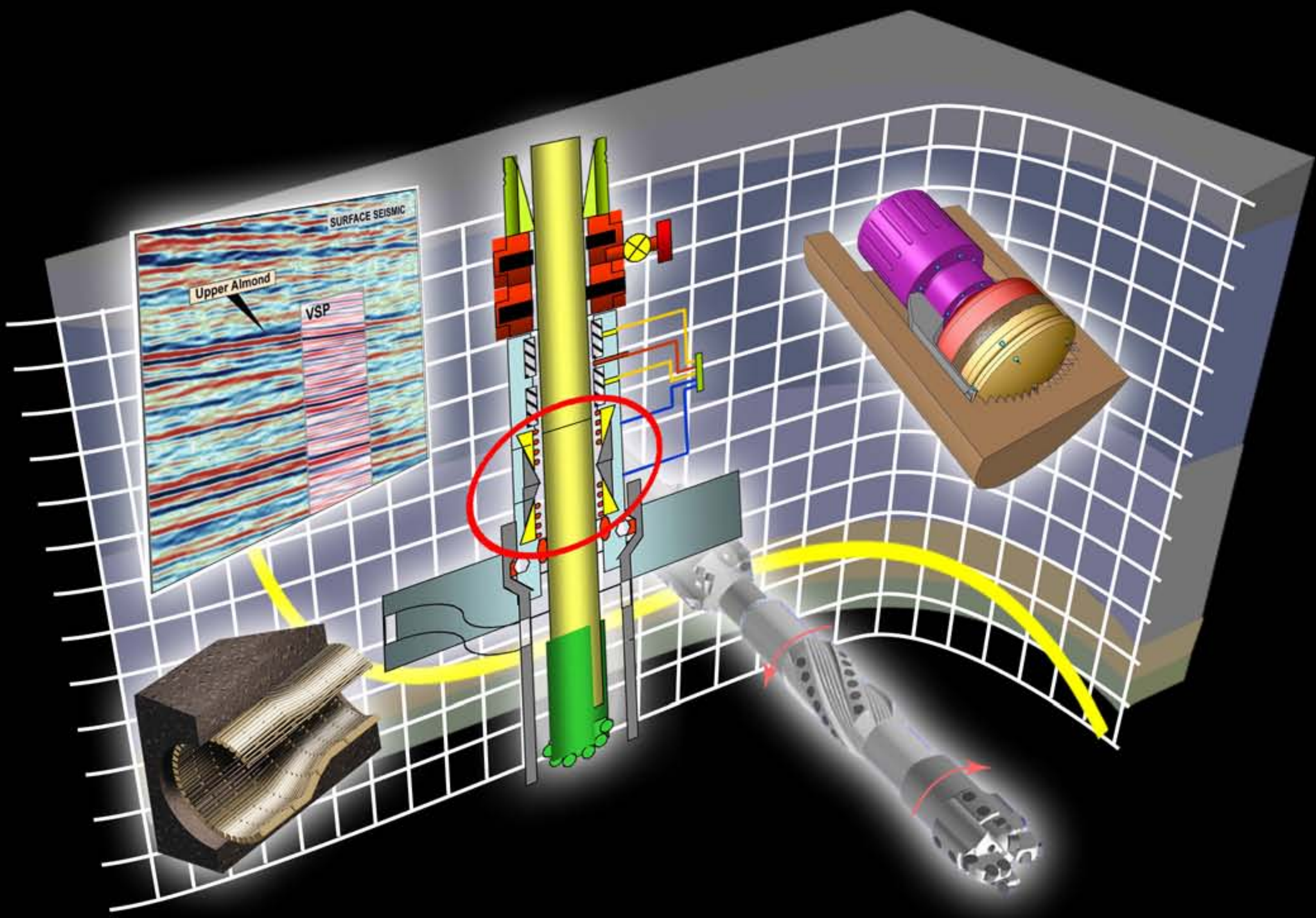
U.S. Department of Energy • Office of Fossil Energy
National Energy Technology Laboratory

Microhole Technology



a systems approach
to mature resource development

Microhole Technology

Background

An estimated 407 billion barrels of onshore discovered oil in the U.S. is non-recoverable with current drilling and production technologies. Of that total, 218 billion barrels can be found at the relatively shallow depths of 5,000 feet or less. Even at today's high oil prices, industry-sponsored research remains on the decline, and operators tend to use familiar technologies rather than risk failure with advanced technology. To bridge this technology gap, DOE partners with industry to develop and demonstrate new technologies to access domestic petroleum resources.

The Microhole Technology (MHT) Program is developing a promising suite of technologies that enable drilling of wells with casings less than 4½ inches in diameter using coiled tubing drill rigs that are relatively small and easily mobilized. These technologies have the potential to reduce the cost of drilling shallow- and moderate-depth holes for exploration, field development, and long-term subsurface monitoring.

Goal

The goal of DOE's MHT Program is to develop cost-effective technologies that enable:

- Development of shallow (<5,000 feet), currently uneconomic oil and gas resources.
- Acquisition of high-resolution, real-time reservoir imaging without interrupting production.
- Reduced environmental impact via lower volumes of drilling fluid, smaller operational footprint and pad/extended-reach drilling.

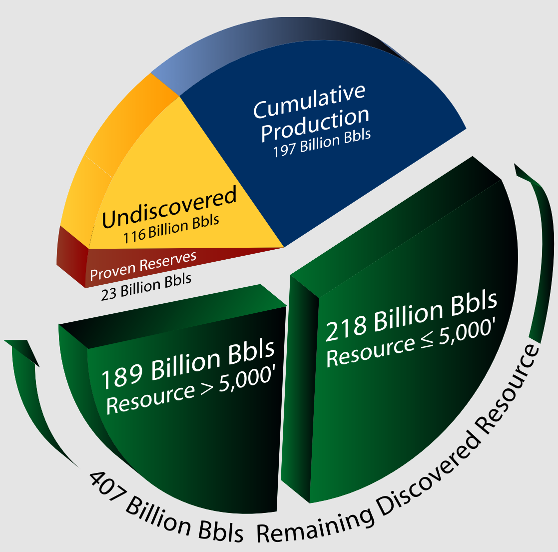
To accomplish these goals the near-term MHT program focuses on two areas of technology development:

- Field demonstrations where existing coiled tubing rigs are showing that economic resource recovery can result from wells with less than 4½-inch casing.
- Development of tools to drill, evaluate, complete, and produce from lateral microholes drilled out of 4½-inch casing.

A Systems Approach

The key to developing resources in mature, complex reservoirs is to recognize that a combination of interrelated technology systems working together toward this common objective will be required. The MHT program employs a systems approach in that it considers the larger picture and takes into account how factors such as technology, research, risk, and the business environment contribute to the overall success or failure of resource development. The systems solutions to resource development must address the following "resource development drivers":

- Reduced reservoir access cost (drilling, including mobilization) to allow more holes to be drilled to penetrate reservoir seals.
- Cost-effective, high-resolution imaging to locate bypassed oil and reservoir seals and allow better management of sweep efficiency in enhanced oil recovery processes.
- Increased drilling efficiency (expressed in more completed wells per week) that will require high-penetration-rate drilling assemblies.
- Smaller drilling footprints to minimize disruption of landowner activities, especially considering the larger number of wells required for access.



Domestic oil production, proven reserves, and discovered and undiscovered resource.

Source: EIA 2004, 2005; MMS 2006; USGS 2004.

The systems approach used to achieve the desired near-term results is best depicted in the MHT Program System diagram shown below. Technologies selected for the program were those that best satisfy the resource development drivers.

The technologies being developed in the MHT program that are in the R&D stage are listed in the blue box. The red box contains those systems that are market-ready. They are technologies that are recognized by operators or business units within major intergrated service companies as having short-term application. The hybrid coiled tubing (CT) drilling rig (shown in green) was used commercially immediately after completion, underscoring the need for the technology. This quickly established commerciality is expected to hasten market penetration for other technologies being developed in the program that support expanded use of hybrid CT rigs. The use of these technologies in combination with leading-edge, high-resolution seismic imaging technologies is expected to be very effective in furthering development of America's mature oilfields.

Applications

Near-term applications of the microhole technologies being developed in this program include drilling:

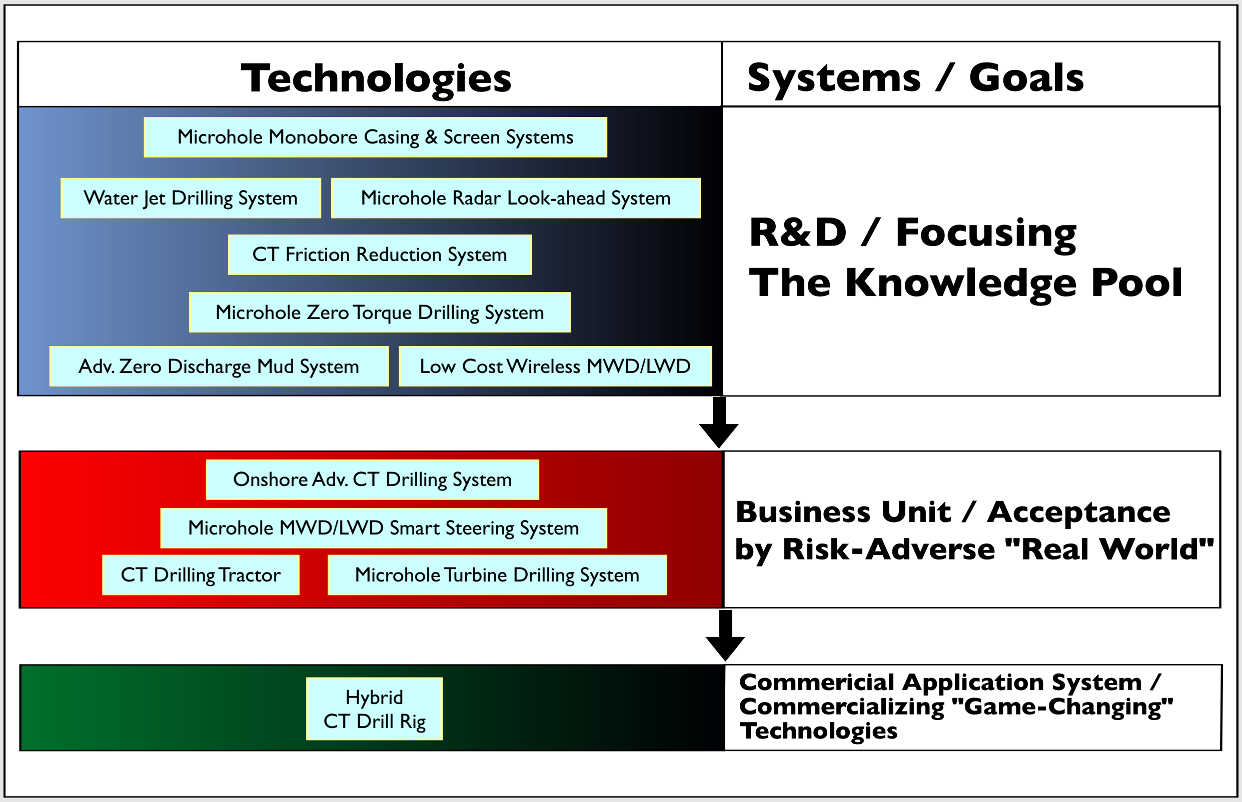
- Shallow development wells with one third the surface area and one third the number of equipment loads when compared with a rotary drilling rig.
- Shallow re-entry wells that allow drilling of multilaterals for economic access into compartmentalized reservoirs.
- Drilling deep exploration tails in existing wells that can cheaply extend the wellbore to evaluate and produce new zones.

Longer-term MHT applications include drilling dedicated wells for continuous reservoir monitoring to enable:

- High-resolution vertical seismic profiling, 4-D seismic imaging of reservoir fluid movement and bypassed oil.
- Low-impact, high-resolution imaging of targets beneath environmentally sensitive areas to allow development via pad/extended-reach drilling.
- Use of passive seismic imaging to take advantage of "free" seismic sources provided by naturally occurring seismic events to provide further resolution for improved reservoir modeling.

Benefits

The MHT Program's potential benefits to the Nation include lower drilling costs resulting from reduced materials, labor, and support equipment; reduced environmental impact from lower volumes of drilling waste, smaller footprints, and lighter equipment; lower exploration risk from low-cost exploration wells; and increased quality and quantity of high-resolution, dynamic, and continuous reservoir data.



Novel High-Speed Drilling Motor for Oil Exploration & Production

DE-FC26-04NT15501

Goal
The project goal is to design and develop a high-speed mud motor assembly, compatible with a coiled tubing drilling (CTD) system, to drill small-diameter holes for vertical, horizontal, and multilateral wells.

Performer
APS Technology Inc.
Cromwell, CT

Results
All of the subtasks of the first year's main task essentially have been completed, with the exception of the critical frequency analysis, which will continue in parallel with the laboratory testing. The manufacture of the laboratory prototype is somewhat ahead of schedule and will begin during Year 1 of the program.

Benefits
This project is intended to develop a high-speed, small-diameter drilling system, with a motor powered by drilling fluid flow and with the ability to support a CTD operation. The use of high-speed motor and bit combinations has the prospect of greatly increasing drilling rates and thereby reducing the costs of both exploration and development wells. The use of smaller-diameter bits and systems, and CTD equipment in conjunction with these systems, will further reduce drilling costs and enhance hydrocarbon recovery in environmentally sensitive and marginally economical areas.

Background
The area of high-speed drillbit development has progressed steadily. It is recognized that a suitable downhole motor will be necessary to fully develop the capabilities of these bits. High-speed drilling holds the potential to reduce drilling costs and produce a smaller environmental footprint. This project will pursue the development of a suitable downhole motor.

Summary
The principal objective of this project is to design and develop a high-speed mud motor assembly compatible with a CTD system, to drill small-diameter holes for vertical, horizontal, and multilateral wells. The drilling motor assembly must contain both a conventional mud motor and an efficient gearing system to produce drillbit speeds of 10,000 rpm and match the requirements of new drillbits now under development.

To accomplish this high-speed drilling, an efficient, reliable, gearing system must be coupled to a conventional mud motor. One advantage of this coupling approach is that by changing the gear ratio, the motor may be adapted to a variety of bits and drillbit requirements. It is anticipated these bits and motors will be initially employed for small-diameter coiled tubing-drilled wells.

Phase I calls for the overall system and key components design and modeling. These components include the motor power section, gearbox, flexible coupling, seals, and bearings. A vital consideration is the reduction of vibrations caused by possible imbalances at high rotation rates; an appropriate vibration damper is to be incorporated into the design. In Phase I, the equipment required to test the motor also is to be designed. Phase II calls for the motor and the test equipment to be built to test the motor in the laboratory. These tests are to be followed by testing at industrial test facilities or test wells.

Current Status (October 2005)
The project is proceeding at or ahead of schedule. APS researchers presented the company profile, related projects, current project goals, and project status to NETL in Tulsa, OK, on March 9, 2005.

Project Start / End: 10-1-04 / 9-30-06
DOE / Performer Cost: $799,081 / $199,770
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NETL – Paul West (paul.west@netl.doe.gov or 918-699-2035)
APS – Carl Perry (cperry@aps-tech.com or 860-613-4450)

Microhole Smart Steering and Logging-While-Drilling System

DE-FC26-03NT15473

Goal

The overall goal of this project is to provide a modular coiled tubing drilling (CTD) system that allows operators to produce existing U.S. oil reservoirs in a much more effective way than is possible today.

The objectives of this project are to design and build 1) a smart drillbit steering motor integrated with a high-performance downhole motor and 2) a logging-while-drilling (LWD) formation resistivity evaluation sensor that provides real-time information about the rock being drilled. The tools will be designed for deployment in ultra-small diameter wellbores.

Performer

Baker Hughes INTEQ
Houston, TX

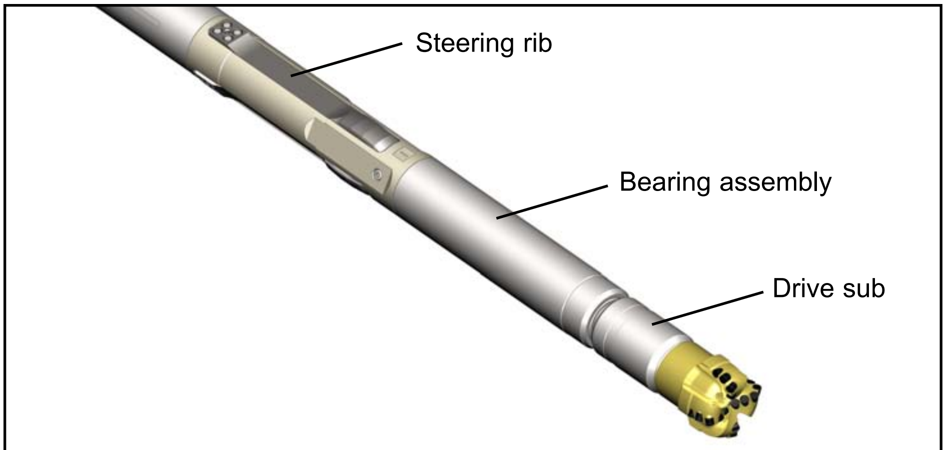
Results

Project accomplishments include the development and evaluation of a number of rib steering motor (RSM) design concepts, and the selection and approval of a final design. This design is now undergoing final manufacture, and assembly of the first of two prototype tools is underway prior to expected field testing in the first quarter of 2006.

Project accomplishments for the magnetic propagation resistivity (MPR) tool include the development of test bench devices and software modeling, which indicate that a resistivity tool employing both 400-KHz and 2-MHz frequencies can be deployed in a 2⅜-inch design. A mechanical design was realized over a couple of iterations, and two prototype tools are currently in manufacturing. It is expected that the tool will meet all project goals.

Benefits

The advanced drilling, steering, and logging bottomhole assembly (BHA) is expected to enable faster drilling, increased well-path accuracy, improved hole quality, and longer horizontal sections. The improvements in drilling and LWD will lead to increased production while decreasing the number of wells.



Schematic of the 2⅜-inch rib steering motor being developed in this project.

Lower costs and reduced environmental risks of drilling smaller holes with smaller-footprint rigs and minimal drilling fluid volumes make the technology ideal for producing remaining oil in shallow, mature U.S. reservoirs. Step-out wells, lateral deep perforations, and well deepening all can improve recovery of domestic resources.

If this technology is developed and deployed, as many as 5,000 new or re-entered wells per year are possible.

Background

State-of-the-art BHAs for CTD of 3½-inch diameter (microhole) horizontal wells tend to drill holes that are not smooth and straight. The lack of straightness leads to higher friction when sliding the coil, which limits the maximum horizontal extension that can be drilled with coiled tubing equipment.

Also absent in the currently available CTD BHAs for microholes is a suitable LWD tool. In order to keep the well within the target zone and above the oil-water contact, resistivity measurements taken during the drilling process are needed to provide instantaneous information about the distance to the water boundary. This allows the well to be drilled for maximum recovery and minimum risk of water invasion. Furthermore, such formation evaluation sensors will be able to detect trapped hydrocarbons along the well path.

Summary

A 2⅜-inch diameter RSM is being designed to serve a 3½-inch or smaller diameter hole. Modules are being designed so they fit seamlessly in the commercially available, modular 2⅜-inch CoilTrak™, a CTD assembly. Hydraulically powered moveable ribs on the steering motor generate steering forces in every direction, allowing both smooth curves and straight borehole sections to be drilled.

An MPR tool is being developed for microholes that will allow true real-time geosteering with instantaneous steering actions based on resistivity (and gamma) measurements.

Current Status (January 2006)

Both components of the project, the RSM prototype and the MPR prototype, have been designed, have passed design reviews, and are currently in manufacturing and assembly. Once assembled, the prototypes will be extensively lab-tested prior to field trails. A special short-radius, 3-inch, bi-center PDC bit has been designed by Hughes Christensen for initial field trials, which are expected to occur March 2006.

Project Start / End: 10-1-04 / 3-31-06
DOE / Performer Cost: $738,667 / $183,417
Contact Information:
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Baker Hughes INTEQ – John Macpherson (john.macpherson@inteq.com or 713-625-6558)

Microhole Wireless Steering-While-Drilling System

DE-FC26-05NT15488

Goal

The project goal is to provide a smart steering tool for a modular and economic coiled tubing drilling (CTD) system that allows domestic operators to produce more oil from existing reservoirs. This will be achieved by providing accurate and precise real-time geosteering even under conditions where the rig surface gear and equipment need to be minimized for cost-effectiveness. The following objectives support this goal:

- Develop a 2⅜-inch diameter bi-directional power and communications module (BCPM) as a part of the modular CTD bottomhole assembly (BHA).
- Develop a fit-for-purpose surface control system that communicates with the BHA.

Performer

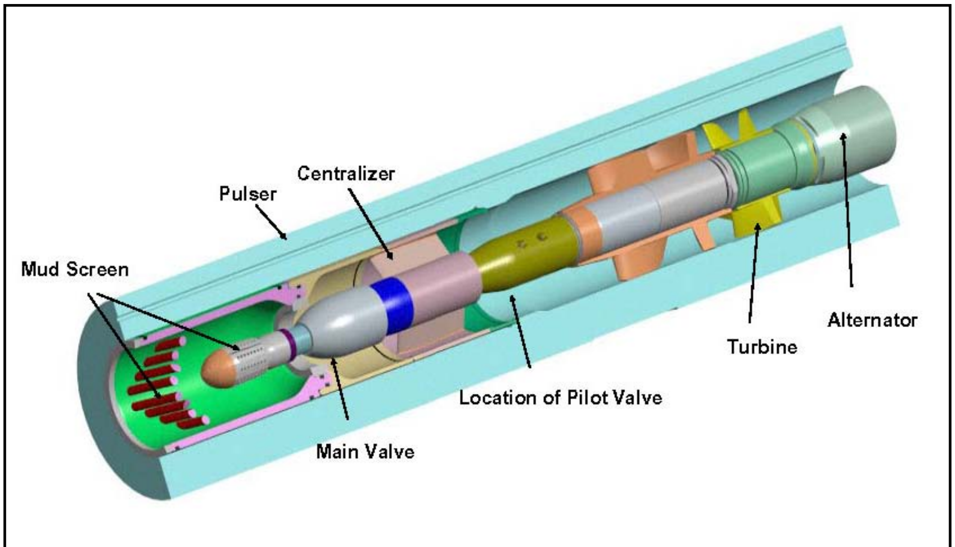
Baker Hughes INTEQ
Houston, TX

Results

A new, smart steering tool for a modular CTD system is the expected result. Progress has been made in the design of a BCPM that complements the existing modular CoilTrak™ drilling BHA. The system includes a fit-for-purpose surface control system.

Benefits

The new BCPM for the 2⅜-inch steerable CTD BHA will considerably reduce the capital expenditure needed to drill a "smart", yet relatively shallow, land well. The BCPM eliminates the need for a coil with an electric wire connection, thereby enabling the use of a smart drilling BHA in locations where an electric line is not affordable. The elimination of the electrically supplied coil saves the cost of one complete reel, which could reach about $100,000. In addition, with land rig day rates averaging $30,000 or more, considerable operational savings may be realized if a change in reels (between wired and non-wired) is avoided for special operations, such as cementing or window cutting.



Schematic of the bi-directional power and communications module MWD component. The surface control system communicates via mudpulse signals. The turbine/alternator provides power to other MWD components in the BHA.

Background

For drilling 3½-inch diameter development wells, CTD technology offers many benefits over rotary drilling. However, insufficient steering accuracy and low borehole quality are often experienced during CTD drilling. Electric wire is currently needed with coiled tubing strings to provide power to the steering tool and for downhole-to-surface communication; however, there are cases where a wired coil requires too much of an effort or expenditure.

This project builds on an existing wireless BCPM for a 6¾-inch tool that integrates an alternator-based electric power supply, an actuator to send information to the surface, and the capability to receive digital signals downhole.

Summary

Project tasks break down into two phases: the system design and the manufacturing and testing phase. The design phase consists of system concept evaluation, draft and detailed design of downhole components, and manufacturing decision.

The manufacturing and testing phase commences after a decision to proceed to manufacturing: This phase consists of manufacture of two prototype 2⅜-inch BCPMs and a surface control system, field testing of the prototypes, and evaluation of their performance.

Conceptual design reviews for the BCPM were held, and preliminary designs for the alternator and pulser currently are being developed. Components for a test setup are being designed and constructed to evaluate power requirements to generate sufficient pulse height with flow rates of 150-300 liters/minute. Long lead-time materials were placed on order.

Current Status (January 2006)

The project is in the preliminary design phase, and the design appears stable. Prototype components were machined and assembled for low-loop testing in January-February 2006, and the design will be re-evaluated based on those tests.

Project Start / End: 2-1-05 / 9-30-06
DOE / Performer Cost: $760,000 / $253,334
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Baker Hughes INTEQ – John Macpherson (john.macpherson@inteq.com or 713-625-6558)

Advanced Mud System for Microhole Coiled Tubing Drilling

DE-PS26-03NT15476

Goal

The overall objective of the project is to develop a mud system that is compatible with a coiled tubing drilling (CTD) system to drill microholes for vertical, horizontal, and multilateral drilling and completion applications. The system must be able to mix the required fluids, circulate that mixture downhole, clean and store the returned fluids, and perform these functions in an underbalanced condition with zero discharge and acceptable levels of environmental impact. A secondary objective is to design and test drilling with an abrasive slurry jet (ASJ) drilling system.

Performers

Bandera Petroleum Exploration LLC
Tulsa, OK

Impact Technologies LLC
Tulsa, OK

Results

The basic designs and concepts for the Advanced Mud System have been developed. The results include setting specifications for components of the system, including pumps to convey the drilling fluids downhole, a subsystem to process the returned well fluids, and a method to drill a hole in rock with an ASJ.

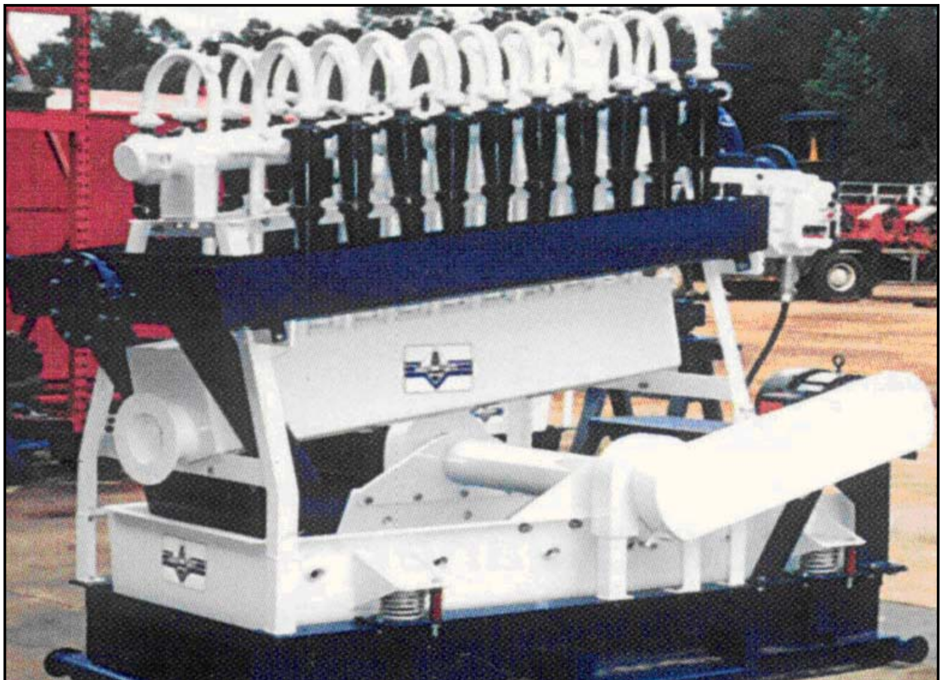
Benefits

Advances in technology that create more efficient development of hydrocarbon resources help the United States to become more energy self-sufficient, create activity and jobs in oil and gas basins, and generate royalty revenue.

More-efficient hydrocarbon development through microhole drilling can be measured in lower finding and production costs and in lower environmental impact when compared with existing conventional technology.

Background

Microhole drilling offers numerous advantages to develop reserves that are currently being bypassed. However, it also presents a new set of equipment and operational hurdles that will have to be solved before CTD systems can be commercialized.



A small-capacity mud processing system for microhole drilling.

One isolated piece of the puzzle is the mud system, which will have to be a departure from currently available and applied pumps and mud processing equipment used on conventional rigs. Proper sizing for a coiled tubing application is a key element for the mud system. The ability to drill holes in rock with abrasive-laden fluids has been of interest to the industry since the 1950s, but there have been equipment or technical limits that prevented its application. The concepts of microhole and coiled tubing drilling make abrasive jet drilling a promising adjunct, and the logical place to develop the ASJ is within the advanced mud system.

Summary

Project researchers have:

- Validated drilling synergies for microhole CTD. The requisite hydraulics, mud types, pump types, and mud processing equipment applicable to microhole CTD was confirmed through computer modeling and investigation of industry standards.
- Investigated ASJ drilling. After a literature review of previous work and consideration of microhole CTD parameters, a laboratory demonstration was able to cut a hole in rock larger than the nozzle diameter while continuously delivering abrasives to the downhole tools.
- Set pump specifications and identified available pumps. After defining true operating parameters for mud pumps in microhole CTD, specific manufacturer and models were identified for viable applications.
- Set mud processing parameters and identified mud processing equipment. Mud processing equipment was identified based on drilling fluids and flow rates applicable to microhole CTD and the resulting desired fluid properties.

Current Status (January 2006)

Budget Phase I has been completed, and a final report was submitted. DOE approval will allow the project to proceed to Budget Phase II, which will entail manufacturing or purchasing and testing prototypes of the designs and concepts from Budget Phase I.

Project Start / End: 8-2-04 / 2-1-07
DOE / Performer Cost: $473,600 / $118,400
Contact Information:
NETL – Jim Barnes (jim.barnes@netl.doe.gov or 918-699-2076)
Bandera Petroleum – Bruce Galbierz (bruce@banderapetroleum.com or 918-747-7771)

Advanced Monobore Concept CFEX Self-Expanding Tubular Technology

DE-FC26-05NT15483

Goal

The goals of this project are to prove technical, economic, and manufacturing concepts for innovative, self-expanding casing technology for monodiameter wells and to successfully deploy a small section of the casing in a demonstration well.

Performers

Confluent Filtration Systems
Houston, TX

AMET, Inc.
Rexburg, ID

Southwest Research Institute
San Antonio, TX

Results

Progress was made in the design of a more efficient, mechanically robust, and economically feasible self-expanding well casing system for use in both microhole and conventional drilling.

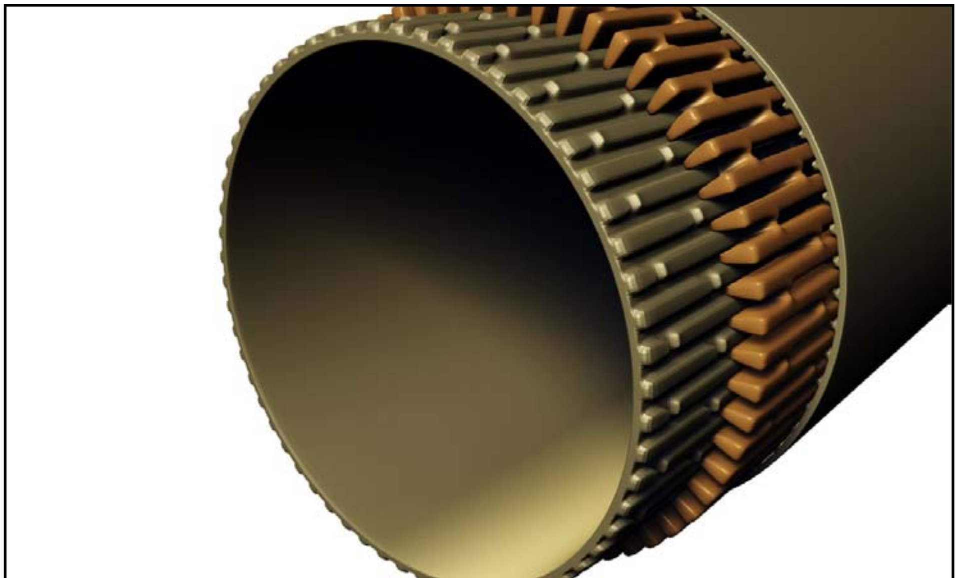
Benefits

The development of expandable casing for monobore wells promises to reduce drilling risks and improve economics throughout exploration and production. Self-expanding technology allows reduction of hole volume, increased inside-diameter production tubing, shortened field schedules, and minimized drillsite footprint. The technology is well-suited for drilling and casing microholes with tight annular spaces.

Background

Current expandable tubular technology relies on fluid pressure to plastically deform the tubular. A fundamental problem with deforming steel is that the process requires shrinkage along its other dimensions. Irregularities in tubular chemistry and wall-thickness—coupled with more-irregular borehole conditions, including excess bend severity, diameter restrictions, and non-concentricity—further reduce current tubular expansion reliability.

Current expandable tubular technology is not feasible for microhole coiled tubing drilling because the pressures required to expand the tubulars are too great.



Elastomer ridges in a self-expanding casing.

This project is developing an expandable casing that consists of pre-stressed cells that eliminate shrinkage and don't require pressure for deployment.

Summary

The expandable casing being developed in this project consists of volumetrically adjustable cells (honeycomb structures) that are compressed to reduce the outside diameter. The reduced size is held in place by temporary metallurgical bonds established between various interior "cell-spring" surfaces. Once inserted into the wellbore, those stabilizing bonds are removed by specific chemical or mechanical activity, and the casing recovers to near its original dimensions.

Tasks of the project include the following:

- Concept development, which includes the development of user definitions and performance measures, basic research of specifications, and detailed qualitative evaluation of prospective design concepts.
- Design optimization, which involves the use of computer analytical methods, design by analysis routines, finite-element analysis, and 3-D geometry export for computer-aided machining.
- Prototype construction, which will include construction of a variety of prototypes to be used in physical tests and field demonstrations.
- Physical testing, which entails conventional laboratory evaluation of mechanical performance against theoretical properties.
- Manufacturing study, which will include research, evaluation, and conceptual development of various methods of joining and forming materials
- Field demonstration, which calls for deployment of a prototype section in a test well.

Current Status (January 2006)

During late 2005, the best of several design concepts was selected for optimization and planned prototyping. The chosen design is capable of 200% expansion and indefinite pressure capacity. Interest in the new technology has been expressed by private investors and major companies with a view towards rejuvenating maturing fields. The next project milestone is completion of design optimization and detailed design phases, to be followed by prototype construction.

Project Start / End: 2-7-05 / 8-31-07
DOE / Performer Cost: $975,644 / $270,600
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Confluent Filtration – Jeffery Spray (jaspray@earthlink.net or 281-597-8784)

Self-Expanding Sandscreen Technology

DE-FC26-05NT15491

Goal

The goals of this project are to prove technical concepts for an innovative self-expanding sand-control screen technology, determine manufacturing systems and economics, and successfully deploy a small section of the screen in a demonstration well.

Performers

Confluent Filtration Systems
Houston, TX

AMET, Inc.
Rexburg, ID

Southwest Research Institute
San Antonio, TX

Stress Engineering Services
Houston, TX

Results

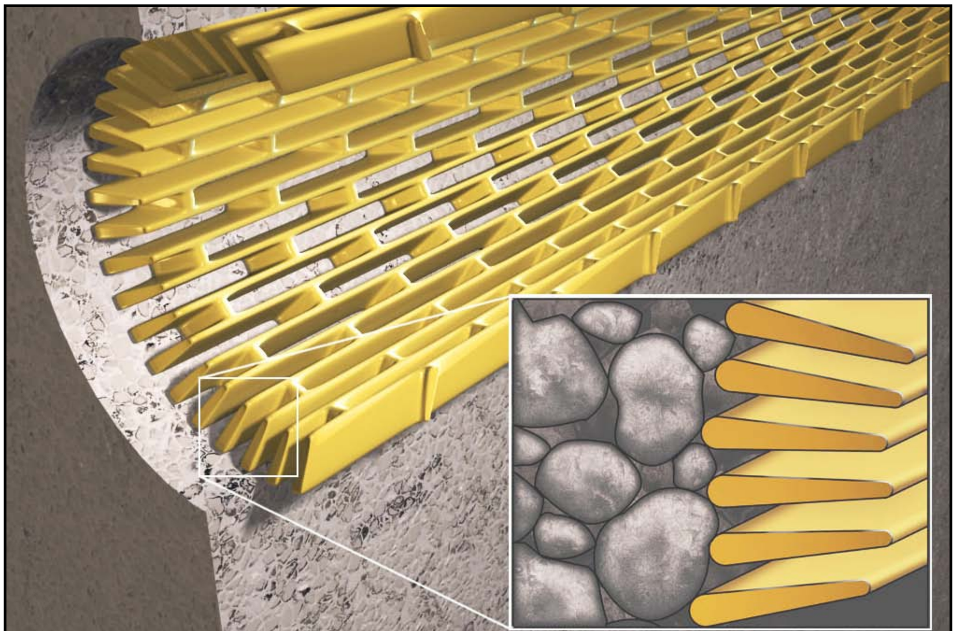
The project is expected to result in the development of self-expanding screens that are capable of <150 micron particle retention, have improved hydraulic efficiencies that will allow increased production, and will work well in the tight annular clearances of microholes. The technology is expected to solve the problems of high flow-rate erosion and pressure loss inherent in microhole producing clearances.

Benefits

Use of a high-flow, stand-alone sandscreen can result in faster well cleanup and reduced field time. Because the sandscreens are designed to be relatively plug-resistant, erosion-less and corrosion-less, fewer shutdowns and greater overall production should result from their use. The sandscreen is expected to weigh and cost one half that of conventional screens.

Background

Small-diameter wellbores pose a unique set of completion and production problems. The fluid velocities inherent in microholes accelerate sand movement, which tends to plug, erode, and corrode sandscreens. The use of gravel packs in microhole operations is constrained by the limited annular volumes. Placing screen tubulars in microholes may create difficulties in allowing passage of other completion equipment, including pumps, sleeves, packers, geophysical tools, etc.



An artist's cutaway rendering of a self-expanding sandscreen.

This project aims to develop a sandscreen technology that offers high flow rates and high hydraulic efficiencies, uses metal alloys resistant to erosion and corrosion, and is lighter and thinner-walled than conventional tubulars.

Summary

The sandscreen technology being developed in this project is a highly supported, grid-type construction of close-tolerance structural panels that have been designed for high hydraulic efficiency. The grid elements are flush about the inside diameter, allowing smooth surfaces for downhole operations. The elements are optimally recessed on the outside diameter, creating a greater open area toward the formation. The tubular strength results from the large numbers of flexible cell bodies, which like wire rope, acquires strength from numbers of components acting collectively. The project entails the following tasks:

- Design model development, which includes adaptation of industry specifications and modification according to self-expansion principles, optimization through computer analytical methods, finite element analysis, and 3-D geometry export for computer-aided machining.
- Prototype construction and physical testing, which entails laboratory evaluation of mechanical performance against theoretical properties.
- Field demonstration, which calls for deployment of a prototype section in a test well.

Current Status (January 2006)

Currently, modeling activities are being completed. The modeling work shows that the concept is capable of becoming the first expandable screen capable of service to all market requirements, with a particle retention as small as 25μ, or .002 inch. The project also is designing the tubulars to withstand collapse values in excess of 4,000 psi, or 2-14 times the current industry standard. The new sandscreen design also has expansion capability in excess of 150% and can produce in excess of 400-psi bias for sought-after compliant wellbore support.

Project Start / End: 2-7-05 / 8-31-07
DOE / Performer Cost: $254,596 / $64,400
Contact Information:
NETL – Paul West (paul.west@netl.doe.gov or 918-699-2035)
Confluent Filtration – Jeffery Spray (jaspray@earthlink.net or 281-597-8784)

Friction Reduction for Microhole Coiled Tubing Drilling

DE-FC26-05NT15485

Goal

The project will create a robust, economical microhole coiled tubing drilling (CTD) friction reduction system that will enable the drilling of wellbores with 3,000 feet or more of horizontal displacement in a 3½-inch wellbore without the use of any other downhole coiled tubing friction mitigation device.

Performer

CTES
Conroe, TX

Results

Selected Phase 1 accomplishments for this report period include the following:

- Researchers completed vibration test fixture fabrication and instrumentation.
- "Free-ended" vibration energy tests were performed over a continuous frequency range of 20-60 Hz for axial, torsional, lateral, and circular vibration modes.
- Test fixture results indicate that vibration energy transmission coefficients increase as vibration frequency is increased.
- Axial vibration modes provided for significantly better vibration energy transmission coefficients versus other modes. Notably, torsional vibrations yielded slightly better results than circular or lateral vibration.

Benefits

The primary benefits resulting from this project will include 1) drilling-cost reduction resulting from the use of less-expensive CTD for long, horizontal wellbores; and 2) the ability to develop additional hydrocarbon reserves in a more environmentally friendly manner due to the smaller footprint associated with a CTD rig.

Background

A key barrier hindering increased utilization of CTD for inclined/horizontal wells is the cost of overcoming downhole friction when attempting to drill long (>2,000 feet) horizontal sections. When drilling these long laterals, the downhole friction forces reach such high levels that the drilling operation is stopped prematurely, or a costly downhole drilling tractor must be used to help pull the coiled tubing at the bottom of the well in order to continue drilling.

The current approach to reducing downhole friction involves the application of downhole vibrators or drilling tractors. Both of these technical approaches have significant limitations. Vibrating pipe to mitigate friction is a proven technology for conventional "jointed" drillpipe operations. However, CTD surface equipment is significantly different from that of a conventional drilling rig. This difference limits the ability to apply some of the existing types of vibration.

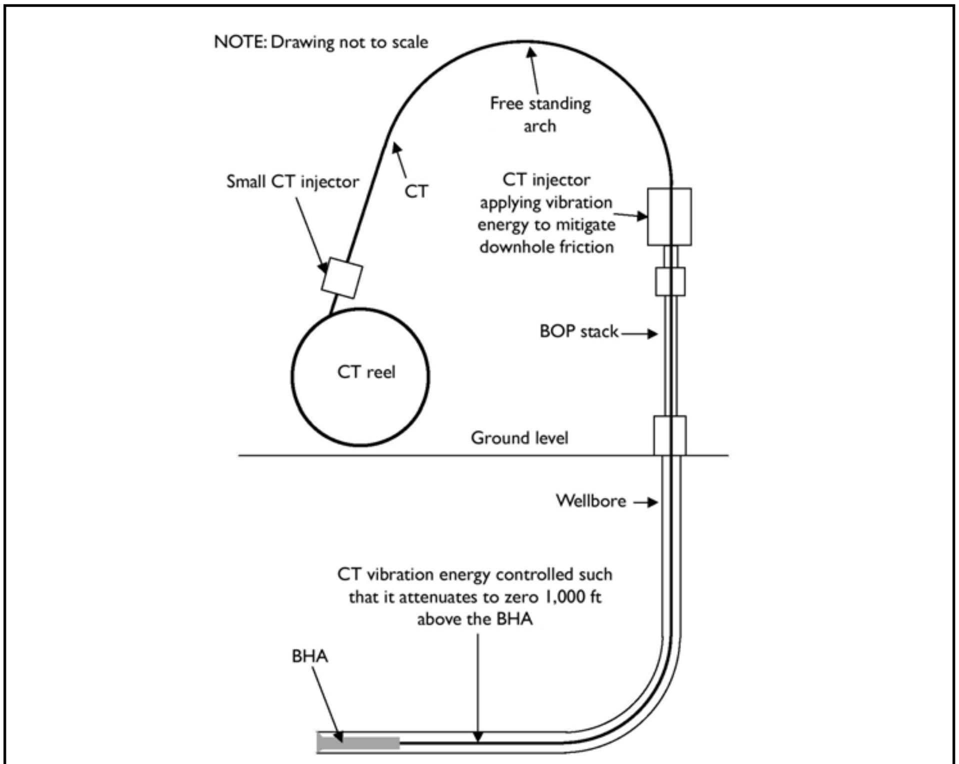
Summary

The project consists of two 12-month phases, with a Go/No Go decision point at the conclusion of the initial phase. Phase 1 work contains four major tasks, including development of a software model to predict downhole vibration attenuation versus depth, engineering and construction of a vibration test fixture, testing and validation of the vibration attenuation model in the vibration test fixture, and conceptual design and optimization of a full-scale friction-reduction system.

Phase 2 work also encompasses four tasks, including finalizing design of the friction-reduction surface equipment, fabricating surface equipment, component-testing surface equipment, and field-testing the complete friction-reduction system.

Current Status (January 2006)

The project is on schedule to complete all Phase 1 tasks by early second quarter 2006. Testing in the vibration test fixture is ongoing. These data will be used for software model validation. Vibration test fixture results also will be used to identify the optimum vibration mode to be used in the conceptual design of a friction-reduction system that could be utilized in the field.



Microhole coiled tubing drilling friction reduction system for horizontal wellbores.

Project Start / End: 4-1-05 / 3-31-07
DOE / Performer Cost: $756,570 / $189,140
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Field Demonstration of Existing Microhole Coiled Tubing Rig

DE-PS26-04NT15482

Goal

The project goal is to field-test a state-of-the-art microhole coiled tubing drilling (CTD) rig and to conduct technology-transfer efforts to generate interest in and gain acceptance of the technology. Utilization of this technology will enable development of marginal oil and gas wells while minimizing environmental impact.

Performers

Gas Technology Institute
Des Plaines, IL

Rosewood Resources
Dallas, TX

Results

This project has demonstrated the advantages of microhole and CT drilling and documented the advantages and economic benefits when compared with conventional drilling. Dissemination of these results through publications and presentations will facilitate expanded use of this technique.

Twenty-three gas wells have been drilled and completed in the mature play of the Niobrara formation of western Kansas and eastern Colorado. A total 40,000 feet of 4¾-inch hole was drilled, ranging in depth per well from 1,500 feet to 3,100 feet. Each of the wells was monitored for rig performance, including rate of penetration, time for rig mobilization, and other parameters.

The small size of the rig resulted in several environmental advantages, including small drilling pads of 1/10th acre and the absence of mud pits where tanks were used to store and move drilling fluids.

The performance of the drilling rig has continuously improved throughout the project. Initially, 1,500-foot Niobrara wells were drilled in one day. Currently, 3,000-foot Niobrara wells are being drilled in 19 hours, including move-in, rig-up, drilling, logging, setting casing, cementing, and rig-down move-out. Rate of penetration (ROP) was as high as 500 feet/hour, with an average ROP per well of 400 feet/hour. The wells drilled resulted in a gauge hole with little hole deviation.

This coiled tubing drilling rig has drilled over 40,000 feet of 4¾-inch borehole. The project garnered nominations as a finalist in the 2005 World Oil Awards and for Operator of the Year by the Colorado Oil and Gas Commission in 2005.

The overall rig performance has led to a new approach for marginal gas fields. Wells that encounter thin pay with gas-water contacts near the perforated interval are being designed for production without hydraulically fracturing. This approach, if proven successful, will allow production of previously non-producible gas reserves.

Benefits

Based on Coiled Tubing Solutions' (CTS) drilling experience with CT rigs in Kansas, Montana, Texas, and Canada, microhole technology can cut the drilling cost of wells by up to 38%. The reduced cost translates to $55,000 cost savings per 1,200-foot well. The CTS rig design provides technical advances over existing drilling systems in seven areas: reduced drilling cost, low mobilization/demobilization times, improved pipe-handling, increased safety, measurement-while-drilling, reduced environmental impact, and increased wellbore transmissivity.

Background

Currently, about 800 wells are drilled per year using coiled tubing in the United States, with the potential for a much larger number if CTD becomes a proven tool. In addition, the cost savings and rig design with CTD are likely to facilitate additional production through the development of resources that are uneconomic at current drilling costs. The most significant economic impact will be the additional oil and gas resources that will be made available to U.S. consumers.

Summary

In this project, a next-generation microhole CTD rig is being field-tested. The rig being used is the MOXIE experimental rig fabricated by ATD/CTS specifically for microhole CTD to depths as great as 5,000 feet.

Sites in Kansas and Colorado that have known gas resources at 1,200-3,500 feet in depth are being drilled and cased with the microhole CTD rig. The rig is being evaluated in six areas: mobilization and rig-up time, drilling surface and production holes, running surface casing and cementing, logging and evaluation, running production casing and cementing, and rigging down and moving the equipment from the drillsite. Measurements are being made of time, equipment weight, penetration rates, rpm, torque, drag, pumping pressures, mud properties, solids control, and other measures of rig performance.

During the early field testing and monitoring of the microhole CT rig, the percentage of time for each operation was calculated. Operations considered included rig-up time, 9%; pick-up of bottomhole assembly (BHA), 9%; drilling, 26%; lay-down of the BHA, 9%; logging, 17%; and casing/cementing, 30%. The relatively low drilling time illustrates the advantage of using CTD where the drillpipe connection is eliminated when compared with conventional drilling. The average rate of penetration for the initial eight wells drilled was 204 feet per hour.

Current Status (January 2006)

All of the field work has been completed. Twenty-three project wells were monitored in the field with over 40,000 feet of 4¾-inch hole drilled. The project contract required only three wells and 1,000 feet of 4¾-inch hole be drilled.

Project Start / End: 2-7-05 / 2-6-06
DOE / Performer Cost: $999,794 / $1,000,000
Contact Information:
NETL – Jim Barnes (jim.barnes@netl.doe.gov or 918-699-2076)
Gas Technology Institute – Kent Perry (kent.perry@gastechnology.org or 847-768-0961)

Counter-Rotating Tandem Motor Drilling System

DE-FC26-05NT15489

Goal

The project objective is to increase the supply of natural gas available to the United States with minimal environmental impact by decreasing the cost and footprint of drilling operations for slim holes (3½ inches) at relatively shallow depths. The technology is specifically directed toward gas reserves in unconventional or low-permeability formations in which a large number of wells are necessary to effectively drain the reservoir. In such cases, economic development requires these wells to be drilled at a lower cost and with less environmental impact than current technology allows.

The project goal is to develop a novel coiled tubing drilling (CTD) system, specifically designed to drill at high rates of penetration (ROP) with low weight on bit and low reactive torque. The Counter-Rotating Tandem Motor Drilling System (CRTMDS) will aid in achieving higher ROP with a coiled tubing system.

Performers

Gas Technology Institute
Des Plaines, IL

Dennis Tool Company
Houston, TX

Results

Manufacturing has begun following development and evaluation of a detailed design for a CRTMDS. After evaluation of the design, the decision was made to proceed with the fabrication and testing of a prototype system. The prototype system is undergoing an extensive testing program to evaluate its performance and reliability vs. conventional CTD systems. By the end of the program, a system suitable for use in commercial gas wells is expected to be available.

A similar tool design was tested for Los Alamos National Laboratory (LANL) in September 2005 at the Rocky Mountain Oilfield Testing Center near Casper, WY. The smaller, 2.625-inch tool averaged 82 feet/hour drilling 130 feet in 1.6 hours. Conventional 2.625-inch PDC bits average 10-30 feet/hour.

Reamer, flow diverter and bit for CRTMDS tool.

The LANL test proved the design elements of higher ROP using low weight on bit (WOB)—about 700 pounds—and low reactive torque.

Design changes to the CRTMDS tool based on the LANL test have been made to maintain the diameter ratio of pilot bit to reamer. A resulting increase in pilot bit size from 2.25 to 2.75 inches allows for the use of a larger, 2.875-inch, right-hand positive-displacement motor (PDM) and a 2.125-inch, left-hand PDM.

Benefits

Drilling costs will be lowered through the development of an improved drilling system suitable for CTD operations. Current CTD systems are able to drill at relatively low cost and with improved environmental characteristics as compared with conventional drilling rigs. However, CTD would have a much greater impact on oil and gas development if the rate of penetration could be increased by 25-60%, while decreasing the drilling cost by up to 40%.

Background

Overall drilling costs can be lowered by drilling a well as quickly as possible. For this reason, a high ROP is desired. In general, high ROP can be achieved by increasing the WOB, the amount of torque on the bit, and the rotary speed of the bit. Two important limitations commonly associated with coiled tubing systems are the inability to apply high WOB to the bottomhole assembly and the torque-handling capacity of the coiled tubing. These two limitations work against the goal of high ROP.

Summary

The CRTMDS developed in this project will combine a counter-rotating pilot bit and reamer to drill with low WOB and reduce reactive torque transmitted to the coiled tubing. The system uses a small-diameter, left-hand polycrystalline diamond compact (PDC) pilot bit driven by a left-hand turning PDM to drill a small pilot hole. A 3½-inch PDC reamer with an integrated stabilizer is run in tandem with and powered by a right-hand turning PDM. The bit contains premium PDC cutting inserts manufactured with advanced microwave-sintered carbide substrates.

The proposed project is divided into six tasks:

- Conceptual design.
- Final design.
- Prototype fabrication.
- Bit testing and evaluation.
- Tool modification.
- Technology transfer.

Current Status (January 2006)

Final designs have been completed and manufacturing begun on the pilot bit, stabilizer, reamer, and left-hand PDM. First tests of the tool were expected in February 2006 at the GTI Catoosa Test Facility near Tulsa, OK.

Project Start / End: 2-1-05 / 1-31-07
DOE / Performer Cost: $654,953 / $163,743
Contact Information:
NETL – Jim Barnes (jim.barnes@netl.doe.gov or 918-699-2076)
Gas Technology Institute – Kent Perry (kent.perry@gastechnology.org or 847-768-0961)

Advanced Ultra-High-Speed Motor for Drilling

DE-FC26-04NT15502

Goal

The project goal is to design ultra-high-speed (10,000 rpm) electric inverted configured motors in two sizes for drilling the earth and man-made materials.

Performers

Impact Technologies LLC
Tulsa, OK

University of Texas-Arlington
Arlington, TX

Results

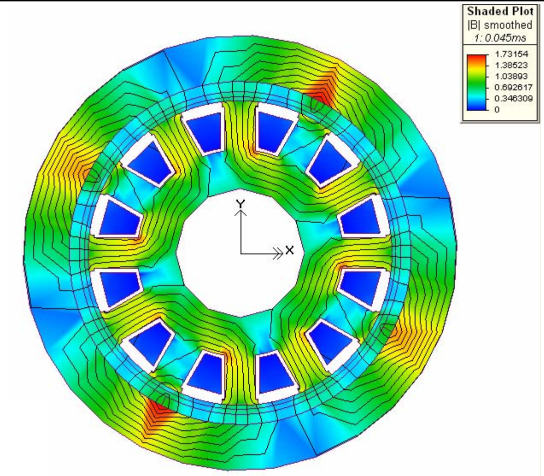
Researchers have developed electromagnetic designs for radial and axial motors in 2 outer diameters (OD) for speeds up to 10,000 rpm. Magnetic saturation and power/torque estimations have been made at various speed and loading conditions. Bearing and seal materials have been studied, but their final design must wait until the electromagnetic motor design has been finalized.

The project completed:

- Review and analysis of ultra-high-speed cutters and bits.
- Selection of motor diameters and torque/horsepower requirements.
- Electric-magnetic radial motor design of 1.69-inch OD for microbore drilling.
- Electric-magnetic radial motor design of 3.0-inch OD for slimhole drilling.
- Electric-magnetic axial motor design of 1.69-inch OD for microbore drilling.
- Initial review of materials for ultra-high-speed bearings (configuration dependent upon final motor design selected).

Benefits

A new motor and drilling process combination will benefit oil and gas exploration and production by finding new reserves as a result of lower finding costs and increased production from existing wells with horizontal drilling applications. The drilling method is applicable to extremely hard or deep reservoirs that are difficult to drill with current technology. The gas storage industry can benefit from horizontal drilling in storage fields, which allows enhanced deliverability. Significant benefits are expected for the trenchless utility industries (telephone, fiber-optics, communications, water, etc.) and pipeline installations across roads and rivers.



Magnetic field distribution in a small, ultra-high-speed electric motor.

Background

Drilling boreholes at ultra-high speeds (>10,000 rpm) has been shown to penetrate faster than at lower speeds. Using abrasive and/or acidic fluids at high pressures also has been shown to increase drill rate. Employing an electric motor in the new "inverted" configuration allows the combination of these two mechanisms (ultra-high speed and high-pressure fluids) to be used for even faster and more-efficient drilling.

Summary

This project initially focused on drillbits that are to be used in ultra-high-speed drilling applications. This was important to determine the required load, torque, horsepower, and sizes. From this study, it was found that few cutter elements and bits can withstand the generated heat, abrasiveness, and shock of this environment, although current work in this area is encouraging.

Based on this work, the motor requirements were set as a first pass for the electromagnetic design. Two sizes planned for initial design were 1.69 inches and 3 inches OD, with the lengths variable and motor power sections stackable. The chief benefit of an "inverted motor" configuration vs. an electrical motor is that the internal high-pressure fluids are not in contact with the electrical components. The weaker permanent magnets are lined inside the outer rotating housing and thus are supported from the extreme centrifugal forces generated by such high speeds. The internal and external flows can efficiently cool the electrical/magnetic-induced heat load. Air gap clearances and magnetic-strength saturation are ongoing concerns.

Radial and axial designs for both OD sizes have been accomplished but not finalized. Both power control and power inverter boards have been designed. Manufacturers of bearings have been identified and contacted, but final design must await the completed final electrical-mechanical design. Ultra-high-speed seals will be selected last, based on the generated heat and pressure ranges required.

Current Status (January 2006)

Researchers are finalizing the electromagnetic design of the motor. The current focus is on electric-magnetic axial design of a 3-inch OD motor for slimhole drilling and on bearing materials and design. The next steps are to mate final electromagnetic-mechanical designs with appropriate bearings and seals, perform heat transfer analysis of final designs, and prepare final machine drawings for prototyping.

Project Start / End: 10-1-04 / 3-31-06
DOE / Performer Cost: $165,882 / $55,441
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NETL – Paul West (paul.west@netl.doe.gov or 918-699-2035)
Impact Technologies – Ken Oglesby (oakk@aol.com or 918-627-8035)

Advanced Sealed-Bearing Assembly for Positive Displacement Motors Used in Micro-Borehole Drilling

DE-FG02-05ER84206

Goal

The goal of this research project is the development of an advanced sealed-bearing assembly for positive displacement motors (PDMs) suitable for microhole drilling.

Performer

Kalsi Engineering, Inc.
Sugarland, TX

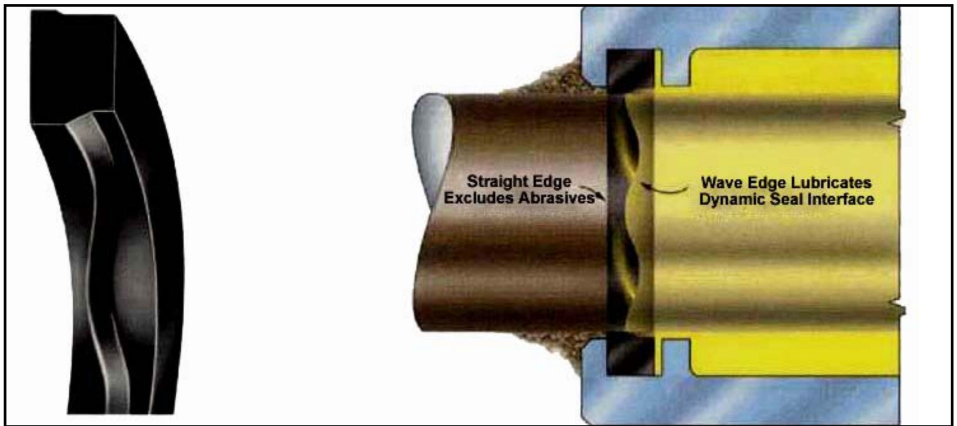
Results

Expected outcome of the project is the development of advanced hydrodynamic rotary seal and thrust bearing designs, as well as the sealed-bearing assembly, in an effort to meet the challenges posed by technical issues related to scaling down components for microhole drilling.

Field tests performed over the last two years with the newly developed, hydrodynamically lubricated, load-responsive, hydrodynamic thrust bearings in 4¾-inch PDMs used in coiled tubing drilling applications have demonstrated that they are very durable and are able to provide long life and reliable performance under the severe loads imposed by high vibrations without any damage, whereas the conventional rolling-element bearings had routinely experienced premature failures. The new bearing technology will be critical in these coiled tubing microdrilling applications, which are expected to impose higher levels of shock and vibrations.

Benefits

DOE has identified the development of PDMs as a critical technology need for its microhole drilling program. This research will lead to an advanced sealed-bearing assembly for PDMs that is very durable, has long life, and can perform reliably with low operating cost under the higher differential pressures required for efficiently drilling microholes. The advanced technology will be available as a modular, self-contained unit that readily mates with the power section of various PDMs being developed by industry. This intensive, parallel development effort will accelerate commercialization of the other critical technologies being developed for the microhole program.



Basic geometry and principle of operation of the hydrodynamic rotary seal.

This technology will be a key contributor to the microhole program goal of faster, cheaper, and safer oil and gas drilling, with DOE projecting savings of 30-50% in drilling costs and 90% in equipment cost. This also will contribute towards the U.S. goal of maintaining global technical leadership.

Background

DOE has undertaken a new research and development initiative to develop microhole technologies that use portable drilling rigs with a smaller footprint and lower environmental impact. It identified PDMs as one of five critical technology development initiatives needed to support the microhole initiative. Another critical technology area identified is the development of integrated rotary-percussion motors (IRPMs). The detailed analysis of the requirements for the drilling-fluid circulation system for microhole drilling (performed by Los Alamos National Laboratory) showed that 1) larger pressure drops will be required across the PDMs as compared with current design, and 2) the motors will need sealed bearings that are cooled by the flow through the motor as opposed to flow through a bearing assembly that bypasses the bit to provide the maximum pressure drop across the bit. The higher pressure drop at the bit nozzles will be converted to jet drilling power, hole-cleaning, or some combination of both to optimize the penetration rate.

Summary

Kalsi Engineering, Inc. will apply its background, field experience, and technical insights to extend this high-pressure, rotary seal-and-bearing technology to the sealed-bearing assembly for the 2-inch and smaller-diameter microhole PDMs targeted under this program. These advances will be accomplished through a systematic and rigorous development program, including detailed analyses, design, and testing to address scaling issues, higher pressures, more-severe vibrations, and proportionately larger radial deflections caused by bit side loads.

The research is aimed at developing the sealed-bearing assembly technology for microhole drilling with PDMs. The technology also can potentially benefit IRPMs for microdrilling.

Current Status (January 2006)

Kalsi Engineering has worked with Novatek and Dresser-Rand to develop two different technologies for rotary percussion drilling to meet sealing requirements. The more recent technology, patented by Dresser-Rand, requires rotary seals capable of performing under higher pressures. These technologies also will need scaled-down versions of the advanced, high-pressure rotary seals for the microhole drilling program.

Project Start / End: 6-27-05 / 3-26-06
DOE / Performer Cost: $99,739 / $0
Contact Information:
NETL – Daniel Ferguson(daniel.ferguson@netl.doe.gov or 918-699-2047)
Kalsi – Monmohan Kalsi (281-240-5400)

The Application and Use of Microholes for Vertical Seismic Profiling

FWP ESD04-006

Goal

The project goal is to evaluate and develop vertical seismic profiling (VSP) technology for microholes to be used to enhance image resolution and depth penetration beyond current technology in a low-cost fashion.

Performers

Lawrence Berkeley National Laboratory
Berkeley, CA

Los Alamos National Laboratory
Los Alamos, NM

Sandia National Laboratory
Sandia, NM

Rocky Mountain Oilfield Testing Center
Casper, WY

Results

A low-cost vertical seismic instrumentation system that can be deployed in a low-cost manner was developed for use in microholes. VSP surveys were completed at the Rocky Mountain Oilfield Testing Center (RMOTC) using a 20-level hydrophone string and a 20-level geophone string. The surveys demonstrated that VSP data can be collected without using expensive rigs and extensive manpower. This work will serve as a baseline study in preparation for a future CO_2 injection monitoring program.

Benefits

The low-cost and easily deployed seismic system developed in this project will make VSP surveys more available to small operators with limited resources.

The increased resolution afforded by VSP can more accurately image subsurface reservoir rock and fluids and is particularly useful in understanding fractured and compartmentalized reservoirs.

Smaller equipment needed to run VSP surveys saves time, makes the system easily transportable through rough terrain and fragile environments, and reduces operational footprint.

Background

While VSP is not a new technology, the routine, low-cost application of VSP at the same scale of surface seismic has not occurred. As oil and gas resources become harder to find and produce in the United States, there is a critical need to enhance seismic resolution of the subsurface. While VSP offers such an increase in resolution, it has been held back by the use of expensive holes and large-scale deployments. Microhole technology offers a means to deploy VSP at lower cost and denser sampling than "conventional" VSP surveys.

The complete system used to acquire the VSP data. The simplicity of the system allowed for hand deployment, a rental vehicle for the "doghouse," and a small vibrator for the source. Note the small tripod used to support the sensor string; normally, a workover rig and many more personnel are needed.

Summary

The project achievements include:

- A low-cost, easily deployed system for conducting VSP surveys was developed and tested.
- The use of hydrophone (fluid-coupled) and geophone (directly clamped) sensor strings were compared. The test showed that geophones were the most effective type of sensor for the situation investigated.
- A new "vacuum-assisted" geophone clamping mechanism was developed and used to minimize the overall size of the sensor package.
- Initial VSP surveys have been completed in and processed from 800-foot microholes.

This project is an integrated program of modeling, instrumentation evaluation and testing, and data acquisition and processing. The effort is tightly coupled with the microdrilling program being conducted by Los Alamos National Laboratory at RMOTC in Teapot Dome, WY. The focus of the project is to model, design, carry out, and process multiple shallow VSP surveys (500-700 feet deep) in microdrilled holes in an area that is well-characterized. The VSP results will be compared with surface seismic and other information such as well logs, existing models, and core analyses.

Current Status (January 2006)

The project's 2006 work in progress includes the following:

- Extending the application of microhole VSP to commercial sites (in planning).
  - Tertiary Oil Recovery Project Kansas site. This includes active time-lapse monitoring of CO_2 injection and passive monitoring of the reservoir between time-lapse measurements.
  - Wyoming deep (>8,500 feet) CO_2 EOR (Perfection Oil).
  - Barnett shale hydrofracture monitoring.
- Investigating the next generation of instrumentation.
  - Fiber optic sensors.
  - Microelectromechanical systems and nanosensors.
- Adapting processing for improved "look-ahead" capability.
  - Improved methods of imaging vertical features in homogeneous geology.

Project Start / End: 3-12-04 / 3-11-06
DOE / Performer Cost: $400,000 / $0
Contact Information:
NETL – Purna Halder (purna.halder@netl.doe.gov or 918-699-2084)
LBNL – Ernest L. Majer (elmajer@lbl.gov or 510-486-6709)

Technology Development and Demonstration of Microhole Oil Production/Microholes for Designer Seismic in Support of CO_2 EOR

FEW03FE06-04/ FEW03FE06-06

Goal

The primary goal of the first project is to show that microholes provide downhole access at significantly lower cost than conventional wells and provide superior acoustic performance when compared with the use of temporarily converted production or injection wells. The second—and related—project's goal is to adapt microhole systems for deploying microseismic arrays in CO_2 enhanced oil recovery operations.

Performers

Los Alamos National Laboratory (LANL)
Los Alamos, NM

Lawrence Berkeley National Laboratory (LBNL)
Berkeley, CA

Dennis Tool Company
Houston, TX

Quality Tubing
Houston, TX

Rocky Mountain Oilfield Testing Center (RMOTC), Casper, WY

Results

Researchers have demonstrated the technical feasibility of microdrilling 1¾-2⅜-inch holes to depths of as much as 1,310 feet using coiled tubing-deployed drilling assemblies consisting of PDC (polycrystalline diamond compact) bits and PDM (positive displacement) motors.

Field demonstrations have been conducted at RMOTC's Teapot Dome oilfield at the Naval Petroleum Reserve No. 3 in Central Wyoming using a prototype coiled tubing unit, an off-the-shelf drilling-mud cleaning unit, and a surplus shallow-well cementing unit to simulate a highly mobile, self-contained, microhole drilling system.

Benefits

Micro-instrumentation holes potentially could cost as little as a quarter to a tenth that of conventional boreholes. Successful demonstration of a nonmetallic casing such as PVC line pipe may reduce acoustic noise and improve the performance of micro-instrumentation holes dedicated to reservoir-monitoring service.

LANL microdrilling at the RMOTC-operated Teapot Dome Field at NPR No. 3. The microdrilling rig includes the coiled tubing drilling unit on the right, mud cleaning system on the left, and the RMOTC drilling-water truck in the center.

Background

LANL's experience with seismic data acquisition in oilfields indicates that low-cost, dedicated microholes for deployment of seismic sensors are needed to enhance acoustic data monitoring of the subsurface. Dedicated data acquisition holes provide reduced natural surface and cultural noise, reduced or eliminated seismic-signal travel paths through highly attenuating surface layers, and a greatly improved signal-to-noise ratio.

Accordingly, microholes promise a low-cost alternative to conventional wells; they can be placed in the desired location and designed for optimal acquisition of seismic data.

Summary

Project researchers are demonstrating the technical and economic feasibility of developing a highly mobile, self-contained, microhole drilling system for seismic data acquisition and other applications. Using prototype systems to simulate the concept microhole drilling system, LANL has drilled and completed six microwells at the RMOTC Teapot Dome field.

LANL is evaluating commercial equipment with the potential to enhance the performance of microdrilling. Two demonstrations are ongoing with good early results:

- Quality Tubing Inc.'s QT16Cr80 stainless steel coiled tubing as a drill stem for microdrilling.
- Dennis Tool Company's low-torque, low weight-on-bit drilling assembly.

Current Status (August 2005)

The LANL drilling team has completed drilling a four-microinstrumentation-hole pattern to field LBNL microseismic arrays at Teapot Dome field. Researchers presently are preparing to deploy to—as yet undetermined—CO_2 EOR sites that very likely will require more adaptations of the microdrilling systems to operated in new drilling conditions and possibly different regulatory requirements.

The project has completed early-stage demonstrations. The research effort to demonstrate the applications will begin in the new project FEW03FE06-06.

Project Start / End: 3-15-03 / 3-14-06   2-15-06 / 2-14-07
DOE / Performer Cost: $1,300,000 / $0 $550,000 / $0
Contact Information:
NETL – Daniel Ferguson (daniel.ferguson@netl.doe.gov or 918-699-2047)
LANL – Donald Dreesen (dreesen@lanl.gov or 505-667-1913)

Demonstration of Microholes for Oil Production and Emplacement of Subsurface Seismic Instrumentation

FEW 04FE09

Goal

The chief objective of this project is to field-test a microhole drilling system capable of drilling and completing small-diameter wells. The wells will be drilled with a coiled tubing rig to lower overall exploration and production costs.

A second objective of the project is to evaluate new commercial drilling and completion equipment. The Los Alamos microdrilling equipment serves as a platform to evaluate commercial technology that is or may be appropriate for microdrilling and completion services.

Foreground: LBNL microgeophone array sonde in the deployment cable.
Background: contract vibroseis unit.

Performers

Los Alamos National Laboratory (LANL)
Los Alamos, NM

Rocky Mountain Oilfield Testing Center (RMOTC)
Casper, WY

Lawrence Berkeley National Laboratory (LBNL)
Berkeley, CA

University of Wyoming
Laramie, WY

Results

The acoustic performance of the geologic formations in the CO_2 injection area has been modeled and was used to select four well locations for CO_2 flood monitoring. Seismic arrays were selected, and the equipment needed to assemble and deploy the arrays was procured.

The first micro-instrumentation CO_2-monitoring hole—one of two 800-foot microholes planned—was drilled and completed in October 2004. The 808-foot well was completed with PVC casing set below 587 feet, where intermediate steel casing was cemented to isolate the Shannon formation. The second micro-instrumentation hole was drilled to 407 feet and later similarly completed. A multi-offset, vertical seismic profile survey was conducted successfully in one of the 800-foot microholes.

Benefits

The overall objective of this project is to demonstrate the technical and economic feasibility of a highly mobile, self-contained, microhole drilling system as an enabling technology for commercially viable seismic-data acquisition. Succeeding in these objectives will result in reduced well cost and improved quality of data. Air-filled microholes completed with PVC (or other nonmetallic casing) are expected to provide the lowest noise environment possible for retrievable seismic instrumentation.

Background

The use of production and injection wells for seismic data acquisition has a number of disadvantages. Deploying seismic sensors and other logging-type tools interrupts field operations, resulting in loss of money through temporarily stopped production and idle time for expensive equipment and personnel. Production and injection wells often are not positioned in the most advantageous locations for obtaining reservoir data. Conventional wells dedicated to seismic monitoring are expensive to drill.

Microholes (wellbores less than 3½-inch diameter) have the advantage of being relatively inexpensive to drill, and locations and completion designs can be selected for optimal acquisition of seismic data.

Summary

This project will 1) investigate the feasibility of installing ¾-inch coiled tubing on the LANL coiled tubing unit to extend microhole depth capability to 1,500 feet; 2) improve the performance of the LANL low-cost, highly portable, micro-sized cement mixing equipment and displacement pumps; 3) demonstrate a low-cost micro-wellhead concept for production; and 4) complete a demonstration microhole production system at RMOTC.

Current Status (January 2006)

Completion of the second monitoring well and drilling and completion of two additional microwells began in spring 2005. The high-resolution seismic data are being processed. CO_2 injection is presently scheduled to begin in late 2006.

Project Start / End: 7-8-04 / 7-7-06
DOE / Performer Cost: $705,000 / $0
Contact Information:
NETL – Daniel Ferguson (daniel.ferguson@netl.doe.gov or 918-699-2047)
Los Alamos – Donald Dreesen (dreesen@lanl.gov or 505-667-1913)

A Built-for-Purpose Coiled Tubing Rig

DE-PS26-03NT15474

Goal

The project goal is to develop a microhole coiled tubing drilling (CTD) rig capable of drilling a 3½-inch open hole to 6,000 ft total measured depth with a 1,000-foot lateral section. The rig will be capable of rotary and coiled tubing drilling and be able to drill efficiently, safely, cost-effectively, and with minimal environmental impact.

Performer

Schlumberger Well Services
Sugar Land, TX

Results

The project started with the review of current CTD rigs, with a plan to modify an existing rig for use as a microhole CT rig (MCTR). Research showed that the majority of built-for-purpose CTD rigs were very large and could prove difficult to move about on small lease roads. This led to a plan to reduce the overall size of the units, without hindering any of the efficiency factors that current purpose-built units have.

Phase 1 is complete, in which many technical issues regarding the operation of the MCTR were addressed. These technical issues then were used to generate a concept for the development of a built-for-purpose MCTR.

Benefits

Microhole technology offers an alternative to conventional rotary drilling techniques. Rotary drilling typically has larger completion sizes due to limitations imposed by jointed pipe. These larger completions account for higher costs for drilling, completion, and disposal. The CTD rig's part in microhole technology is to keep the operating cost to a minimum so that all of the economic benefits of drilling a microhole can be realized.

Cost savings to the operator could be as much as $1,071,144 per year. The estimated cost savings was based primarily on increases in efficiency compared with conventional units and the reduction of accidents. Based on economic calculation, the MCTR could perform an additional 50 days of drilling, or nearly $1,100,000 worth of billable drilling, each year. A day rate of $20,000 for basic overbalanced drilling was used in the estimate.

Coiled tubing unit to be modified.

Background

Coiled tubing drilling of oil and gas wells has been practiced since the early 1990s. Primary drivers for the development of coiled tubing services have been the ability to perform through-tubing reentry work and to drill underbalanced. A variety of purpose-built CTD rigs exists around the world. None of them is specifically designed to access the shallow oil and gas reservoirs in the United States in a cost-effective way.

Summary

This project is developing and building an MCTR for U.S. shallow oil and gas reservoirs. The rig is being designed to improve the economics of shallow-well drilling by using small and purposed-built equipment that is easy to move and fast to mobilize, yet versatile in its application.

Among the project's achievements:

- Market analysis for the MCTR has been completed, illustrating the need for a scalable rig that can perform slimhole as well as microhole work. This will ensure that utilization is kept high, which will keep the unit's day rate as low as possible.
- Operational analysis showed that it is feasible to drill a microhole with coiled tubing. However, with smaller coiled tubing, artificial means of obtaining weight on bit may be necessary.
- Operating scenarios were developed to evaluate various MCTR concepts with regard to rig-up efficiency and the ability to perform the necessary tasks associated with drilling a microhole.
- The final concept was developed and is currently in the detailed design process.

Current Status (January 2006)

The original proposal called for the development of an MCTR. Because of time constraints, a suitable CTD unit was found that could be modified to make the requirements set forth in the Microhole Initiative. The rig performance is being evaluated before modifications begin.

Project Start / End: 10-1-04 / 9-30-07
DOE / Performer Cost: $1,200,000 / $636,423
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Development of Radar Navigation and Radio Data Transmission for Microhole Coiled Tubing Bottomhole Assemblies

DE-PS26-03NT15477

Goal
The overall goals of this project are to design, manufacture, and test two advanced technologies for the oil and gas industry: 1) real-time measurement-while-drilling (MWD) for guidance and navigation of coiled tubing drilling in hydrocarbon reservoirs and 2) two-way inductive radio data transmission on coiled tubing or via an insulated slickline fed inside the coiled tubing.

Performer
Stolar Research
Raton, NM

Results
A data transmission system has been developed that uses only the outer surface of the drill pipe to propagate communications signals. The system, which is small enough to fit inside a 1.661-inch diameter housing, was successfully tested over 500 feet of pipe inside an uncased, water-filled test hole in the Deer Creek coal mine in Utah. The signal-to-noise ratio at the receiver for the one-way communications test was better than 30 dB. During aboveground tests that simulated borehole conditions, the system was successfully tested over 1,700 feet of pipe.

A prototype digital signal processing (DSP)-based radar system capable of coherent detection of radio waves has been designed and fabricated that provides MWD guidance and navigation of coiled tubing. To track the boundaries in an oil reservoir, a radar system has been devised that operates below 1 MHz with multiple transmitter and receiver antennas to provide directionality and spatial diversity.

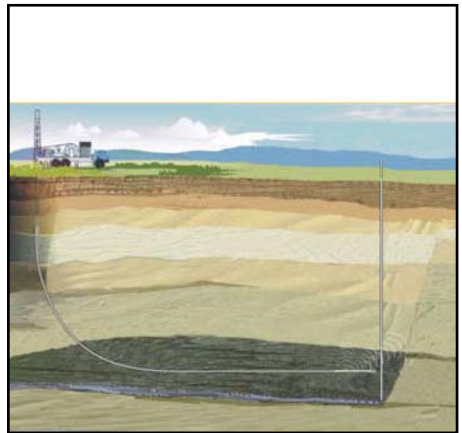
Benefits
The technologies developed in this project allow real-time navigation and imaging during exploration with minimum land disturbance and fewer drillholes. The proposed technologies are expected to improve the recovery efficiency of shallow production wells. Through real-time navigation, the operator can eliminate the expensive practice of sidetracking in horizontal drilling.

Background
The information from MWD sensors in a bottomhole assembly must quickly be transmitted to the drill operator for real-time navigation of the drillbit. Two methods are currently employed. One common method of transmitting downhole sensor data to the surface is by sending extremely low-frequency (e.g., 40 Hz) signals though the layers of the earth to reach a surface receiver antenna. This method provides a slow communications channel due to its low frequency. The other method uses wire lines (or fiber optics) embedded in the drill pipe to provide high-speed communications with the topside receiver. This is generally an expensive and irreversible process. Stolar's data communications system is a cost-effective alternative to these methods of MWD communication.

Currently, the location of the drillbit in the hydrocarbon reservoir is determined from the gamma ray, neutron, and resistivity sensors. There is no tool available to let the horizontal drilling operator know the distance between the drillbit and the bounding walls of the reservoir. The radar navigation tool eliminates this deficiency.

Summary
Among the project highlights:

- A proof-of-concept prototype data communications system suitable for propagating communications signals along the outer skin of a metal drill rod has been designed, fabricated, and successfully tested in a borehole.
- A prototype DSP-based radar system has been designed and fabricated that can detect and map the reservoir boundary.
- A test of a prototype, 800-kHz system, which employed a transmitter/receiver pair of loop antennas in a deviated borehole, showed that the resonant frequency and the transmission loss can be used in tracking an air-soil boundary in conductive soil.



Radar measurements while drilling for horizontal directional drilling, navigating, and structure detection.

The data transmission system uses frequency-shift keying modulation of 91.5-kHz signals. Radio waves are inductively coupled to and from the skin of the drill pipe using loop antennas. The system takes advantage of the natural waveguide properties of the hydrocarbon seam; the entire drill rod and the immediate surrounding layers of rock become the data transmission channel. The system transmits data collected by the DSP radar at a rate of 2,400 bits/second. The system also is equipped with a downhole navigation package (3-axis magnetometer and accelerometer) that provides bottomhole assembly orientation data that complements the data from the radar.

Current Status (January 2006)
With the communications concept proved with the success of the first prototype in the Deer Creek mine, the focus has been on the design and fabrication of a second, more robust pre-production prototype suitable for MWD applications. This second prototype refines the communication concept and focuses on the practical and operational design aspects required during actual drilling conditions.

Project Start / End: 7-26-04 / 9-25-06
DOE / Performer Cost: $737,000 / $184,875
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High-Power Turbodrill and Drillbit for Drilling with Coiled Tubing

DE-FC26-05NT15486

Goal

The project entails developing and testing an effective downhole drive mechanism and a novel drillbit for drilling small-diameter vertical and horizontal wellbores with coiled tubing.

Performers

Technology International, Inc.
Houston, TX

Smith International, Inc.
Houston, TX

Results

Baseline testing of an existing 2⅞-inch diameter turbodrill with polycrystalline diamond compact (PDC) and impregnated diamond drillbits has been successfully performed at Gas Technology Institute's Catoosa, OK, field test site. The hydraulic efficiency of the baseline MK2 turbine blades has been increased so far by 13%.

Benefits

Benefits to the industry from successful development of a microhole coiled tubing (CT) turbodrill and high-speed drillbit include:

- Delivery of more power to the bit than with positive displacement motors.
- Lower reactive torque for improved directional control.
- Longer drillbit life, less vibration, and steady dynamics at the bit.
- Smaller cuttings that are easier to clean from the hole.
- Drilling at a higher rate of penetration (ROP) with less weight on bit (higher rotary speeds to 2,200 rpm provide higher ROP and lower cost per foot drilled).
- Operation at high downhole temperatures.
- Operation in two-phase muds at higher rotary speeds and for underbalanced drilling applications.
- Improved hole quality and high reliability.

The PDC and impregnated diamond drillbit being developed in this project.

Background

Dr. Steve Holditch, 2002 president of the Society of Petroleum Engineers, said, "To economically recover gas, we need to learn how to drill smaller boreholes more rapidly and less expensively." But drilling today does not necessarily mean using a conventional drilling rig. CT units increasingly are being used to drill for oil and natural gas deposits at lower costs and with a much smaller environmental footprint. CT drilling is a cost-effective alternative for drilling highly deviated wells or drilling new hole sections in existing wells. The use of a relatively high-speed turbodrill and high-temperature drillbit will reduce the cost per foot drilled.

Summary

The prototype CT turbine motor and drillbit being developed in this project are designed to:

- Drill a vertical hole to 5,000 feet and drill laterals to 1,000 feet.
- Demonstrate the economic advantages of the CT drilling operation when compared with conventional drillpipe-conveyed downhole assemblies.

The performance of the turbodrill and bit system will lead to an advance in the design of components that ultimately will lead to a higher-power turbine section.

The next step in the project is to incorporate the design improvements into a new downhole drilling assembly for a microhole drilling system. Tools will be made available to microhole project partners for independent field applications in re-entry wells and workover operations using commercial coiled tubing rigs.

A thermal model is being developed to predict cutter temperatures while drilling hard and abrasive rock at high rpm. Being able to estimate cutter tip temperatures will aid in the development of a more durable drillbit employing high-temperature cutters.

A fluid dynamic model developed by NASA Ames Research Center, Mountain View, CA, is being used to increase the hydraulic efficiency of the existing 2⅞-inch diameter Turbodrill. The result will be a shorter tool to aid directional control and greater torque to increase ROP.

Current Status (January 2006)

Initial tests of prototype hardware were conducted at drilling research centers to expedite the testing process and to ensure maintenance of carefully controlled operating conditions not compromised by customers' operational drilling requirements. Task 1, the baseline turbodrill and drillbit testing, was completed in March 2005. A turbine blade hydraulic design model was used to redesign the turbine blades, and successful dynamometer testing was completed in June 2005. Further Turbodrill hydraulic modeling is under way, as well as thermal modeling of the drillbit cutters.

A drillbit thermal model has been completed and is being tested for 3½-4⅛-inch diameter fixed-cutter bit designs employing both PDC and thermally stable diamond cutters. Cutter temperatures will be estimated for bits operating at rotary speeds that match the capabilities of the improved 2⅞-inch diameter Turbodrill, with rotary speed capabilities up to 2,200 RPM.

Project Start / End: 2-7-05 / 8-6-06
DOE / Performer Cost: $759,668 / $200,000
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Small, Mechanically Assisted High-Pressure Waterjet Drilling Tools

DE-FC26-05NT15484

Goal

The goal of this project is to produce a high-pressure jet-drilling system that will dramatically reduce the torque and thrust required for drilling, thereby increasing reliability, drilling rate of penetration (ROP), and lateral reach.

Performer

Tempress Technologies, Inc.
Kent, WA

Results

Project researchers have:

- Completed review of the jet drilling system commercial market, configuration, and sizing, including integration with microhole-sized coiled tubing drilling (CTD) equipment.
- Completed modeling and designs for gas separator, intensifier, jet drill, and circulation in coiled tubing.

Benefits

The economic benefits of the high-pressure waterjet microhole CTD system are derived from both increased capabilities and reduced drilling costs. This drilling system will be able to drill deeper and farther in deviated wells than current coiled tubing technology because of 1) increased downhole power, 2) the ability to drill underbalanced, 3) improved cuttings transport, 4) reduced tendency to stick in the hole, and 5) increased drilling efficiency in pressure-sensitive shales. Other economic benefits result from the decreased hole size. When the volume of a 3½-inch diameter hole is compared with that of a conventional 8½-inch diameter hole, 83% less fluid is required to fill and circulate the microhole.

Background

Small downhole positive-displacement motors (PDMs) have limited power output and are prone to stall when run with aggressive polycrystalline diamond compact bits. PDMs are designed to operate at a limited pressure differential on single-phase, water-based mud. Also, as lateral reach increases, the thrust available for mechanical drilling drops due to coiled tubing friction and helical buckling. Drilling with high-pressure fluid jets makes more efficient use of available downhole power and has proven effective in most rock formations. High-pressure jet drilling dramatically reduces the torque and thrust required for drilling, thus increasing ROP and lateral reach.

Tempress jet drill (top). Sandstone showing, 1.165-inch diameter tool face and tight-gage hole (bottom).

Summary

This project involves the development of a downhole intensifier (DHI) to boost the hydraulic pressure available in conventional CTD to the level required for high-pressure jet erosion of rock. The first phase of the project consists of three major tasks:

- Analyzing the CTD system to define operating parameters for the drilling assembly (completed).
- Designing the downhole intensifier, jet drill, PDM motor modifications, and drillbit.
- Fabricating and testing components.

A review of high-pressure jet drilling and mechanically assisted jet drilling was carried out to define the bottomhole assembly (BHA) configuration and DHI performance specifications for CTD applications. Two BHA configurations were evaluated: mechanically assisted high-pressure jet drilling with the DHI deployed below a PDM drill motor and high-pressure jet drilling with the DHI deployed upstream of a rotary jet drill.

The analysis showed that high-pressure jet-drilling with a high-pressure drill motor and DHI could allow drilling at 3-5 times conventional drilling rates.

The project will provide both a mechanically assisted, high-pressure jet-drilling tool and a pure high-pressure rotary jet-drilling tool. Both tools will utilize a common DHI. The downhole intensifier and high-pressure rotary jet drill designs represent modifications of existing tools designed for coiled tubing scale milling. Researchers will work with PDM, seal, and bearing suppliers to provide high-load bearings and seals to maximize the pressure capacity of conventional motors and with a bit supplier to provide a custom dual-passage drillbit to provide both high-pressure jetting and mechanical cutting capabilities. The tools then will be assembled for functional testing. Endurance testing on two-phase flow will be carried out in a pressure-test facility with full power water and nitrogen pumpers.

The jet-drilling system is expected to provide sustained drilling rates of 80 feet per hour or more with a microhole CTD system, while providing over 100 hours of reliable motor operation.

Current Status (January 2006)

Design of the system components is complete, and the prototype tools are currently being fabricated. Tempress has obtained a no-cost time extension to accommodate delays in manufacturing and availability of test equipment. The prototype tools are scheduled for yard testing in spring 2006.

Project Start / End: 2-10-05 / 1-31-07
DOE / Performer Cost: $737,000 / $184,875
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Microhole Coiled Tubing Bottomhole Assemblies

DE-FC26-05NT15487

Goal

The project goal is to combine existing technologies for measurement-while-drilling (MWD) and logging-while-drilling (LWD) into an integrated measurement system to facilitate low-cost drilling of small (3½-inch diameter), shallow (<5,000 foot depth) boreholes using coiled tubing drilling (CTD) technology. The project will deliver two prototypes ready for field testing.

Performer

Ultima Labs
Houston, TX

Results

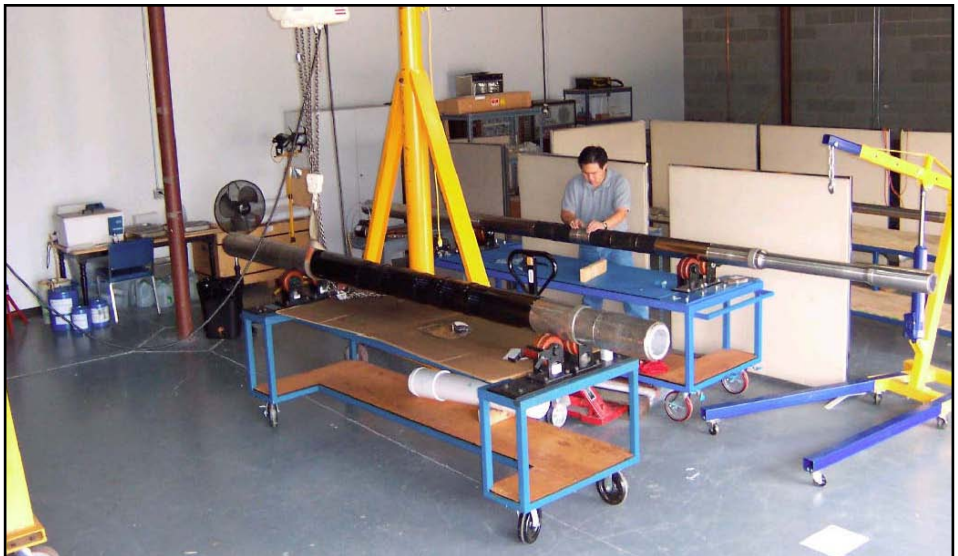
The project was launched in April 2005. The first prototypes are scheduled for field testing in 2007. The measurement system will provide critical enabling measurements for efficient CTD and formation evaluation. MWD measurements include inclination and azimuth for directional control and weight on bit (WOB), torque, and bore and annular pressure for drilling optimization. LWD measures natural gamma ray and propagation resistivity.

Benefits

The project will combine existing, proven technologies for MWD and LWD into an integrated, cost-effective downhole measurement system. Drillers will use the MWD measurements to optimize drilling performance. Geologists will use the LWD measurements to optimize wellbore placement and completion for maximum production and to estimate resources in place.

Widespread adoption of microhole technology will enable low-risk infill development that could potentially tap billions of barrels of bypassed hydrocarbons at shallow depths in mature fields. Exploration efforts in search of new reserves will benefit from the anticipated cost and environmental benefits. DOE estimates remaining U.S. shallow resources at 218 billion barrels. Recovery of just 10% of the targeted resource would yield a volume equivalent to 10 years of OPEC imports at current rates.

Mature producing areas worldwide also will benefit from the technology. Development of technology that expands global sources of hydrocarbons ensures a diversity of supplies and maintains the United States as the leading global supplier of oilfield technology.



Ultima Labs' bottomhole assembly.

Background

As the technology to drill microhole wells develops, the tools to conduct downhole measurements in the smaller holes will be needed as well. This project is developing an integrated tool to improve drilling efficiency and reduce cost. In addition, the increased information about the downhole rocks and environment will allow more accurate reserves estimates and development planning.

Summary

The early phase of the project establishes design requirements and generates a conceptual design that meets these requirements. The conceptual design phase has been extended to incorporate industry input on sensor placement. Following review and approval of the conceptual design by the project team, most detailed design will begin on the mechanical and electronic subassemblies and sensors. Some detailed design and evaluation of low-cost directional sensors is already underway. Detailed design will accelerate during Q1 2006 as additional personnel are added to the project. Individual subassemblies will be tested and incorporated into the prototypes during prototype assembly. The completed prototypes will be tested in the lab and in a flow loop to verify pulser operation prior to the first field test.

Here is the project timetable:

- Project launch, April 2005.
- Conceptual design, Q3-Q4 2005.
- Detailed design, Q4 2005-2006.
- Prototype assembly, Q3-Q4 2006.
- Two prototypes ready for field test, Q1 2007.

Current Status (January 2006)

Efforts to date have focused on the detailed design specification and conceptual design. Valuable industry feedback was received at Microhole Technology Integration meetings in August and November sponsored by the Petroleum Technology Transfer Council. Staffing on the project is being increased for detailed design efforts.

Project Start / End: 2-1-05 / 1-31-07
DOE / Performer Cost: $795,515 / $189,879
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Microhole Downhole Drilling Tractor

DE-PS26-03NT15475

Profile of microhole drilling tractor gripper expanded against hole.

Goal

The project goal is to design, manufacture, and demonstrate a reliable and economical, hydraulically powered coiled tubing (CT) tractor that will transport the drillbit and bottomhole assembly into long (>3,000 feet) horizontal well sections.

Performer

Western Well Tool, Inc.
Anaheim, CA

Results

The baseline design of a 3¼-inch Microhole Drilling Tractor (MDT) was completed. Experiments were conducted with low-solids drilling mud that verified component functionality and operational life.

Work started on a redesign of the MDT. The MDT is being completely redesigned with a 3⅜-inch outside diameter. This allows a greater inside diameter for flow to the downhole motor and drillbit, for returning cuttings to the surface, and for improved hole cleaning.

Improved start-stop valve and gripper designs are being developed. Long-lead items are being designed and released on a priority basis to shorten manufacturing times.

Benefits

The MDT will allow drilling of horizontal holes up to 2,000 feet beyond conventional CT drilling.

Using CT and the MDT can be 25-50% less expensive than rotary rigs in some applications, especially in environments where set-up time is costly.

Controls are simple and direct using the injector and pump pressure, thus eliminating need for expensive electrical controls.

The MDT is capable of high loads (3,500+ lbs) through dog-legs up to 15 degrees per 100 feet.

Grippers for tractor movement are highly reliable, have a long life (>175,000 feet traveled before maintenance), are highly debris- and fluid-tolerant, can efficiently traverse washed-out hole sections, do not damage casing, and are proven to operate in both very soft and hard formations.

Using a simple principle of operation, power is provided by differential pressure of the drilling mud at the tool.

Background

Although there are many advantages of CT drilling, one area of needed technology development is a method to exert enough weight on the bit to drill through rock. Coiled tubing easily buckles, which makes it difficult to impart drillbit weight. One technology that has been recently developed to overcome this problem is a downhole tractor that thrusts the drillbit into the formation while pulling the coiled tubing along behind.

Summary

The MDT to be designed and manufactured is a drilling fluid-powered unidirectional downhole CT tool. The tractor outside diameter will be 3⅜ inches to accommodate 3⅝-inch holes, and the tractor will be able to drill >3,000 foot horizontal well sections.

The MDT builds on previously developed Western Well Tool Tractor technology that has demonstrated the capability to operate downhole with a variety of drilling muds, operating parameters, and drilling equipment. The tractor consists of a central control assembly that directs the mud flow and provides the pull and thrust of the tractor and a forward and aft shaft assembly with patented grippers that operate successfully in soft and hard formations.

The microhole tractor walking process consists of several steps. A forward roller-toe gripper is expanded (inflated) against the walls of the hole, thrusting the bit forward and pulling the coiled tubing as the tractor progresses. The forward roller-toe gripper deflates while the aft roller-toe gripper expands against the hole wall, pushing the bit forward and pulling the drillstring into the new position. This process repeats, allowing the tractor to "walk" down the hole while drilling in front of the tractor and pulling the drillstring behind it.

In the first phase of the project, a drilling tractor will be designed that is reliable, economical, field-ready, and can drill horizontal well sections of 3,000 feet or more. In the second phase of the project, a prototype drilling tractor will be built and field-tested to demonstrate its performance with a CT rig by drilling multiple inclined and horizontal holes.

Current Status (December 2005)

Design of the major components, including the control assembly, grippers, and shaft assemblies is nearing completion.
Procurement will begin in first quarter 2006, with the long-lead items ordered on a priority basis.

A three-well demonstration program is scheduled for fourth quarter 2006.

Project Start / End: 7-1-04 / 8-22-06
DOE / Performer Cost: $795,515 / $189,879
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