.0095	156.9	2.833	0.0089	0.5553
10	800.0	800.0	1710.7	3.112	0.0095	188.3	3.048	0.0092	0.5261
11	900.0	900.0	1731.0	3.111	0.0095	222.1	3.247	0.0095	0.4988
12	1000.0	1000.0	1751.2	3.111	0.0095	258.0	3.432	0.0097	0.4735
13	1100.0	1100.0	1771.4	3.110	0.0095	296.1	3.602	0.0100	0.4500
14	1200.0	1200.0	1791.7	3.110	0.0095	335.9	3.759	0.0102	0.4282
15	1300.0	1300.0	1811.9	3.109	0.0095	377.5	3.903	0.0104	0.4081
16	1400.0	1400.0	1832.1	3.109	0.0095	420.7	4.035	0.0106	0.3895
17	1500.0	1500.0	1852.3	3.108	0.0095	465.3	4.155	0.0107	0.3723
18	1600.0	1600.0	1872.5	3.108	0.0095	511.3	4.266	0.0109	0.3563
19	1700.0	1700.0	1892.7	3.107	0.0095	558.4	4.368	0.0111	0.3416
20	1800.0	1800.0	1912.9	3.107	0.0095	606.7	4.461	0.0112	0.3279
21	1900.0	1900.0	1933.1	3.106	0.0095	655.9	4.547	0.0113	0.3152
22	2000.0	2000.0	1953.2	3.106	0.0095	706.1	4.626	0.0114	0.3033
23	2100.0	2100.0	1973.4	3.106	0.0095	757.1	4.699	0.0116	0.2923
24	2200.0	2200.0	1993.6	3.105	0.0095	808.9	4.732	0.0117	0.2758
25	2300.0	2300.0	2013.7	3.105	0.0095	861.0	4.741	0.0118	0.2564
26	2400.0	2400.0	2033.9	3.104	0.0095	913.3	4.749	0.0119	0.2383
27	2500.0	2500.0	2054.0	3.104	0.0095	965.6	4.756	0.0120	0.2212
28	2600.0	2600.0	2074.1	3.104	0.0095	1018.1	4.763	0.0121	0.2052
29	2700.0	2700.0	2094.3	3.103	0.0095	1070.6	4.769	0.0121	0.1902
30	2800.0	2800.0	2114.4	3.103	0.0095	1123.1	4.774	0.0122	0.1760
31	2900.0	2900.0	2134.5	3.102	0.0095	1175.8	4.779	0.0123	0.1626
32	3000.0	3000.0	2154.7	3.102	0.0095	1228.5	4.784	0.0123	0.1499
33	3100.0	3100.0	2174.8	3.102	0.0095	1281.2	4.788	0.0124	0.1380
34	3200.0	3200.0	2194.9	3.101	0.0095	1334.0	4.792	0.0125	0.1266
35	3300.0	3300.0	2215.0	3.101	0.0095	1386.8	4.796	0.0125	0.1159
36	3400.0	3400.0	2235.1	3.101	0.0095	1439.7	4.799	0.0126	0.1057
37	3500.0	3500.0	2255.2	3.101	0.0095	1492.6	4.802	0.0126	0.0960
38	3600.0	3600.0	2275.3	3.100	0.0095	1545.6	4.805	0.0127	0.0868
39	3700.0	3700.0	2295.4	3.100	0.0095	1598.6	4.808	0.0127	0.0780
40	3800.0	3800.0	2315.5	3.100	0.0095	1651.6	4.811	0.0128	0.0697
41	3900.0	3900.0	2335.5	3.099	0.0095	1704.6	4.813	0.0128	0.0617
42	4000.0	4000.0	2355.6	3.099	0.0095	1757.7	4.815	0.0128	0.0541
43	4100.0	4100.0	2375.7	3.099	0.0095	1810.8	4.818	0.0129	0.0468

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MUDLITE - Air/Mis/oam Hydraulics Model
Cuttings Transport

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Well: Test Well
Company: Impact Technologies LLC
Project: Microbore CT Drilling
Field: Anywhere
Location: Anywhere
Date: 12/5/03 2:34:51 PM
Comments: Test for 1000' 3.5" lateral out of 7" casing with 1.75"CT at 5000'TVD

	MD (ft)	TVD (ft)	Pipe Pressure (psi)	Pipe App. Viscosity (cp)	Pipe Friction Factor	Annulus Pressure (psi)	Annulus App. Viscosity (cp)	Annulus Friction Factor	Cuttings Transport Ratio
44	4200.0	4200.0	2395.8	3.098	0.0095	1863.9	4.820	0.0129	0.0399
45	4300.0	4300.0	2415.8	3.098	0.0095	1917.1	4.822	0.0129	0.0332
46	4400.0	4400.0	2435.9	3.098	0.0095	1970.2	4.823	0.0130	0.0269
47	4500.0	4500.0	2456.0	3.098	0.0095	2023.4	4.825	0.0130	0.0208
48	4600.0	4600.0	2476.0	3.097	0.0095	2076.7	4.827	0.0130	0.0149
49	4700.0	4700.0	2496.1	3.097	0.0095	2129.9	4.828	0.0130	0.0093
50	4800.0	4800.0	2516.1	3.097	0.0095	2183.1	4.830	0.0131	0.0039
51	4900.0	4900.0	2536.2	3.097	0.0095	2236.4	3.193	0.0127	0.6425
52	4950.0	4949.9	2546.2	3.097	0.0095	2255.4	3.195	0.0127	0.6422
53	4955.0	4954.9	2547.2	3.097	0.0095	2257.3	3.196	0.0127	0.6422
54	4960.0	4959.7	2548.1	3.097	0.0095	2259.2	3.196	0.0127	0.6422
55	4965.0	4964.2	2549.0	3.097	0.0095	2260.9	3.196	0.0127	0.6422
56	4970.0	4968.3	2549.7	3.097	0.0095	2262.5	3.196	0.0127	0.6421
57	4980.0	4975.4	2550.9	3.096	0.0095	2265.2	3.197	0.0127	0.6421
58	4990.0	4981.1	2551.6	3.096	0.0095	2267.4	3.197	0.0127	0.6421
59	5000.0	4985.3	2551.9	3.096	0.0095	2269.1	3.197	0.0127	0.6420
60	5010.0	4987.9	2551.8	3.096	0.0095	2270.2	3.197	0.0127	0.6420
61	5020.0	4988.8	2551.1	3.096	0.0095	2270.6	3.197	0.0127	0.6420
62	5100.0	4988.8	2543.8	3.093	0.0095	2271.5	3.198	0.0127	0.6420
63	5200.0	4988.8	2534.6	3.091	0.0095	2272.6	3.198	0.0127	0.6420
64	5300.0	4988.8	2525.5	3.088	0.0095	2273.7	3.198	0.0127	0.6419
65	5400.0	4988.8	2516.3	3.085	0.0095	2274.8	3.198	0.0127	0.6419
66	5500.0	4988.8	2507.1	3.082	0.0095	2275.9	3.199	0.0127	0.6419
67	5600.0	4988.8	2497.9	3.079	0.0095	2277.0	3.199	0.0127	0.6419
68	5700.0	4988.8	2488.7	3.076	0.0095	2278.1	3.199	0.0127	0.6418
69	5800.0	4988.8	2479.5	3.074	0.0095	2279.2	3.199	0.0127	0.6418
70	5900.0	4988.8	2470.3	3.071	0.0094	2280.2	3.200	0.0127	0.6418
71	5990.0	4988.8	2462.0	3.068	0.0094	2281.2	3.137	0.0135	0.8419
72	6000.0	4988.8	2461.8	3.028	0.0103	2283.0	3.138	0.0135	0.8419
73	6020.0	4988.8	2461.4	3.028	0.0103	2286.4	3.139	0.0135	0.8419

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MUDLITE - Air/Mistoam Hydraulics Model
Profile

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Field: Anywhere
Location: Anywhere
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Comments: Test for 1000' 3.5" lateral out of 7" casing with 1.75"CT at 5000'TVD

	MD (ft)	TVD (ft)	Pore Pressure (psi)	Fracture Pressure (psi)	Pipe Pressure (psi)	Pipe Liquid Holdup	Pipe Fluid Density (ppg)	Pipe Fluid Velocity (ft/min)	Annulus Pressure (psi)	Annulus ECD (ppg)	Annulus Liquid Holdup	Annulus Fluid Density (ppg)	Annulus Gas Velocity (ft/min)	Annulus Liquid Velocity (ft/min)
1	CT Inlet	0.0	0.0	0.0	1909.2	0.6222	5.65	477.38	N/A	N/A	N/A	N/A	N/A	N/A
2	0.0	0.0	0.0	0.0	1548.4	0.6198	5.63	479.92	10.0	N/A	0.1563	1.98	801.12	100.89
3	100.0	100.0	45.1	71.0	1568.8	0.6220	5.65	477.53	22.2	2.35	0.2448	2.60	582.65	76.78
4	200.0	200.0	90.2	142.0	1589.1	0.6218	5.65	477.69	37.6	2.65	0.3036	3.23	450.29	61.92
5	300.0	300.0	135.3	213.0	1609.4	0.6217	5.65	477.85	56.2	2.96	0.3618	3.85	368.04	51.96
6	400.0	400.0	180.4	284.0	1629.7	0.6216	5.65	478.00	77.9	3.26	0.4184	4.45	310.31	44.93
7	500.0	500.0	225.5	355.0	1649.9	0.6214	5.64	478.15	101.9	3.54	0.4712	5.01	273.30	39.89
8	600.0	600.0	270.6	426.0	1670.2	0.6213	5.64	478.29	128.1	3.79	0.5199	5.53	248.10	36.16
9	700.0	700.0	315.7	497.0	1690.5	0.6212	5.64	478.43	156.9	4.04	0.5659	6.02	230.34	33.21
10	800.0	800.0	360.8	568.0	1710.7	0.6211	5.64	478.56	188.3	4.29	0.6091	6.48	218.14	30.86
11	900.0	900.0	405.9	639.0	1731.0	0.6209	5.64	478.69	222.1	4.53	0.6492	6.91	210.28	28.95
12	1000.0	1000.0	451.0	710.0	1751.2	0.6208	5.64	478.82	258.0	4.77	0.6864	7.30	205.97	27.39
13	1100.0	1100.0	496.1	781.0	1771.4	0.6207	5.64	478.94	296.1	5.00	0.7206	7.66	204.72	26.09
14	1200.0	1200.0	541.2	852.0	1791.7	0.6206	5.64	479.06	335.9	5.22	0.7521	7.99	206.27	24.99
15	1300.0	1300.0	586.3	923.0	1811.9	0.6205	5.64	479.17	377.5	5.44	0.7810	8.30	210.56	24.07
16	1400.0	1400.0	631.4	994.0	1832.1	0.6204	5.63	479.29	420.7	5.64	0.8075	8.57	217.69	23.28
17	1500.0	1500.0	676.5	1065.0	1852.3	0.6203	5.63	479.39	465.3	5.84	0.8318	8.83	227.97	22.60
18	1600.0	1600.0	721.6	1136.0	1872.5	0.6202	5.63	479.50	511.3	6.02	0.8541	9.06	241.94	22.01
19	1700.0	1700.0	766.7	1207.0	1892.7	0.6201	5.63	479.61	558.4	6.20	0.8745	9.27	260.49	21.49
20	1800.0	1800.0	811.8	1278.0	1912.9	0.6200	5.63	479.71	606.7	6.37	0.8932	9.47	285.03	21.04
21	1900.0	1900.0	856.9	1349.0	1933.1	0.6199	5.63	479.81	655.9	6.54	0.9105	9.64	317.81	20.64
22	2000.0	2000.0	902.0	1420.0	1953.2	0.6198	5.63	479.90	706.1	6.69	0.9264	9.81	362.67	20.29
23	2100.0	2100.0	947.1	1491.0	1973.4	0.6197	5.63	480.00	757.1	6.84	0.9410	9.96	426.47	19.98
24	2200.0	2200.0	992.2	1562.0	1993.6	0.6197	5.63	480.09	808.9	6.98	0.9476	10.02	454.18	19.84
25	2300.0	2300.0	1037.3	1633.0	2013.7	0.6196	5.63	480.18	861.0	7.12	0.9494	10.04	446.66	19.80
26	2400.0	2400.0	1082.4	1704.0	2033.9	0.6195	5.63	480.26	913.3	7.24	0.9511	10.06	439.67	19.76
27	2500.0	2500.0	1127.5	1775.0	2054.0	0.6194	5.62	480.35	965.6	7.35	0.9525	10.08	433.15	19.73
28	2600.0	2600.0	1172.6	1846.0	2074.1	0.6193	5.62	480.43	1018.1	7.46	0.9539	10.09	427.04	19.71

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Field: Anywhere
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	MD (ft)	TVD (ft)	Pore Pressure (psi)	Fracture Pressure (psi)	Pipe Pressure (psi)	Pipe Liquid Holdup	Pipe Fluid Density (ppg)	Pipe Fluid Velocity (ft/min)	Annulus Pressure (psi)	Annulus ECD (ppg)	Annulus Liquid Holdup	Annulus Fluid Density (ppg)	Annulus Gas Velocity (ft/min)	Annulus Liquid Velocity (ft/min)
29	2700.0	2700.0	1217.7	1917.0	2094.3	0.6193	5.62	480.52	1070.6	7.55	0.9551	10.10	421.29	19.68
30	2800.0	2800.0	1262.6	1988.0	2114.4	0.6192	5.62	480.60	1123.1	7.65	0.9562	10.12	415.87	19.66
31	2900.0	2900.0	1307.9	2059.0	2134.5	0.6191	5.62	480.67	1175.8	7.73	0.9572	10.13	410.75	19.64
32	3000.0	3000.0	1353.0	2130.0	2154.7	0.6191	5.62	480.75	1228.5	7.81	0.9581	10.14	405.90	19.62
33	3100.0	3100.0	1398.1	2201.0	2174.8	0.6190	5.62	480.83	1281.2	7.89	0.9590	10.15	401.30	19.60
34	3200.0	3200.0	1443.2	2272.0	2194.9	0.6189	5.62	480.90	1334.0	7.96	0.9598	10.16	396.93	19.58
35	3300.0	3300.0	1488.3	2343.0	2215.0	0.6189	5.62	480.97	1386.8	8.02	0.9605	10.16	392.77	19.57
36	3400.0	3400.0	1533.4	2414.0	2235.1	0.6188	5.62	481.04	1439.7	8.09	0.9612	10.17	388.80	19.56
37	3500.0	3500.0	1578.5	2485.0	2255.2	0.6187	5.62	481.11	1492.6	8.15	0.9619	10.18	385.01	19.54
38	3600.0	3600.0	1623.6	2556.0	2275.3	0.6187	5.62	481.18	1545.6	8.20	0.9624	10.18	381.39	19.53
39	3700.0	3700.0	1668.7	2627.0	2295.4	0.6186	5.62	481.25	1598.6	8.26	0.9630	10.19	377.93	19.52
40	3800.0	3800.0	1713.8	2698.0	2315.5	0.6186	5.62	481.31	1651.6	8.31	0.9635	10.20	374.61	19.51
41	3900.0	3900.0	1758.9	2769.0	2335.5	0.6185	5.62	481.38	1704.6	8.36	0.9640	10.20	371.43	19.50
42	4000.0	4000.0	1804.0	2840.0	2355.6	0.6184	5.62	481.44	1757.7	8.40	0.9645	10.21	368.37	19.49
43	4100.0	4100.0	1849.1	2911.0	2375.7	0.6184	5.61	481.50	1810.8	8.45	0.9649	10.21	365.44	19.48
44	4200.0	4200.0	1894.2	2982.0	2395.8	0.6183	5.61	481.56	1863.9	8.49	0.9653	10.22	362.62	19.47
45	4300.0	4300.0	1939.3	3053.0	2415.8	0.6183	5.61	481.62	1917.1	8.53	0.9657	10.22	359.91	19.46
46	4400.0	4400.0	1984.4	3124.0	2435.9	0.6182	5.61	481.67	1970.2	8.57	0.9660	10.22	357.30	19.46
47	4500.0	4500.0	2029.5	3195.0	2456.0	0.6182	5.61	481.73	2023.4	8.60	0.9664	10.23	354.79	19.45
48	4600.0	4600.0	2074.6	3266.0	2476.0	0.6181	5.61	481.79	2076.7	8.64	0.9667	10.23	352.36	19.44
49	4700.0	4700.0	2119.7	3337.0	2496.1	0.6181	5.61	481.84	2129.9	8.67	0.9670	10.24	350.03	19.44
50	4800.0	4800.0	2164.8	3408.0	2516.1	0.6180	5.61	481.90	2183.1	8.71	0.9673	10.24	347.77	19.43
51	4900.0	4900.0	2209.9	3479.0	2536.2	0.6180	5.61	481.95	2236.4	8.74	0.6383	7.12	132.05	125.60
52	4950.0	4949.9	2232.4	3514.5	2546.2	0.6179	5.61	481.98	2255.4	8.72	0.6388	7.12	131.68	125.51
53	4955.0	4954.9	2234.7	3518.0	2547.2	0.6179	5.61	481.98	2257.3	8.72	0.6388	7.12	131.64	125.50
54	4960.0	4959.7	2236.8	3521.4	2548.1	0.6179	5.61	481.99	2259.2	8.72	0.6389	7.13	131.61	125.49
55	4965.0	4964.2	2238.9	3524.6	2549.0	0.6179	5.61	481.99	2260.9	8.72	0.6389	7.13	131.57	125.48
56	4970.0	4968.3	2240.7	3527.5	2549.7	0.6179	5.61	482.00	2262.5	8.72	0.6390	7.13	131.54	125.48

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MUDLITE - Air/Mis/oam Hydraulics Model
Profile

Data file: V:\Documents and Settings\Ken Oglesby\My Documents\HS7 MHT Test Well.ml3
Well: Test Well
Company: Impact Technologies LLC
Project: Microbore CT Drilling
Field: Anywhere
Location: Anywhere
Date: 12/5/03 2:34:51 PM
Comments: Test for 1000' 3.5" lateral out of 7" casing with 1.75"CT at 5000'TVD

	MD (ft)	TVD (ft)	Pore Pressure (psi)	Fracture Pressure (psi)	Pipe Pressure (psi)	Pipe Liquid Holdup	Pipe Fluid Density (ppg)	Pipe Fluid Velocity (ft/min)	Annulus Pressure (psi)	Annulus ECD (ppg)	Annulus Liquid Holdup	Annulus Fluid Density (ppg)	Annulus Gas Velocity (ft/min)	Annulus Liquid Velocity (ft/min)
57	4980.0	4975.4	2243.9	3532.5	2550.9	0.6179	5.61	482.02	2265.2	8.72	0.6390	7.13	131.49	125.46
58	4990.0	4981.1	2246.5	3536.6	2551.6	0.6179	5.61	482.05	2267.4	8.72	0.6391	7.13	131.45	125.45
59	5000.0	4985.3	2248.4	3539.6	2551.9	0.6178	5.61	482.09	2269.1	8.71	0.6391	7.13	131.41	125.44
60	5010.0	4987.9	2249.6	3541.4	2551.8	0.6178	5.61	482.13	2270.2	8.71	0.6392	7.13	131.39	125.44
61	5020.0	4988.8	2249.9	3542.0	2551.1	0.6178	5.61	482.19	2270.6	8.71	0.6392	7.13	131.38	125.44
62	5100.0	4988.8	2249.9	3542.0	2543.8	0.6173	5.60	482.68	2271.5	8.72	0.6392	7.13	131.35	125.43
63	5200.0	4988.8	2249.9	3542.0	2534.6	0.6168	5.60	483.30	2272.6	8.72	0.6393	7.13	131.31	125.42
64	5300.0	4988.8	2249.9	3542.0	2525.5	0.6162	5.59	483.93	2273.7	8.73	0.6393	7.13	131.27	125.41
65	5400.0	4988.8	2249.9	3542.0	2516.3	0.6156	5.59	484.56	2274.8	8.73	0.6394	7.13	131.23	125.40
66	5500.0	4988.8	2249.9	3542.0	2507.1	0.6151	5.58	485.20	2275.9	8.73	0.6394	7.13	131.19	125.39
67	5600.0	4988.8	2249.9	3542.0	2497.9	0.6145	5.58	485.84	2277.0	8.74	0.6395	7.13	131.15	125.38
68	5700.0	4988.8	2249.9	3542.0	2488.7	0.6139	5.57	486.49	2278.1	8.74	0.6395	7.13	131.11	125.37
69	5800.0	4988.8	2249.9	3542.0	2479.5	0.6133	5.57	487.14	2279.2	8.75	0.6396	7.13	131.07	125.36
70	5900.0	4988.8	2249.9	3542.0	2470.3	0.6127	5.56	487.80	2280.2	8.75	0.6396	7.13	131.03	125.35
71	5990.0	4988.8	2249.9	3542.0	2462.0	0.6122	5.55	488.40	2281.2	8.76	0.6271	7.02	291.91	294.79
72	6000.0	4988.8	2249.9	3542.0	2461.8	0.6041	5.50	254.25	2283.0	8.76	0.6272	7.02	291.79	294.74
73	6020.0	4988.8	2249.9	3542.0	2461.4	0.6041	5.50	254.26	2286.4	8.78	0.3725	7.02	291.57	294.63

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MUDLITE - Air/Mis'oam Hydraulics Model
Flow Pattern

Data file: V:\Documents and Settings\Ken Oglesby\My Documents\HS7 MHT Test Well.ml3
Well: Test Well
Company: Impact Technologies LLC
Project: Microbore CT Drilling
Field: Anywhere
Location: Anywhere
Date: 12/5/03 2:34:51 PM
Comments: Test for 1000' 3.5" lateral out of 7" casing with 1.75"CT at 5000'TVD

	MD (ft)	TVD (ft)	Pipe Pressure (psi)	Pipe Flow Pattern	Pipe Reynolds#	Annulus Pressure (psi)	Annulus Flow Pattern	Annulus Reynolds#
1	CT Inlet	0.0	1909.2	Distributed		N/A	N/A	N/A
2	0.0	0.0	1548.4	Distributed	19365	10.0	Transition	80102
3	100.0	100.0	1568.8	Distributed	19372	22.2	Transition	56852
4	200.0	200.0	1589.1	Distributed	19379	37.6	Transition	42129
5	300.0	300.0	1609.4	Distributed	19385	56.2	Transition	32462
6	400.0	400.0	1629.7	Distributed	19391	77.9	Transition	25881
7	500.0	500.0	1649.9	Distributed	19397	101.9	Transition	21355
8	600.0	600.0	1670.2	Distributed	19403	128.1	Transition	18117
9	700.0	700.0	1690.5	Distributed	19408	156.9	Transition	15660
10	800.0	800.0	1710.7	Distributed	19414	188.3	Transition	13760
11	900.0	900.0	1731.0	Distributed	19419	222.1	Transition	12264
12	1000.0	1000.0	1751.2	Distributed	19424	258.0	Transition	11069
13	1100.0	1100.0	1771.4	Distributed	19429	296.1	Transition	10101
14	1200.0	1200.0	1791.7	Distributed	19434	335.9	Transition	9306
15	1300.0	1300.0	1811.9	Distributed	19438	377.5	Transition	8646
16	1400.0	1400.0	1832.1	Distributed	19443	420.7	Transition	8092
17	1500.0	1500.0	1852.3	Distributed	19447	465.3	Transition	7623
18	1600.0	1600.0	1872.5	Distributed	19452	511.3	Transition	7222
19	1700.0	1700.0	1892.7	Distributed	19456	558.4	Transition	6876
20	1800.0	1800.0	1912.9	Distributed	19460	606.7	Transition	6576
21	1900.0	1900.0	1933.1	Distributed	19464	655.9	Transition	6314
22	2000.0	2000.0	1953.2	Distributed	19468	706.1	Transition	6083
23	2100.0	2100.0	1973.4	Distributed	19472	757.1	Transition	5879
24	2200.0	2200.0	1993.6	Distributed	19475	808.9	Transition	5698
25	2300.0	2300.0	2013.7	Distributed	19479	861.0	Transition	5537
26	2400.0	2400.0	2033.9	Distributed	19482	913.3	Transition	5395
27	2500.0	2500.0	2054.0	Distributed	19486	965.6	Transition	5267
28	2600.0	2600.0	2074.1	Distributed	19489	1018.1	Transition	5153
29	2700.0	2700.0	2094.3	Distributed	19492	1070.6	Transition	5050
30	2800.0	2800.0	2114.4	Distributed	19496	1123.1	Transition	4956
31	2900.0	2900.0	2134.5	Distributed	19499	1175.8	Transition	4871
32	3000.0	3000.0	2154.7	Distributed	19502	1228.5	Transition	4793
33	3100.0	3100.0	2174.8	Distributed	19505	1281.2	Transition	4721
34	3200.0	3200.0	2194.9	Distributed	19508	1334.0	Transition	4656
35	3300.0	3300.0	2215.0	Distributed	19511	1386.8	Transition	4595
36	3400.0	3400.0	2235.1	Distributed	19514	1439.7	Transition	4539
37	3500.0	3500.0	2255.2	Distributed	19517	1492.6	Transition	4487
38	3600.0	3600.0	2275.3	Distributed	19519	1545.6	Transition	4438
39	3700.0	3700.0	2295.4	Distributed	19522	1598.6	Transition	4393
40	3800.0	3800.0	2315.5	Distributed	19525	1651.6	Transition	4351
41	3900.0	3900.0	2335.5	Distributed	19527	1704.6	Transition	4311
42	4000.0	4000.0	2355.6	Distributed	19530	1757.7	Transition	4274
43	4100.0	4100.0	2375.7	Distributed	19532	1810.8	Transition	4239

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MUDLITE - Air/Mis\oam Hydraulics Model
Flow Pattern

Data file: V:\Documents and Settings\Ken Oglesby\My Documents\HS7 MHT Test Well.ml3
Well: Test Well
Company: Impact Technologies LLC
Project: Microbore CT Drilling
Field: Anywhere
Location: Anywhere
Date: 12/5/03 2:34:51 PM
Comments: Test for 1000' 3.5" lateral out of 7" casing with 1.75"CT at 5000'TVD

	MD (ft)	TVD (ft)	Pipe Pressure (psi)	Pipe Flow Pattern	Pipe Reynolds#	Annulus Pressure (psi)	Annulus Flow Pattern	Annulus Reynolds#
44	4200.0	4200.0	2395.8	Distributed	19535	1863.9	Transition	4206
45	4300.0	4300.0	2415.8	Distributed	19537	1917.1	Transition	4175
46	4400.0	4400.0	2435.9	Distributed	19539	1970.2	Transition	4146
47	4500.0	4500.0	2456.0	Distributed	19542	2023.4	Transition	4119
48	4600.0	4600.0	2476.0	Distributed	19544	2076.7	Transition	4092
49	4700.0	4700.0	2496.1	Distributed	19546	2129.9	Transition	4068
50	4800.0	4800.0	2516.1	Distributed	19548	2183.1	Transition	4044
51	4900.0	4900.0	2536.2	Distributed	19550	2236.4	Intermitent	6320
52	4950.0	4949.9	2546.2	Distributed	19552	2255.4	Intermitent	6310
53	4955.0	4954.9	2547.2	Distributed	19552	2257.3	Intermitent	6309
54	4960.0	4959.7	2548.1	Distributed	19552	2259.2	Intermitent	6308
55	4965.0	4964.2	2549.0	Distributed	19552	2260.9	Intermitent	6307
56	4970.0	4968.3	2549.7	Distributed	19552	2262.5	Intermitent	6307
57	4980.0	4975.4	2550.9	Distributed	19553	2265.2	Intermitent	6305
58	4990.0	4981.1	2551.6	Distributed	19554	2267.4	Intermitent	6304
59	5000.0	4985.3	2551.9	Distributed	19556	2269.1	Intermitent	6303
60	5010.0	4987.9	2551.8	Distributed	19558	2270.2	Intermitent	6303
61	5020.0	4988.8	2551.1	Distributed	19560	2270.6	Intermitent	6302
62	5100.0	4988.8	2543.8	Distributed	19580	2271.5	Intermitent	6302
63	5200.0	4988.8	2534.6	Distributed	19605	2272.6	Intermitent	6301
64	5300.0	4988.8	2525.5	Distributed	19630	2273.7	Intermitent	6300
65	5400.0	4988.8	2516.3	Distributed	19656	2274.8	Intermitent	6299
66	5500.0	4988.8	2507.1	Distributed	19681	2275.9	Intermitent	6297
67	5600.0	4988.8	2497.9	Distributed	19707	2277.0	Intermitent	6296
68	5700.0	4988.8	2488.7	Distributed	19733	2278.1	Intermitent	6295
69	5800.0	4988.8	2479.5	Distributed	19760	2279.2	Intermitent	6294
70	5900.0	4988.8	2470.3	Distributed	19786	2280.2	Intermitent	6293
71	5990.0	4988.8	2462.0	Distributed	19810	2281.2	Distributed	5182
72	6000.0	4988.8	2461.8	Intermitent	14294	2283.0	Distributed	5181
73	6020.0	4988.8	2461.4	Intermitent	14294	2286.4	Distributed	5178

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APPENDIX D

Literature Search BY Dr. D. Summers at UMR

A Summary of the Existing Literature Concerning Submerged and Sheathed High Pressure Waterjets and Ways of Enhancing Their Performance

Introduction

The literature describes both laboratory investigations and studies of practical applications of submerged jets in the field. For ease of interpretation the literature reviewed has been divided into segments, bringing together the references in to three groupings. Although some studies cross over from one section to another, they have been listed where it was felt most appropriate.

The initial segment covers laboratory investigations, including theoretical fluid mechanical studies as well as experimental parametric evaluations. These studies of the fluid mechanics of turbulent submerged jets are discussed below under “Theoretical and Basic Studies”.

Descriptions of practical applications of submerged jets include slurry jetting for civil engineering applications such as the emplacement of grout; the decommissioning of nuclear facilities and for deep ocean applications such as the maintenance and decommissioning of offshore oil platforms. These applications are discussed below under “Applications of Submerged Jets”

The “Parametric Studies” section includes studies of: air shrouds around waterjets and abrasive waterjets; direct injected abrasive jets; the effect of confining pressure on jet erosion; the use of chemical additives to enhance the reach of waterjets and abrasive jets; optimization of nozzle design for submerged jets; cutting of rocks, concrete and steel with submerged jets; and the diffusion of submerged jets.

Theoretical and Basic Studies

The cutting process discussed is one in which high-pressure waterjets are mixed with an injected abrasive to form a slurry jet that is accelerated to a designed velocity at which it strikes the target and begins to cut. Although the initial design for the abrasive slurry jet has been assigned to Fairhurst (1) in 1982, there was a significant body of work available prior to that time. The initial study by Leach and Walker (2) included work on nozzle design and the need for high levels (around 0.15 micron) of surface finish and smoothness of flow in nozzle construction. Selberg and Barker (3, 4) validated these conclusions and showed that jet throw could be significantly increased, where care is taken with the entrance flow path. The importance of having a straight section to stabilize flow was shown by Kovscek et al (5) who showed that a 10 cm straight section ahead of the nozzle was effective, a distance not available in this case.

Lohn and Brent (6, 7) analyzed the fluid mechanics related to the energy losses incurred by a waterjet cutter operating in the confines of a well casing. They designed improved nozzles and an efficient means of changing the direction of water flow immediately upstream of the nozzle, using turning vanes and showed that they could achieve equivalent performance as a "straight" inlet to a throw distance of 30 ft. White (8) analyzes viscous fluid flow. Tesar (9) analyzes the turbulence engendered by the issuance of a waterjet into water.

Erdmann-Jesnitzer et al (10) examined the effect of nozzle configurations on the performance of a waterjet under water. The study revealed that nozzles with a conical contraction angle of 60 degrees and a straight section half the diameter of the orifice exit are the most suitable for cutting with a submerged waterjet.

Brandt et al (11) studied the acceleration of abrasives in suspension jet nozzles. The study showed that the cutting efficiency of short nozzles is higher than that of long nozzles and that increasing the length of the cylindrical part of the nozzle increases the jet coherence. Yazici (12) found that the use of long nozzle designs had little benefit in drilling operations where the nozzle was very close to the target, although Summers et al (13) have shown that where the jet is allowed to properly accelerate a 700 bar ASJ will give as much energy to abrasive at the same water and abrasive feed rates as a 2,800 bar conventional abrasive waterjet system (AWJ).

Applications of Submerged Jets

Yahiro and Yoshida (14) found that grouting operations with a slurry jet is aided by the addition of air to the jet. Their work involved the optimization of downhole induction grouting with a 2-mm diameter, 700 bar jet surrounded by an annular airflow of up to 250 cfm. Their data showed nearly a 500% improvement in downstream centerline jet impact pressures at a standoff distance of 15 cm. Although the waterjet reach improved steadily as the flow increased from zero to 180 cfm, a trend of asymptotically diminishing returns also appeared i.e. up to 400% improvement was measured with airflows of only 21 cfm. Beyond 180 cfm the added air destabilized the waterjet.

Savanick(15) showed that an air shroud increased the useful range of a 2.5-cm diameter submerged waterjet to about 5.4 m in a borehole phosphate mining operation. In this operation phosphate was mined remotely from the surface through a 72 m-deep borehole .The submerged cutting jet pressure ranged from 70 to 133 bar and the corresponding flow rate was 1700 to 2000 lpm. The air shield pressure was 175-bar and the corresponding air shield flow rate was 150std cfm.

Alba et al (16), Bach(17),Blickwedel et al(18).Eckert et al (19, 20, 21), Haferkamp et al(22, 23), McGough et al (24, 25) , Reiter et al(26) And Usii et al(27) discuss the application of abrasive suspension jets for the dismantling of nuclear power plants. This work demonstrated that it is possible to increase the working distance of the submerged jet by using an air shield.

An important problem in these applications is the lifetime of the nozzle which is limited because of wear. It is necessary to choose the cutting parameters to achieve a balance between the cutting efficiency (which is normally associated with higher wear) and nozzle life. The nozzle must last long enough to complete the cutting job.

The selection of the abrasive might be useful in achieving the balance described above. Recently Martinec et al (28) investigated the cutting efficiency and wearing effects of a series of abrasives used in abrasive jet cutting. Garnet was found to be the most efficient cutting abrasive, followed by olivine. However, olivine gave a 25% longer nozzle life than olivine, and can be significantly cheaper to purchase. Thus, in certain cases, olivine abrasive can be a suitable, less expensive alternative to garnet abrasives for cutting metals.

Domann et al (29),Haferkamp et al (30) ,Alberts et al (31), Bailey(32), and Olds (33) discuss subsea applications of waterjets. These applications include cleaning and cutting under water. Cutting applications include severing pipes under the seabed. Cemented pipe strings which have been severed by an abrasive jet are shown by Oil States MCS (34) and Raghavan (35). These pipe strings are severed below the mud line when the offshore platforms are decommissioned. The literature search revealed no instances where uncemented, nested pipe strings have been severed by an abrasive jet.

Raghavan et al (36) have patented a method and apparatus for using an abrasive jet to cut piles and conductors under offshore oil production platforms.

In a related field Meyer et al (37, 38) have been drilling coal at depth and have found that cavitation around the submerged jet can impact performance. Because Mazurkiewicz (39) has shown that cavitation is a very powerful crusher of particles, the effect of cavitation on ASJ performance underwater, briefly discussed by Shimizu (40, 41) needs further investigation.

Parametric Studies

Miller et al (42) demonstrated the use of an air shroud to increase the reach of a submerged water jet using an air shroud flow rate of 280 cfm. Improvement with waterjet reach was found to correlate strongly with volume flow rate of air at standoff distances between 10 and 180 nozzle diameters from the nozzle. At greater standoff distances no improvement was measured.

Savanick et al (43) demonstrated that it is possible to increase the effective reach of an abrasive jet by collimating it i.e. by enclosing it in a pipe (44, 45). This phenomenon was used to build an abrasive jet drill one-inch-diameter holes in hard rock to a depth of 4.5-m. Miller et al described the physics of three-phase flow in a collimating pipe (46) and measured the velocity of abrasives in the collimation pipe (47).

Ultrahigh–pressure, direct-pumped abrasive suspension jets were compared with entrainment-type abrasive waterjets for cutting under up to 6000 m of water by Alberts et al(48). This paper showed that the abrasive suspension jet system is more effective and easier to operate in the laboratory and potentially in the field.

Okita et al (49) evaluated nozzle wall wear of three types of abrasive suspension jet nozzles: a conventional suspension jet nozzle and two nozzles with a conventional suspension jet nozzle fitted with annular conduits.
Howells (50, 51, 52) reviewed the use of polymeric additives for jet collimation and abrasive suspension. Jets collimated with chemical additives carry further than ordinary jets and thus have been useful in fire fighting. Polymers have also been useful for suspending abrasive particles and to form a coherent suspension jet.

Dormann et al (53) describe underwater research with abrasive jets aimed at development of undersea robots. Cutting was performed to a simulated depth of 600 m. Haferkamp et al (54) discuss the deep sea applications of abrasive waterjets produced by injection of the abrasives at the cutting head. This research points up the limitations of this kind of abrasive jet at greater water depths and indicates that premixed jets such as the DIAJET are more suitable for working in the deep sea. Surle (55) performed abrasive jet cutting tests in a pressure chamber. This research indicates that abrasive jet cutting is reliable at depths up to 400 to 500m and that the direct injection of pressurized slurry is more efficient and practical to use than other methods of transporting abrasive to the cutterhead.

Alberts and Hashish (56) evaluated the performance of directly pumped abrasive suspension jets in a test chamber that simulated ocean depths up to 6100 m. They recommend using an air shroud around the submerged jet.

Bibliography

Note: all bibliography references from this section are fully reported in the BIBLIOGRAPHY section of this report.

APPENDIX E

Report on Task 2 from Dr. Summers at the University of Missouri at Rolla
Attached (see next page).

The Use of Dispersed Abrasive Slurry Jet Systems for Rock Drilling

by

David A. Summers, Robert D. Fossey & Pradeep Nambiath

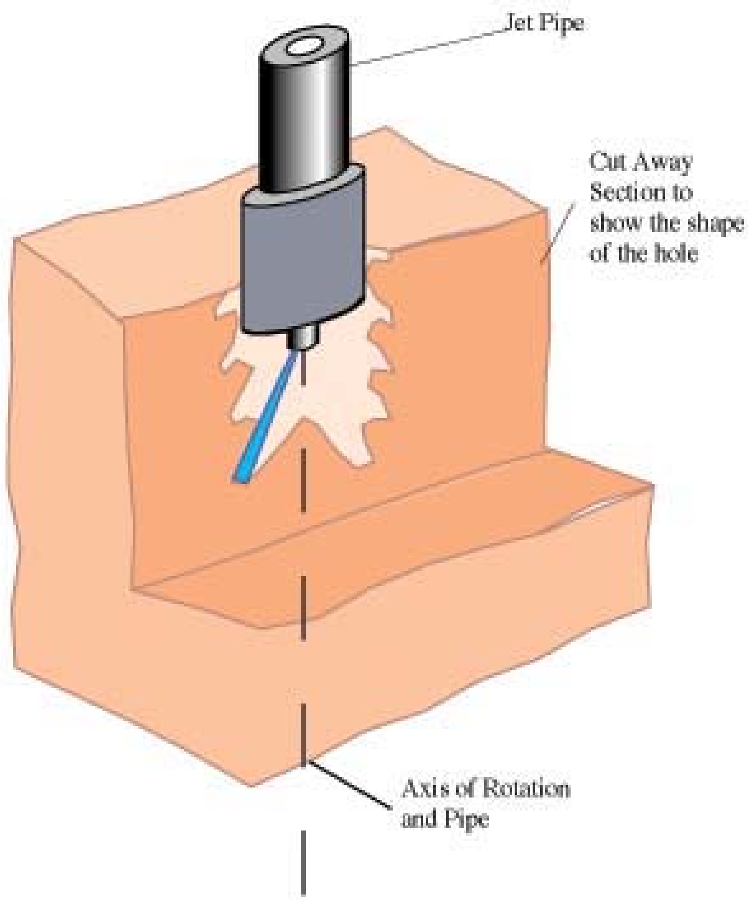
to

Bandera Petroleum Exploration LLC
Impact Technologies LLC

UMR UNIVERSITY OF MISSOURI-ROLLA
The Name. The Degree. The Difference.

March 31, 2005

Successful waterjet drilling of rock has been one of our goals since Dr. Summers PhD program in England.



Summers D.A. 1968 *Disintegration of Rock by High Pressure Jets*. PhD dissertation, Mining Engineering, University of Leeds, UK.

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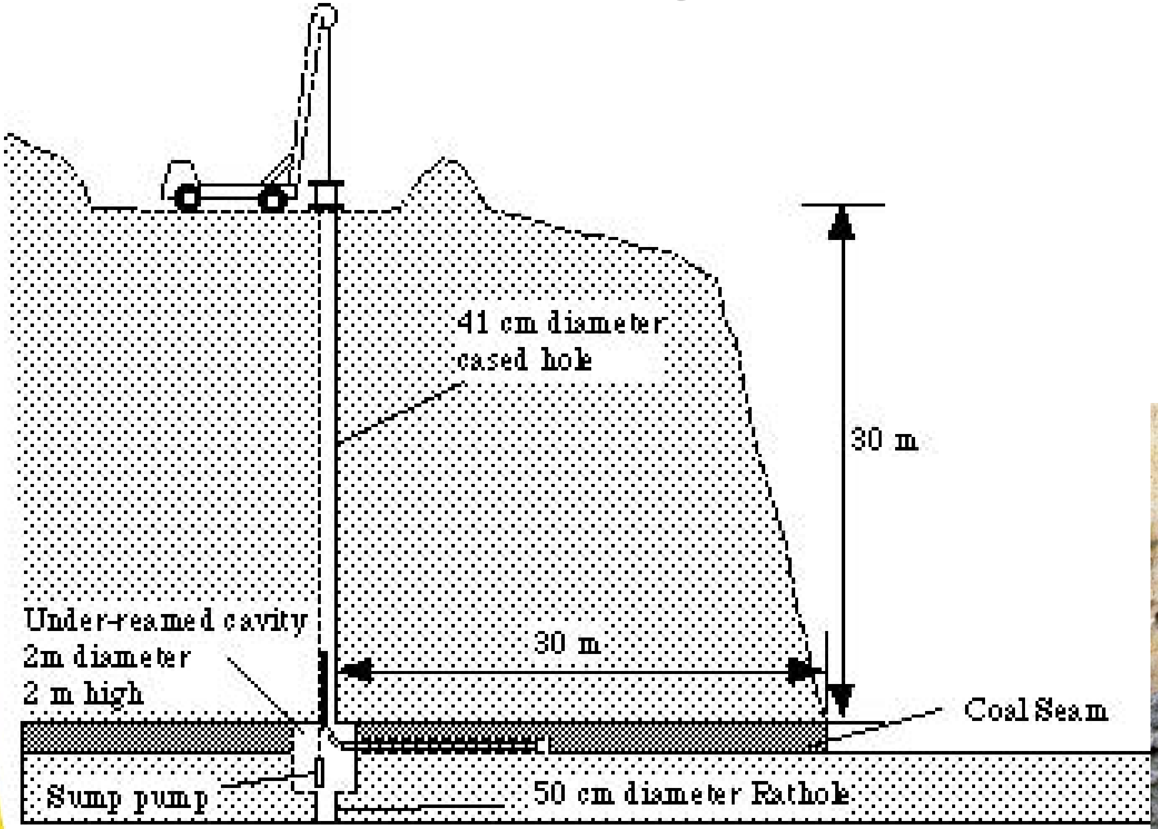
We have demonstrated that waterjets alone can drill aggressive sandstone underground at viable rates

Summers D.A. and T.F. Lehnhoff 1978 *The Design of a Waterjet Drill for Development of Geothermal Resources*, Final Report on Contract DOE EY 76 02 2677

Under a sub-contract from Sandia National Laboratories we showed waterjets can "drill around corners"



This is now a commercially available technique in Australia.

But to be effective in rock a drill must cut all rocks.

In excavating the OmniMax theater under the St. Louis Arch we cut the walls with an abrasive slurry jet at a pressure of 5,000 psi. The darker material is a chert layer 4 inches thick.

A jet from this system will cut steel and concrete

The line shows that the jet drilled all three barriers, although it took 2 minutes to cut all the way through these blocks.

We designed a drill to cut the holes without rotation

It drilled 1 ft of concrete in 1 min 20 sec.

But by changing nozzle geometry we increased drilling diameter

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And initial trials showed that it could drill through concrete and gravel

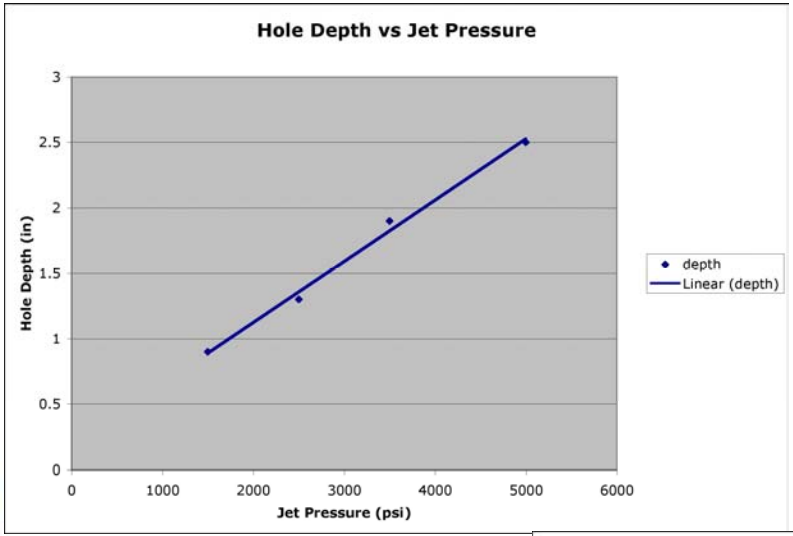
Water level

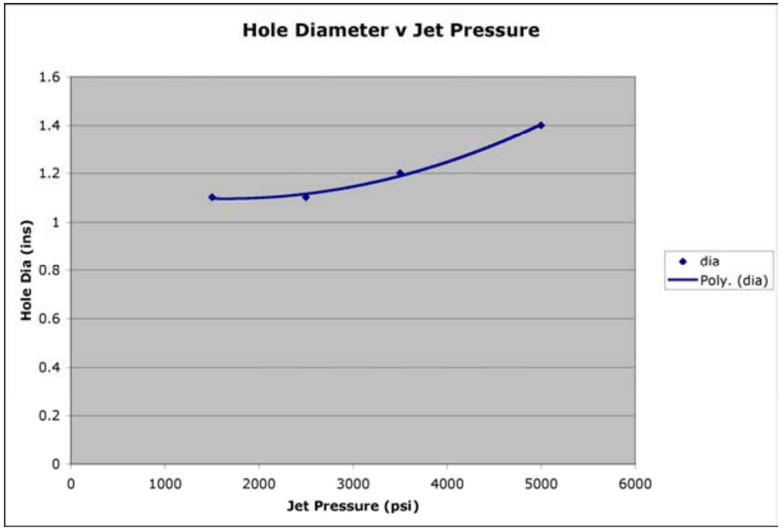
But when under water the hole diameter dropped significantly

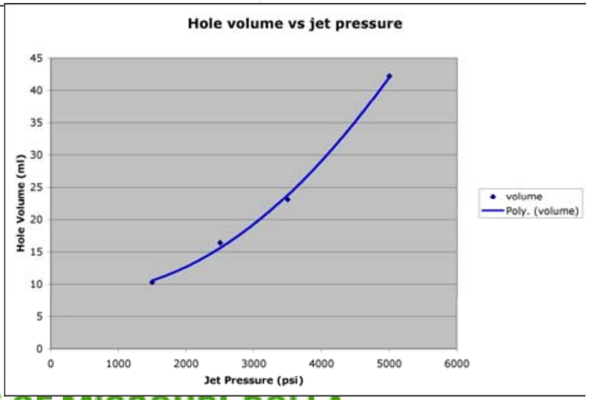
Air

Submerged

Tests showed that changing pressure and abrasive feed did not change diameter much





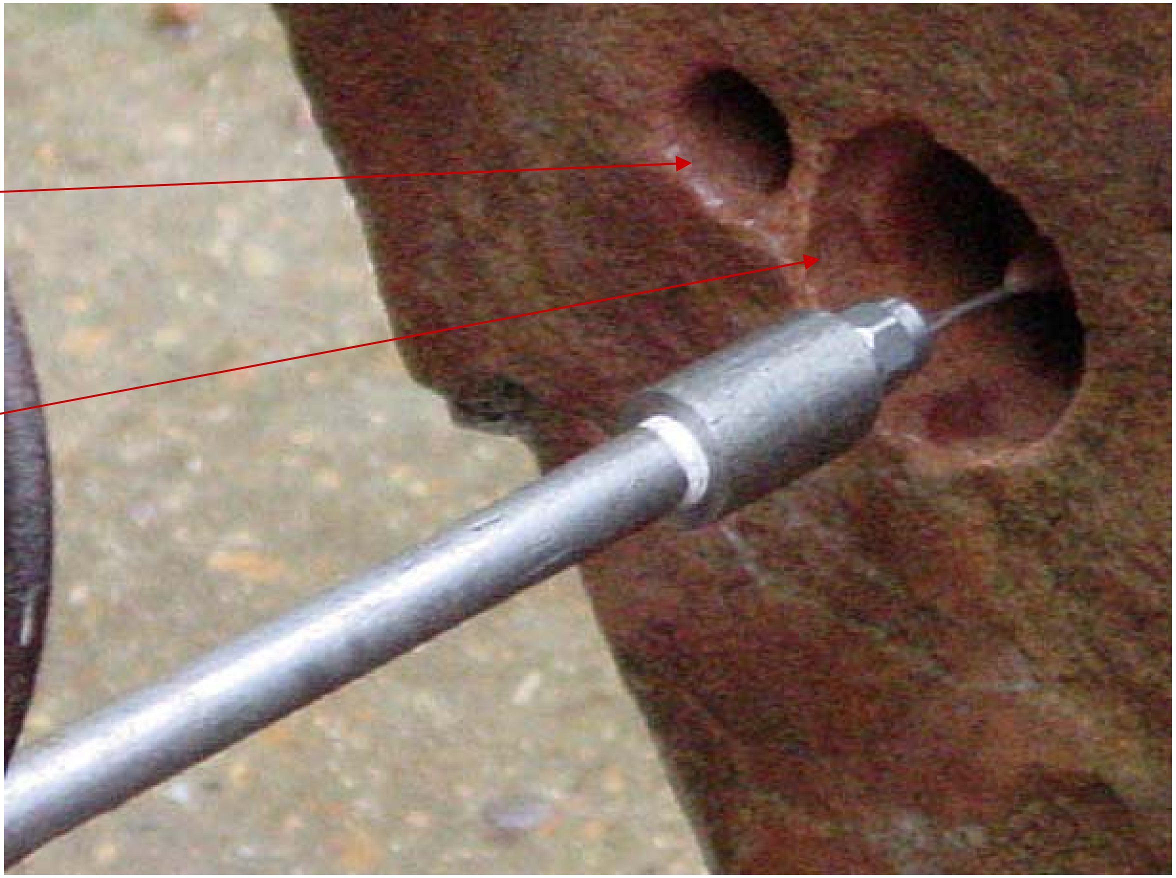


Based on static testing

A further change in design allows much larger holes to be drilled

Original design

New design



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A second modification let the system cut larger holes underwater

(

gage).

Specific energy calculation

- A 3,000 psi DASjet through a 0.043 inch nozzle flows 2.63 gpm. This uses 4.6 hp. It drilled a hole 6-inches deep and 2-inches in diameter in Sandstone, and slightly shallower in mudstone and dolomite, in one minute without drill advance. The specific energy of cutting in the sandstone is thus around 670 j/cc.

Performance was also improved by changing the abrasive injection circuit

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In Summary

- A method for drilling 2-inch diameter holes with a non-rotating 0.043 inch diameter jet has been developed
- The design has been modified to operate underwater
- A new method for injecting abrasive into a high pressure waterjet line has been demonstrated.
- Data on preliminary testing has shown that this new tool has the potential to provide a low-cost, energy-effective way of drilling through rock from a coiled tube platform.