Advanced ASJ Drilling System

Final Report
For time period:
1 July 2006 to 31 December 2008

Report Issued:
31 January 2009

by
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DOE Prime Cooperative Agreement to
Penn State University / Stripper Well Consortium:
DE-FC26-04NT42098

Sub-Contract to Impact Technologies LLC:
3181-IT-USDOE-2098

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ABSTRACT:

Major components of a new drilling system utilizing abrasive slurry jetting (ASJ) have been designed, many built and bench tested. This new system can be used for vertical and directional drilling in many industries. These major components developed were a high pressure, hydraulic driven, dual cylinder, slurry piston pump (HPSP) that can pump up to 30 gallons per minute (gpm) at up to 15,000 psi. It was modified for Impact's FLASH ASJ drilling system.

A patented downhole Inverted Motor (IM) in a gerotor hydraulic version was designed in several versions, but none built. It was replaced with an ASJ swivel that was designed and built for rotational force and little torque for mechanical drilling. A new bearing (thrust and journal) and seal assembly was designed for the Inverted Motors (IMs), but not built due to the swivel use. A new downhole separator was designed for IM-hydraulic and CFD studied, but not built again due to the swivel use.

A near bit directional control tool as a ten (10) degree bent sub in a 1.25" tubing size was designed, built and bench tested for ASJ drilling. It would be installed immediately above the cutting tip assembly for immediate hole direction control.

A concentric pipe directional control device was patented, designed, built and bench tested. This is a two part device with an outer and an inner pipe. The outer pipe provides torque and orientation to the inner pipe as needed.

This technology has been encompassed into and accepted for a DOE SBIR Phase I (completed) and Phase II (ongoing) project. That project is to drill a 2000 foot well to install geophone seismic sensors for CO_2 monitoring.

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EXPERIMENTAL WORK:

The High Pressure Slurry Pump (HPSP) in the hydraulic piston version was designed in SolidWorks. It was studied by Finite Element Analysis (FEA) in three (3) passes. It was tested at Impact's shop for performance and operation. That work horse pump operated very well in the optimization steps, generating up to 15,000 psi and 20 wt/wt% solids in the outlet stream. Rock slabs were cut on a moving target rail. Problems with the inlet mixing tank, resulting in unstable solids concentration and entrained air, prevented additional testing until those side issues were resolved.

The Inverted Motor was designed in SolidWorks in two (2) gerotor versions, single stage and multiple stages. Parker Hanniffin also designed two (2) more versions and built one of those versions. None were tested.

To replace the IM-h motors that were not built, Impact designed a swivel in SolidWorks and built a prototype off that swivel design. It has not been tested since we are awaiting additional coatings. Similar swivels have been built and tested for waterjetting, thus no test surprises are anticipated.

For the Inverted Motors, an inverted bearing and seal assembly was designed, but not built due to no need.

The downhole separator was designed in two (2) versions, FEA studied in one (1) and Computed Fluid Dynamic (CFD) studied in one (1) version. None were built since the new ASJ Swivel does not need downhole separation.

The concentric tubing directional control (CTD) device was designed in SolidWorks, prototyped and tested in Impact's shop. It provided at least 125 foot lbs of torque per one foot, based on a 4" long lobe holding 50 ft-lbs of torque. A US patent has been applied for this technology.

EXECUTIVE SUMMARY:

Major components of a new abrasive slurry jet (ASJ) cutting and drilling system were developed, for vertical and directional drilling. Additional work is required, but no impediments were found to prevent this system from providing significant benefit to the industry. Selected components of this project were used in a DOE SBIR Phase I (completed) and Phase II (ongoing) project (DE-FG02-07ER84670). Specifically from this project, the high pressure (up to 15,000 psi), hydraulic driven, dual cylinder, slurry piston pump (HPSP) was designed in SolidWorks (a computer 3D graphical design program), FEA studied, manufactured and tested. This pump was de-rated to 10,000 psi due to component limitations. It was redesigned for Impact's FLASH ASJ drilling system as well.

A gamma ray densitometer was purchased and set up to analyze, control and optimize the HPSP performance on the outlet leg.

A new inlet mixer is being built instead of the mixer tanks used in this testing.

The downhole inverted configured hydraulic motor was modeled in both single stage and multiple stage using Solidworks designs. Those designs were sent to Parker-Hannifin, an international gerotor manufacturer, for prototyping. Parker lost interest due to a lack of existing markets. A new rotational ASJ swivel device was designed, manufactured and will be tested at Impact and Missouri University of Science and Technology.

A new sealed bearing assembly was designed for these (and other) inverted motors. A bearing manufacturer will be found to make these bearings, but this is not critical since the Parker motor does not need them. An alternate swivel also does not need the bearing/ seal system.

A Computed Fluid Dynamic (CFD) model of the one version of the downhole concentrator / separator /filter was made. Fully 100% separation was obtained of the liquid and solids at 20gpm and 10% solids. However, erosion concerns and inlet/outlet boundary conditions are of concern with this version. A new version was designed, but not built nor tested. This work was abandoned as un-needed since the new swivel rotational device with FLASH ASJ does not need separation.

One of the patent pending downhole directional control tools was modeled in SolidWorks. This tool was prototyped and bench tested. A near bit bent sub for directional initiation was designed for ASJ, built and tested.

INTRODUCTION:

The oil and gas industry, particularly stripper well operators, need a new drilling system to lower the cost of vertical and horizontal drilling. Unless commodity product pricing is high, no one would intentionally drill a low volume/ rate stripper well. However, not all wells, and especially in mature areas like the US, are high volume wells. Such a new drilling system must deploy new technologies to drill and complete wells in conventional/ unconventional reservoirs and/or in installing lateral drain holes or extended perforations. Maurer (4) and others identified many of these new technologies back in the 1950s. They showed that high pressure jetting and abrasive slurry jetting plus mechanical action will significantly improve drilling penetration rates. They showed that abrasive slurry jetting and high pressure jetting can greatly improve drilling penetration rates by factors up to 20 times conventional rates. Powered rotation by a motor with this pre-cutting (kerfing) will provide the mechanical action to grind cuttings to smaller sizes to ensure that particles are small enough to be swept out of the hole for good hole cleaning. This project proposed the use of abrasive slurry jetting (ASJ) systems with traditional mechanical cutting. This combination can provide very fast erosive cutting of the rock ahead of the bit and mechanical action for good hole cleaning. It should also provide trimming of the hole wall for full hole boring (i.e. no obstructions) for advancement of the bottom-hole assembly (BHA, includes the cutting tip/ nozzle); provide a known base for directional drilling; and, if desired, rotate the nozzle(s) for a larger cut hole diameter.

Current methods for drilling most wells utilize 1950s and earlier technologies that have been updated on the edges. Most of these rigs are getting very old, require a lot of man power to setup/teardown/mobilize, operate and have a lot of downtime for repairs- just to drill a conventional 6-1/2 to 8-1/2 inch wellbore. They also require a large land site, large fluid volumes and mud system. Predominately weight on the bit and less hydraulic power is used to break/crush the rock and make new hole. Directional drilling with such a rig is expensive since the rig hands do not know the technology, the rig is not specifically designed for that activity and the repair downtime drives the directional charges to the sky. But they are worth it to increase productivity, injectivity or to prevent water coning in oil or gas reservoirs. Figure 1 shows water coning in a gas reservoir or gas storage zone. Such coning increases water production which increases cost or stops oil or gas production. Figure 2 shows how laterals can reduce the pressure drawdown that causes the water to be produced. Typical cost to directionally drill a well runs from $150,000 up to $500,000. Multilaterals are even more expensive, but are beneficial to injectivity and productivity. A specialty rig for deepening and directional work is needed to drive the cost down.

Current technology utilizes jointed pipe, mostly rotated from the surface, although motors are used in more wells now. Coiled tubing drilling (6) is rapidly growing in Alaska, Canada and in Kansas (Tom Gipson’s rig for Rosewood). This technology provides better well control (no joints to make up) and faster tripping for more time on bottom actually drilling. The disadvantages are that the pipe is not as strong as conventional pipe and it cannot be rotated from the surface.

Los Alamos National Laboratory was the pioneer in developing a small 1" coiled tubing rig for drilling microholes (about 2" hole) Figure 4 (2). The PI went out to see this rig in about 2001 and was impressed by its small size and capability. Figure 3 shows the relative size of conventional wells, Slimholes (less than 4-3/4" holes) and Microholes (less than 3.75" holes, by DOE definition). The US Department of Energy has had a Microhole Technology Initiative to push microhole technology development. Several projects were being developed for the DOE, including 2 projects by Impact and the PI (1). Advantages of microhole drilling is that a smaller rig is possible with lower cost to build and maintain, fewer people to operate, can be automated further, less site footprint and less environmental impact. These factors result in less of everything including steel to build, energy to run and cuttings/ mud disposal. Faster drilling may be possible due to the smaller hole size. Disadvantages are few tools for such small holes- motors, bits, fishing tools, etc…(2)(3).

High pressure jetting and/or slurry drilling would allow more hydraulics and cutting energy to be put at the bit for faster cutting of the hole, i.e., faster drilling penetration rate. With coiled tubing and microholes, this additional energy would make up for the small amount of force (as weight) that can be put on the bit.

High pressure jetting (HPJ, 15,000-30,000 psi) has been proven (4) to be effective in cutting a variety of materials and rocks. Pressures in excess of a given material's critical pressure are required for cutting. For rocks, this is in the range of 12,000- 18,000psi (4). Penetration rates with HPJ are greater than mechanical means only, but not impressive due to the added expense and limited coverage. Abrasive jetting has also proven effective in cutting even faster than HPJ for most materials and rocks, but 20,000+ psi systems are required for existing air induced systems and such induced air abrasive systems are not conducive to downhole applications. Newer abrasive slurry jetting systems (ASJ) use no induced air and are more efficient in generating sufficient cutting forces at lower pressures (5000psi+) while still yielding very high penetration rates. That power can be transmitted downhole. Pumping systems for ASJ are the limiting factor due to high erosion on critical parts. As a note of interest- the SWC had earlier funded a slurry slotting method for well casings (ie., Hydroslotters).

The business end of the ASJ system is the nozzle. Conventional abrasive nozzles are available in the industry and can be utilized in this project. However, a new nozzle design has been developed, and now is being optimized, by the Missouri University of Science and Technology (MST), with exclusive licensing rights held by Impact, which will drill a hole larger than itself (0.45" nozzle cutting up to 2" hole) without rotation. Rotation will be required for larger hole sizes using a motor or rotational device that can operate with such high pressure slurries.

Pumping systems for such abrasive slurries include conventional high pressure triplexes (with shortened life and high repair costs), batch systems (cumbersome) and a new patent pending High Pressure Slurry Piston Pump (HPSP) by Impact. This new HPSP has been developed for pumping high pressure abrasive slurries with minimal wear. Development of a larger (or multiple) version (required oilfield manufacturer and higher rate 350+gpm)

HPSP is being performed under a DOE microhole grant; however, lower cost, lower rate (0-50 gpm) and more compact versions are needed and are specifically proposed for this ASJ project. Pressure capability to 20,000+ psi is possible with this pump, but only 5000 to 7500 psi is targeted and required in this project.

A patented electric motor and a patented hydraulic/ pneumatic motor configuration (IM) allow operation at high pressures and with acids, bases and slurries. Inverted Motors (IMs) will allow full use of advanced and smart drilling methods, such as HPJ, ASJ, MWD (measurement of drilling parameters) at the bit, LWD (measurement of reservoir rock properties) at the bit, multiple motors in series and other advanced technologies. IMs can be in electric, gerotor, roller-vane, moyno (mud) and other versions. Two IM electric versions were designed by Impact and the University of Texas-Arlington (UTA) under a US Department of Energy (DOE) grant for development of ultra-high speed motors. A third, low speed, IMe prototype was made by Impact and UTA/ Dr. Fahimi. A hydraulic/ pneumatic gerotor IM (IM-h) version was proposed for design and development in this project.

Conventional motors have the housing connected to the drillstring, an internal radial motor that turns an internal shaft onto which is attached a drilling tool/bit. Inverted motors have the internal shaft connected to the drillstring, an internal radial motor turns the external housing and the tool/ bit is attached to the housing. The key benefit of this design is that internal channels in the non-rotating shaft now allow fluid flow and wires to bypass the motor power section. Several large hydraulic motor/ pump manufacturers have been contacted for design and manufacturing of the proposed IM-hydraulic motors for drilling.

Tools that will be used with a IM-h motor are: rotating nozzle(s) for hole enlargement, bit/mill to grind and trim, fins for pipe movement and counter rotation. Also a downhole separator/ filter will be needed to provide clean fluids to the motor(s). The concentrated solids will be further used for the cutting process.

Microhole sized drilling (3) is the direction the industry must go to allow the use of smaller rig (in cost, materials, volumes to dispose, surface foot print), faster drilling due to less rock to remove and less environmental impact (3). The Principal Investigator has used jointed 1.25" high pressure pipe and 2.125"- 2.75" bits in his field directional work. CTD has grown significantly over the last few years and is the method of choice for Canadian shallow gas and heavy oil drilling and on the north slope of Alaska (6). Use of CTD allows faster tripping, faster drilling, better well control, easier use of gasified, underbalanced or managed pressure drilling.

Ultra-short radius (less than 30 ft) directional drilling allows the wellbore to kick-off in and stay in the top of the producing formation. This allows less drilling footage and forgoes the need to install liners in overlying problem or unstable shales. It also allows the drain hole lateral to remain high in the reservoir, avoiding water coning problems or other bottom water concerns even at high production rates, however, it requires a short powerful drilling system to make such tight turns.

Specifically not included in this project are: Zero Discharge Mud or cuttings processing equipment; managed pressure (MPD) or Under Balanced Drilling; or ‘Smart’ or electrified drilling systems. This project only proposes key components for a ‘dumb’ system, but the developed motor/ rotational device will later allow MWD and LWD capabilities ad be applicable with coiled tubing.

Current drilling rigs and drilling technology rely on the ‘weight-on-bit, crush and grind’ method and are big, slow and expensive in performing vertical and/ or horizontal drilling tasks. Specialized rigs are needed to perform some of these tasks much faster and better. New technologies are available or can be developed and deployed to drill faster at lower costs and provide environmental benefits. This proposal targets the first level of development toward an ultimate very fast, highly portable, highly automated and controlled, ‘smart’, electrified, environmentally friendly, Abrasive Slurry Jet (ASJ) drilling system. This ultimate drilling system includes the proven rapid cutting abilities of abrasive slurry jetting (ASJ) using standard ASJ nozzles or a newly developed ASJ nozzle by the MST; a new patented high pressure abrasive slurry piston pump (HPSP); US patented Inverted Motors (IM); microhole size boreholes (less than 3.875”OD); forward and reverse traction near the bit; electrified downhole tools for MWD and LWD at the bit; patent pending advanced directional steering; and full automation. This ultimate system would also utilize coiled tubing, provide very long and multiple laterals (significantly higher production and injection capabilities) and be highly compact and light weight for quick mobility. While stripper well operators do not need this ultimate system, this first level of development is ideally suited for marginal and shallow, low volume wells. The new drilling process will be extremely mobile, compact, light and very fast. It will provide 25 to 50% lower cost than current drilling methods (2)(3). We will now be able to drill wells where we have not been able to before including tight locations, hard rock locations and deepening below 3.5”, 2.875”, 2.375” and smaller casing.

The beneficiaries of this technology will be the end users of the technology – stripper well operators of the fields that now need low-cost drilling and horizontal laterals/ drainholes/ extended perforations. Secondary beneficiaries include the service companies, who can deliver this new product more cheaply and efficiently than in the past. Landowners will benefit from less surface damage and space needed for drilling. The environment will benefit from less materials and energy needed to construct and maintain these rigs, including steel, muds, chemicals and mud disposal.

If applied to only 5000 wells drilled per year where the drilling cost is $90,000, this results in savings to the stripper well operators of about $150 million each year. This does not take into account the environmental benefits of smaller unit, the savings from less water production due to avoidance of water coning due to lateral drainholes installed or the increase in oil and gas production due to new wells drilled and lateral drainholes installed.

This particular SWC project began in July 2006 and concluded in December 2008 to further the design and prototyping of a new abrasive slurry drilling system for directional laterals. Such a drilling system will provide a very fast and low cost method to drill microhole and full sized well bores for multiple industries. This work is based on multiple patents, patents pending and proprietary designs of the Principal Investigator. This includes US and international patents on the High Pressure Slurry Pump and the Inverted Motor for Drilling. In addition a new patent was filed for the Concentric Tubing Directional Controller. New applications of this new drilling method have been found in Ground Sourced Heat Pumps, Geothermal wells and in Energy Storage- all besides the original targeted oil and gas vertical and directional wells.

To meet that goal the key original tasks and descriptions of the project were set as:

Original Task 1- High Pressure Slurry Piston Pump
This task redesigned and developed the hydraulic piston prototype version of the patent pending High Pressure Slurry Piston Pump (HPSP) that will drive the high pressure slurry system. This is primarily a modification of the direct drive hydraulic pump with modified fluid head for introduction of clean fluids.

Original Task 2 – Hydraulic Inverted Motor
This task was to design, develop the prototype and test the new gerotor hydraulic version of the patented Inverted Motor. Internal modeling using SolidWorks was to be done as an initial design for the manufacturers. Several existing hydraulic motor manufacturers were contacted and, since this potential market was considered small, it's design was expected to be by fee design.

Original Task 3-Downhole Separator/ Concentrator
This task was to acquire and/or modify existing or design / develop and test a down hole separator/ filter. This was felt needed for the downhole Hydraulic Inverted Motor.

Original Task 4 – ASJ Nozzle
This task was to take the MST specialty nozzle (developed under another DOE project) for use with the Inverted Motor-ASJ system. This task included mounting of such nozzles for ASJ drilling.

Original Task 5 –Related ASJ Tools
This task was to build additional tools as needed for the ASJ drilling operation- surface and downhole. This included the bits, swivels and other tools. It included threading and other issues.

Original Task 6 –Kickoff and Build Angle Tools
This task was to design and build a whipstock and near bit tools for initiating an angle and exit out of the vertical casing. Extent of work to be controlled by time and budget.

Original Task 7 –Directional Control
Methods to control the direction of the bore were to be developed and prototyped. Extent of work to be controlled by time and budget.

Original Task 8- Bench Tests
Bench testing of individual sections and the combined assembly were to be performed.

Original Tasks 9- Combined Vertical Field Test (optional)
A combined assembly field test in a vertical orientated well was to be performed, as possible by time and budget.

Original Tasks 10- - Combined Horizontal Extension Field Test (optional)
A combined assembly field test in a directional or horizontal well was to be performed, as possible by time and budget.

Original Task 11- Reporting
Technology transfer as it becomes ready for marketing was to be performed. Presentations and publications considered are to the Society of Petroleum Engineers, World Oil, American Oil and Gas Reporter, Petroleum Technology Transfer Council (PTTC) website and newsletters, and the Oklahoma Marginal Well Commission newletters and workshops. SWC will be credited for its support of this project.

RESULTS AND DISCUSSION:

A discussion of the status of each task follows.

Task 1- High Pressure Slurry Piston Pump

The HPSP in the dual cylinder, hydraulically driven version has been designed by D. Whitehead, 3D modeled in Solidworks, three FEA studies performed by EngATech and a second designer. It was manufactured by Danco Pump and Supply and assembled by Impact. Two cylinders of a dual hydraulic pump system (plus extra parts) were built. Delays occurred due to warping of some components during the heat treating process. Some parts were modified and remade for retreating. Other parts required grinding out the warped section. This pump will be rated for pumping slurries (solids in water) at 15,000 psi- all parts must fit precisely due to the pressure and the fluidized slurries utilized.

Testing of the HPSP at Impact's shop began in January 2008. The goal of testing was to prove the abrasive cutting of the pump and the life expectancy under these extreme conditions. A stand for linking the tandem pumps and shielding was built based on the patent pending design. Tanks, abrasive solids, targets and polymer were onsite. Nozzles were ordered and nozzle holders built. Testing of the prime mover (Cumming 180 Hp diesel powered the FMC 20,000 psi water pump) for the HPSP testing was successfully accomplished.

A gamma ray densitometer was purchased to analyze the flow density and optimize the performance of the HPSP.

In that testing, the HPSP performed as expected and was considered successful. However, the commercially available control valves utilized were not reliable and a new CV was needed. Several new control valves have been build and the last version is now being assembled. New linkages for the CV and new clean fluid valving for the new fluid systems are required as well.

In addition, the cable linkage between the cylinder pistons came undone repeatedly with each CV problem. It has been replaced with a rack and pinion gear for greater reliability.

Lastly, the inlet mixing of the slurry was insufficient and allowed air to be induced into the pump suction at times. This limited the maximum pressure obtainable. A new inlet mixer has been designed and construction continues to date.

Adding to these factors is the development of the Impact FLASH ASJ drilling system. This specialized fluid, pumping and nozzle system has required upgrading of the pump, inlet mixer and other components for safety and operation efficiency. That concurrent upgrade is currently ongoing.

Task 2 – Hydraulic Inverted Motor
An agreement with Parker-Hannifin, an international gerotor motor and pump manufacturer, was made for the final designing and prototyping of a version of the Inverted Motor in a hydraulic version. Solidworks models were made by Impact of single stage and multiple stage hydraulic/ pneumatic motors in the patented inverted configuration. The SolidWorks program is a graphical 3 Dimenional computer program for designing equipment. These base computer models or designs were sent to Parker-Hannifin for their redesign and upgrade based on their expertise. However, due to internal Parker problems, this work was transferred to another Parker division. Four prototype designs or models were made and one has been built. This hydraulic motor will need a downhole separator for operation under these high pressure slurry drilling conditions.

Due to the delays with Parker and the final outcome of their work, as well as the development of the new FLASH ASJ drilling system, a new rotational device was designed and built. This rotational device is a redesigned Inverted configured, self propelled swivel that does not need a downhole separator. It was designed and prototyped, but not tested in its current configuration. Similar models have been lab, bench and field tested at the MST in earlier studies.

Task 3-Downhole Separator/ Concentrator
An industry and patent search found no existing designs for downhole solids-liquids filtering/ separation and thus a new design was made and flow model tested utilizing Computed Fluid Dynamic (CFD) modeling. That model showed 100% separation of the 10% 250 micron sized solids out of 20 centipoise liquid flowing at 20 gpm rate. However, erosion concerns and inlet/out boundary concerns necessitate a design change. That new design was made, but still needs CFD analysis, prototyping and testing. With the development of FLASH ASJ systems and the delay and termination of the Parker design, this work was put on hold since the inverted swivel built does not need this component for downhole separation.

Task 4 – ASJ Nozzle
Off-the-shelf abrasive slurry jet nozzles were utilized for testing the pump and testing of the ASJ cutting capabilities. This was done in January 2008 at Impact's Testing Facilities near Tulsa, Oklahoma. The Impact's FLASH ASJ fluids and the Missouri University's specialty nozzles, part of the DOE Microhole project, were not yet adopted for this project due to safety and limited pumping capabilities. These nozzles require special fluids and special handling in the HPSP pumps.

Task 5 –Related ASJ Tools
Multiple other components were researched, purchased or rejected. Different threads were studied and the tapered National Pipe Thread was found to provide sufficient strength and sealing for 15,000 psi since little torque or side bending is expected with ASJ systems. An alternate CS Hydril connection was suitable for 15,000 psi under more demanding conditions.

Surface and downhole swivels were researched and were found to be commercially available for a price. With no field test looming, none were purchased.

High pressure 10,000 psi hoses for slurries were found commercially available. Designs for the rates considered required 1" hoses. Lower rates could use ¾" hoses. The mixture velocity must be kept less than 1 meter per second to prevent erosion.

Task 6 – Kickoff and Build Angle Tools
Impact has a 5-1/4" OD whipstock with a hardened face and a 2-1/8" bore. It is similar to the system shown in Figures 13 and 14. Figure 13 shows the basic whipstock assembly with tubing attached. Figure 14 shows the smaller drill tube and drill tip extending through the whipstock, exiting the casing and cutting the rock. Impact's whipstock will be used with the ASJ directional drilling assembly in 5-1/2" and larger casings.

A bent sub of 1.25" pipe was made for the near bit directional control. The prototyped bent sub is shown in Figure 15. This bent sub provides a continuous, inline 10 degree build angle that is compatible with high pressure slurries. It will be positioned immediately above the Drill Tip (nozzle assembly) for immediate impact on the hole direction.

A directionally orienting sub above the bent sub was designed, but not built, for use with Impact's Topari and Microsync 1" directional measurement tools. The orientation prong must be hardened to withstand the erosive nature of the abrasive fluids. Since the flow area at this point can be maintained large enough to minimize erosion, this should not be a problem.

Task 7 –Directional Control
A new method to control coiled tubing was designed, prototype built and tested. A new US patent application(s) was submitted for this design and method of control. Components of the downhole directional control tools were modeled in Solidworks, built and bench tested. These two major components (in one version) are seen in Figures 16, 17 and 18. The basic operation is that an outer tube (silver in the Figures) extends from the surface down to some depth. That depth can be down to the whipstock, but that is not required. A section of this outer tube or the full length, has a 'restrictor" (red interior line in the Figures) installed that prevents full rotation of the inner drill string (black in the Figure). The outer tube must be allowed to be rotated at the surface and downhole. This can be by swivels on both ends or by no attachments. The inner string has lobes (yellow in the Figures) which are free to the full Internal Diameter (ID) of the outer tube, but contact the 'restrictor' when rotated. These lobes are installed for the length of control that is desired. During operation, and only when the need to control the top-dead-center line of the inner string exists, the outer tube can be turned to apply torque and rotation to the inner string. This torque must be held until the section is finished. Based on bench tests this assembly can provide up to 125 ft-lbs of torque per foot.

Task 8- Bench Tests
Testing of the HPSP at Impact's shop was performed using the diesel driven FMC pump as the prime mover and a gamma ray densitometer to measure output density. Rock blocks and other targeted materials were used for targets of the extended testing. Testing of the Concentric Tubing Directional Control components were made to confirm a 125 foot-lbs torque per foot of length. This should be sufficient for twisting long lengths of tubing (especially coiled tubing) for aligning the cutting tip. The bent sub was bench tested for strength and for angle control.

Tasks 9- Combined Vertical Field Test (optional)
Time and budget gave out before this test could be performed.

Tasks 10- Combined Horizontal Extension Field Test (optional)
Time and budget gave out before this test could be performed.

Task 11- Reporting
A presentation was given to the University of Kansas- Lawrence's Tertiary Oil Recovery Projects (TORP) meeting in Wichita, Kansas on 5 April 2007. Another talk was given to the Rocky Mountain Oilfield Testing Center Open House meeting in Casper Wyoming on 20 August 2007. A presentation to the Oklahoma i2E group was made in Tulsa, OK on 17 September 2007. A presentation in Wichita, Kansas for the SWC was made on 30 October 2007. A booth was manned at the Oklahoma Marginal Well Commission's Trade Fair in Oklahoma City, OK on 16 October 2008. Quarterly progress reports were submitted as required.

CONCLUSIONS:

Progress on this project was delayed by a lack of qualified and available vendors. That problem was partially resolved by finding a part time pump designer. Once designed, the high pressure slurry piston pump (HPSP) was designed manufactured by Danco Pump and Supply. Testing of that pump at Impact's shop began in January 2008. New control valves had to be designed to replace unreliable commercially available ones. Modifications to the piston connector, originally a cable-sheave, were made to a linear gear setup. The pump frame and the inlet suction manifold were modified for FLASH ASJ systems and ease in operation and maintenance.

The downhole hydraulic Inverted Motor was modeled in four designs for prototyping by Parker-Hannifin, an international motor and pump manufacturer. One prototype version was designed and built by Parker. Further prototyping and testing was delayed until the work was transferred to another Parker division. That new division considered the market too small to pursue unless Impact committed to a large purchase. That work was dropped. An Inverted Swivel was designed and built for FLASH ASJ systems to replace the IM-hydraulic motor. The swivel does not need a downhole separator and, thus, work on that additional component was discontinued.

A new directional control methodology was designed, patent applied and built. It was then bench tested to provide sufficient torque for control of the ASJ cutting tip direction. A bent sub specifically designed for microhole drilling and abrasive slurry systems was designed, built and bench tested.

Overall, nothing stands in the way for ASJ drilling and FLASH ASJ drilling to make significant contributions to drilling in the oil and gas industry. It also has applications in several other industries including tunneling, trenchless drilling for utilities and pipelines, earth sourced heat pump installations, and many other applications.

This technology has been encompassed into and accepted for a DOE SBIR Phase I (completed) and II project. That project is to drill a 2000 foot well to install geophone sensors for CO_2 monitoring.

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BIBLIOGRAPHY: No additional given

APPENDICES: None

Figure 1 Water Coning Problem in Gas Reservoirs

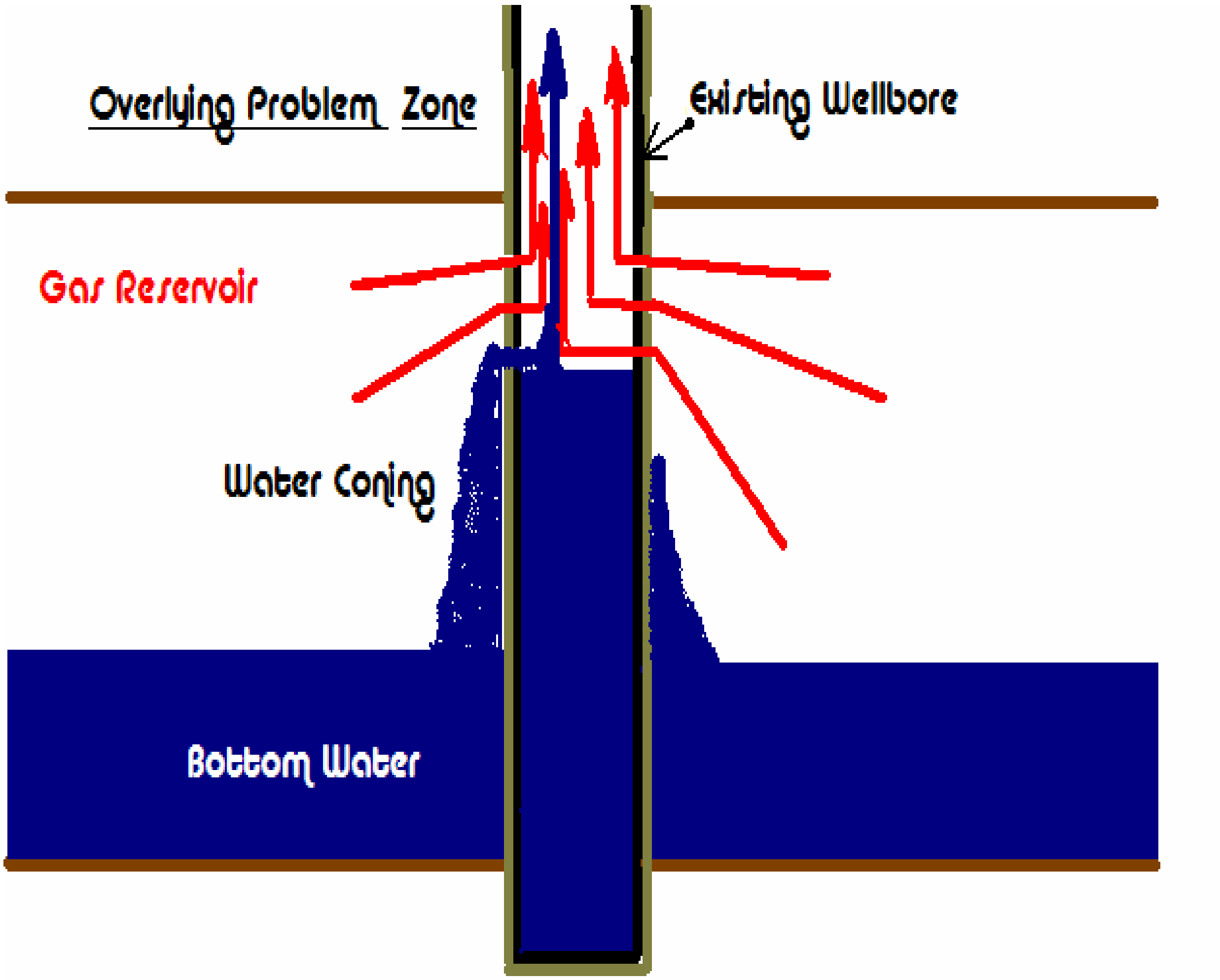

Figure 2 Horizontal Lateral Solution to Water Coning

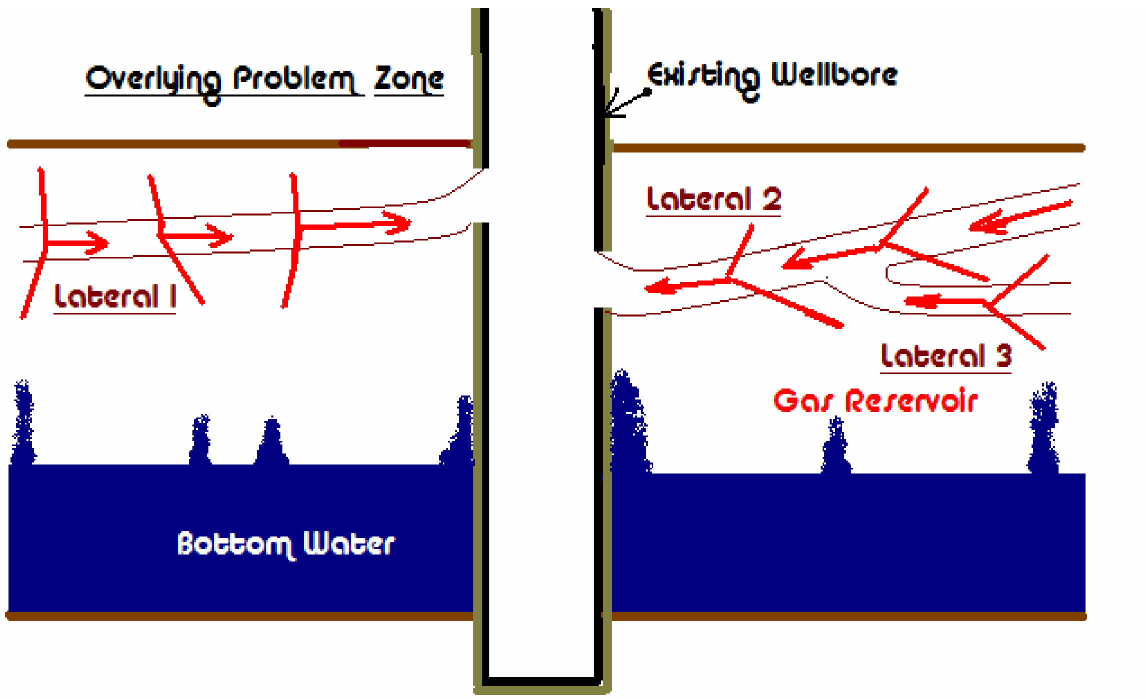

Figure 3 Current Industry Wellbore versus Microbore Sizes (after DOE)

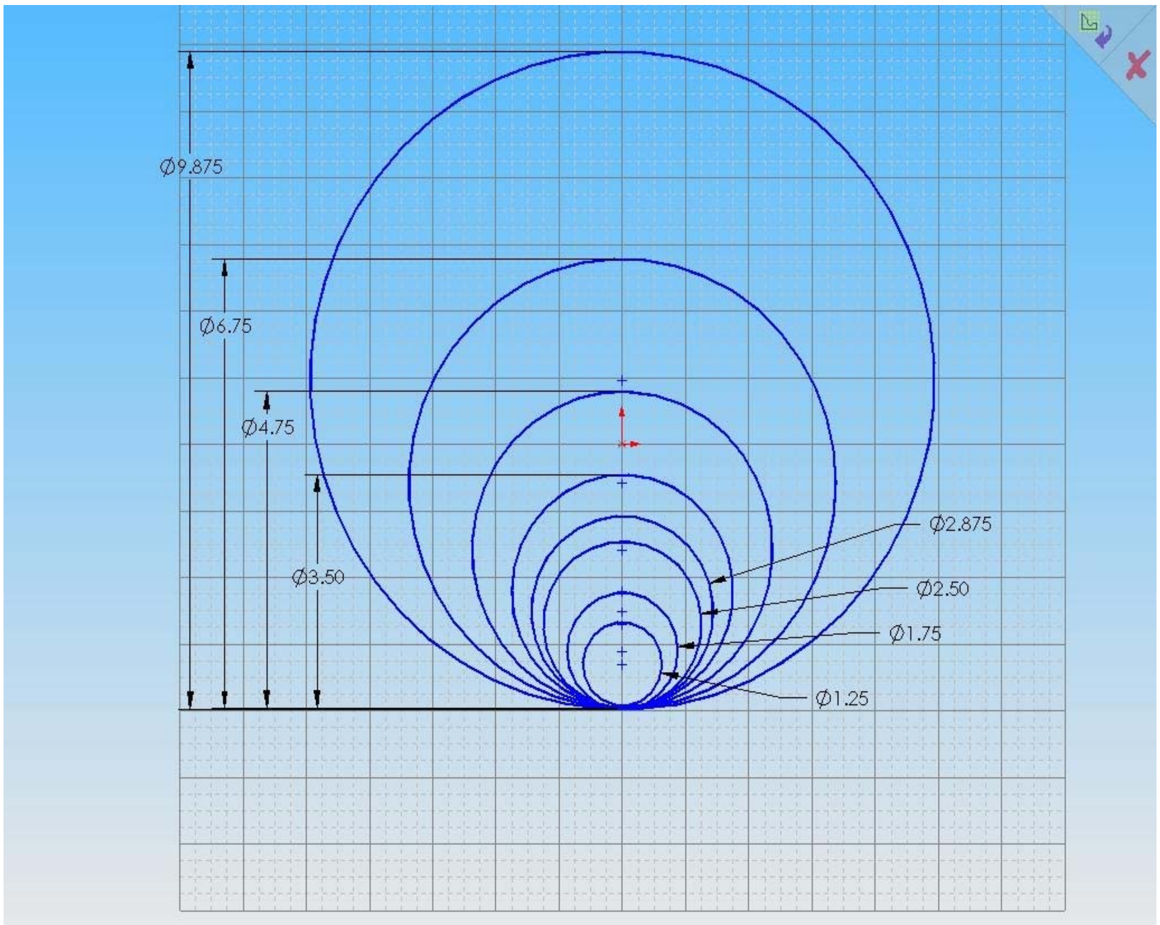

Figure 4   US DOE Microhole Rig at Los Alamos National Laboratory


WARNING
PINCH POINT
WARNING
PINCH POINT

Figure 5 Abrasive Slurry Jet Drilling Bench Tests

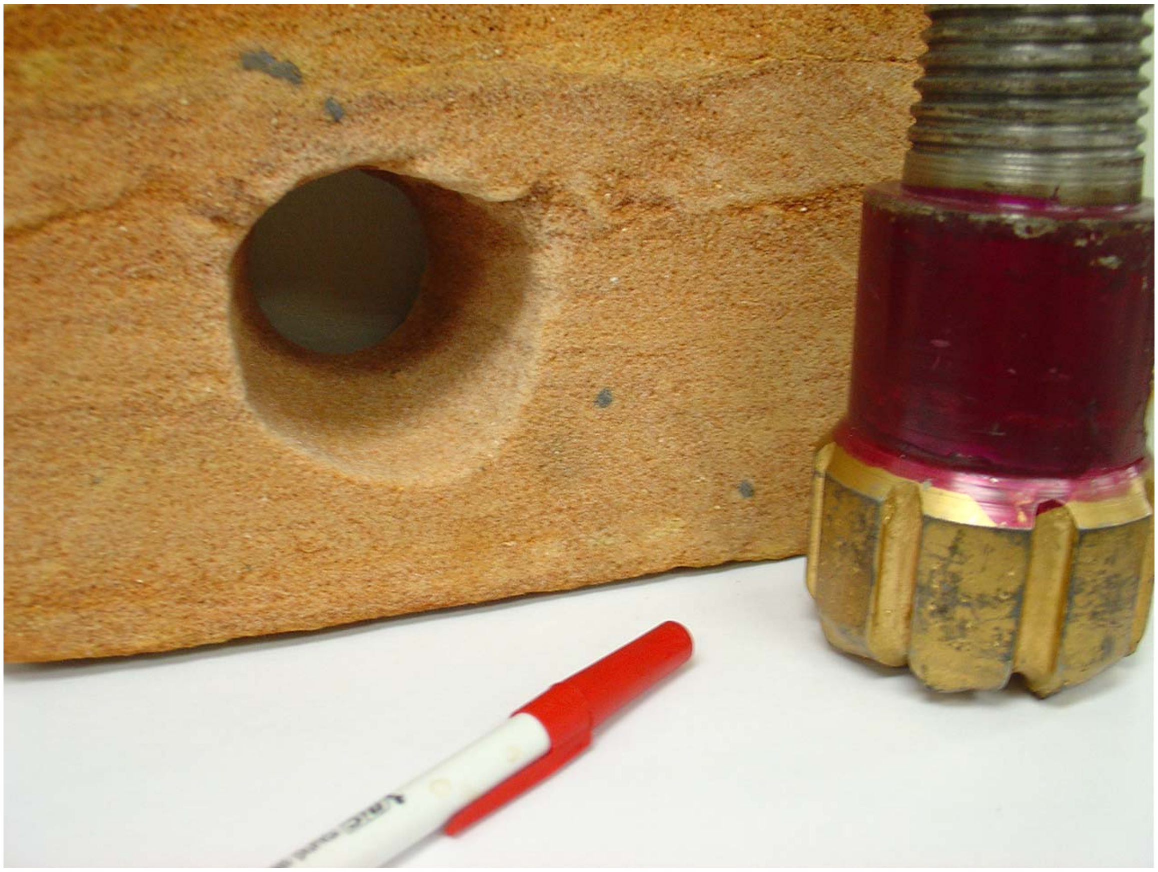

Figure 6 Proposed ASJ Drilling Rig

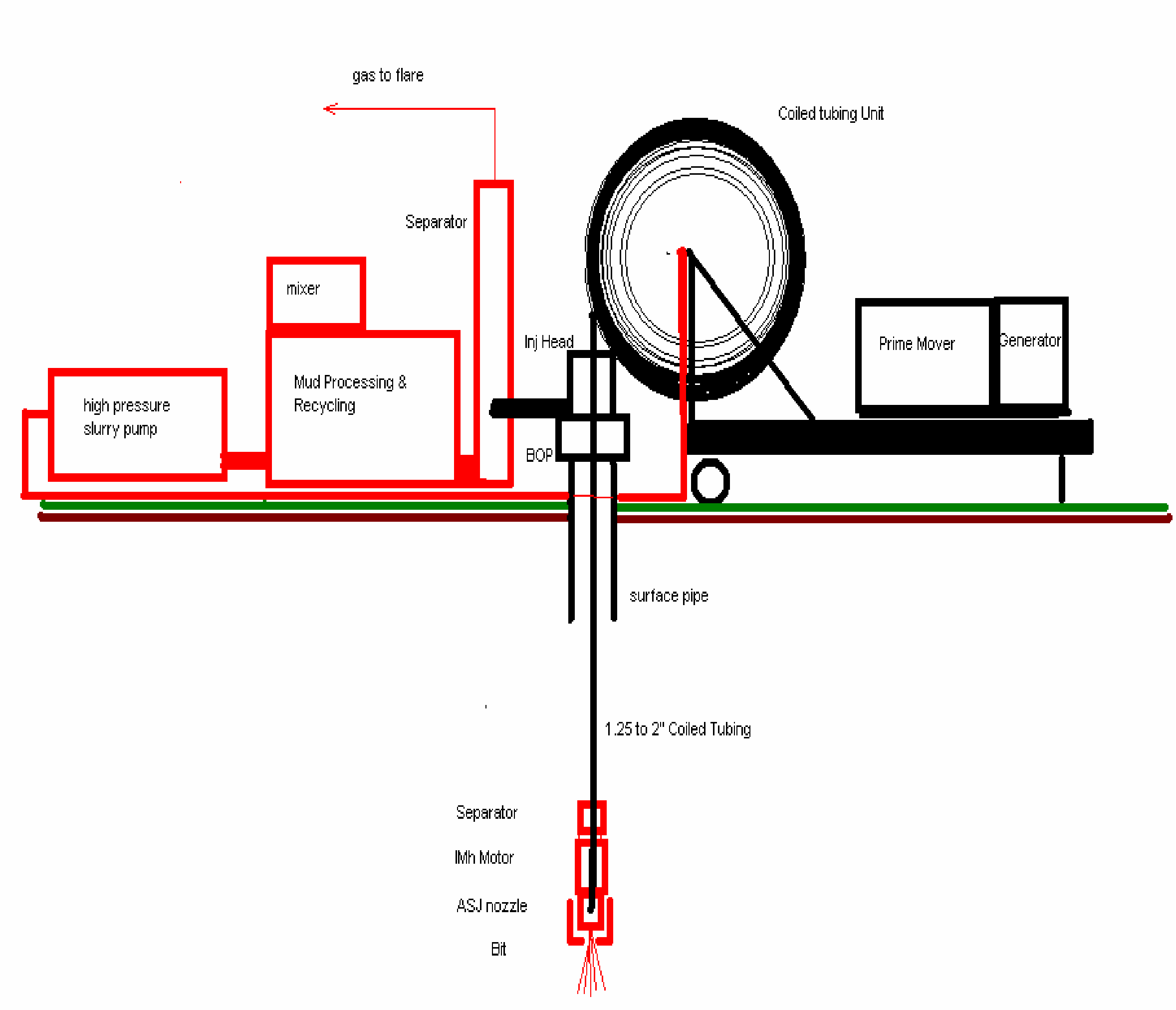

Figure 7   HPSP Hydraulic Piston Version under Test at Impact's shop.

Figure 8 HPSP Hydraulic Piston Version under Test at Impact's Test Facility

Figure 9   Impact Shop Test Facility for ASJ Drilling

Figure 10 HPSP Hydraulic Piston Version upgraded in Impact Shop

Figure 11 Second View of upgraded HPSP Hydraulic Piston Version

Figure 12   Downhole FLASH ASJ Swivel and Test Hex Nozzle Holder

Figure 13 Typical Whipstock Casing Exit Strategy

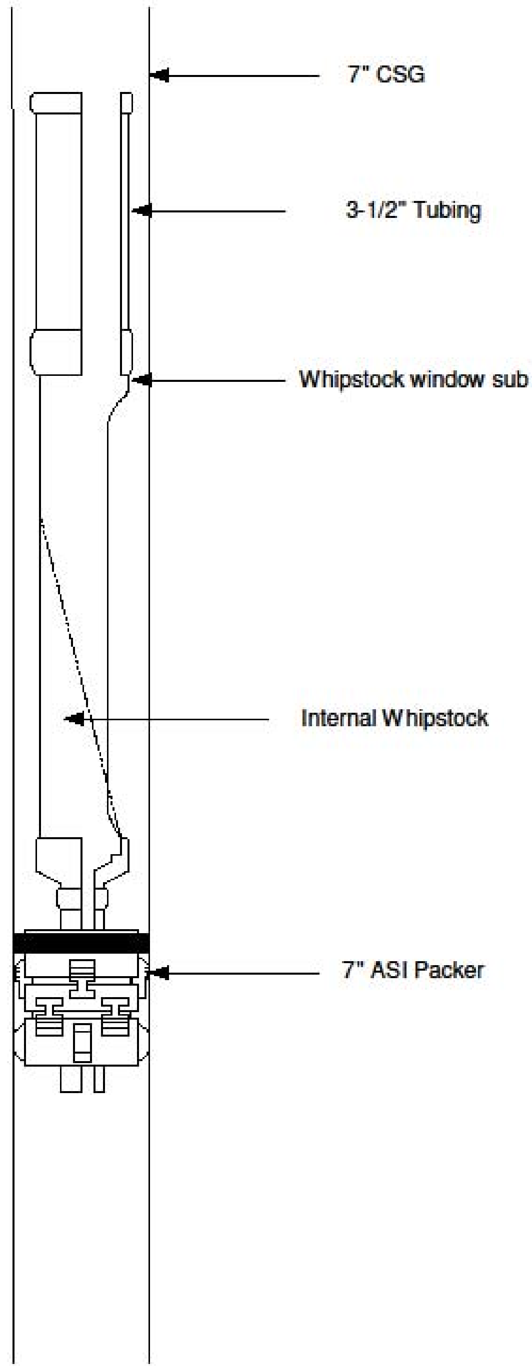

Figure 14   Standard Whipstock Assembly with Bent Sub & Cutting Tool

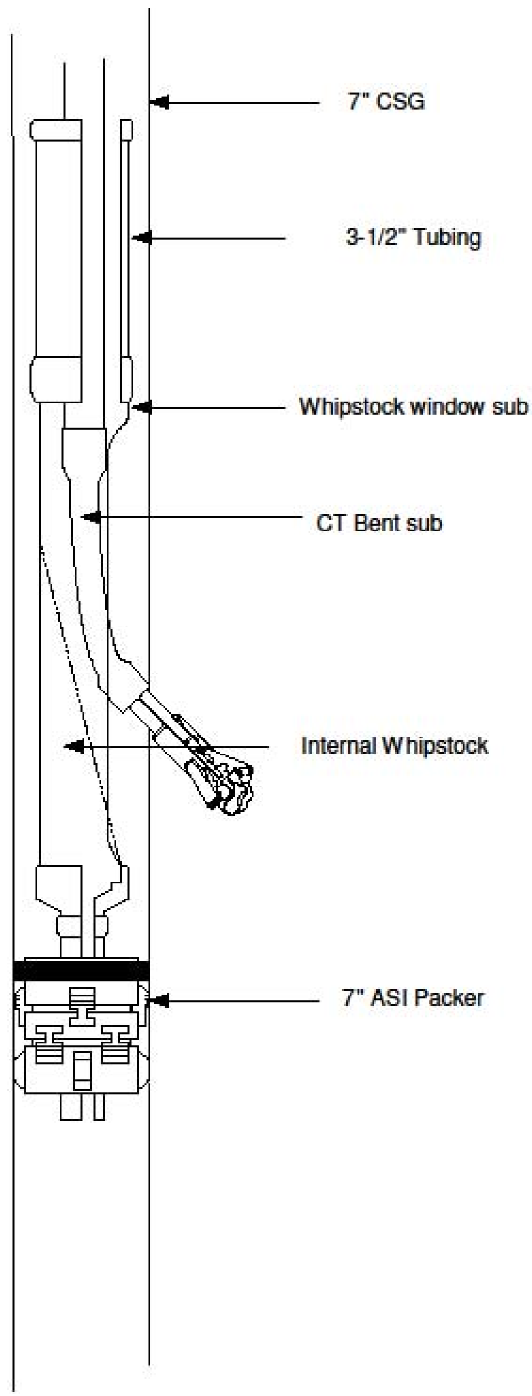

Figure 15 Bent Sub for Directional FLASH ASJ Drilling

Figure 16   Outer and Inner Concentric Tubing Directional Control Prototypes

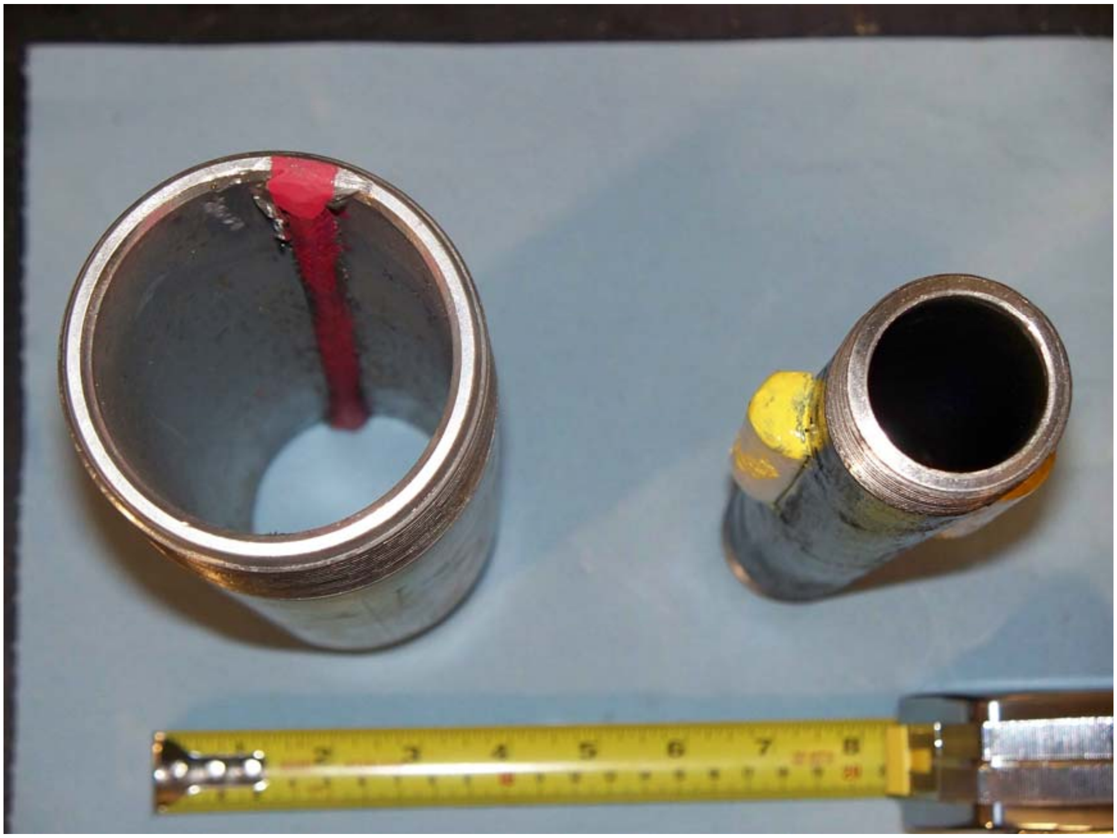

Figure 17 Top View of Combined Concentric Tubing Directional Control Prototype

Figure 18 Isochronal View of combined Concentric Tubing Directional Control Prototype

Figure 19   Related Equipment and Tools for CTD and FLASH ASJ Drilling