TECHNOLOGY CONNECTIONS
PETROLEUM TECHNOLOGY TRANSFER COUNCIL

DEVELOPMENTS IN WELL STIMULATION AND SLIM-HOLE TECHNOLOGY

BOTTOM LINE

Coiled tubing has several distinct advantages for well fishing operations. It offers additional tensile strength above that of braided line and the ability to use heavier tools is helpful in most applications. The capacity to circulate fluid through the system can also be helpful in some situations. Coiled tubing drilling operations are also increasing, with cost savings of 50% or more reported. With both fishing and drilling operations, operational know how is required to reap maximum benefit. For selected wells, high-energy gas fracturing technologies provide a low cost alternative to hydraulic fracturing. Production increases over 250% have been reported for U.S. applications in marginal wells.

PROBLEM ADDRESSED

Operations in the U.S.'s mature oil and gas reservoirs require producers to continually look for new or improved technologies that lower cost or improve well productivity. Applications of coiled tubing in both drilling and well maintenance are expanding, but the nature of the technology makes it critical that producers apply the prior lessons learned when using coiled tubing. These insights come only from those who have been out there doing it. With mature, often marginal, wells, producers are looking for low cost yet effective stimulation treatments to improve well productivity. High-energy gas fracturing technologies being developed are one alternative, but producers must be exposed to theory/field performance data to develop the confidence to apply this evolving technology.

KEY WORDS:
Coiled Tubing Applications
High-Energy Gas Fracturing
Slim-hole Technology
Well Stimulation

TECHNOLOGY OVERVIEW

Coiled Tubing Operations. Coiled tubing has several distinct advantages for fishing. It offers additional tensile strength above that of braided line and the ability to use heavier tools is helpful in most applications. The capacity to circulate fluid through the system can also be helpful in some situations. To properly evaluate a well as a candidate for coiled tubing fishing and make proper decisions during the operation, producers must fully understand the advantages, disadvantages, strengths and limitations of coiled tubing.

Major tools used in coiled tubing fishing include: (1) slip-type connectors, (2) overshots and spears, (3) hydraulic disconnects, (4) jars, (5) accelerators, (6) knuckle joints and bent subs, and (7) centralizers. When planning coiled tubing fishing operations, it is important to consider cost versus chance of success, well conditions, overpull at the fish, and lubricator length. Pre-job quality control steps should include installing a new connector, ensuring all connections are tight, and function testing hydraulic tools. When attempting to latch a fish and when jarring on a fish, the same section of coil is repeatedly pulled across the goose neck. This may cause the coiled tubing to become oval, resulting in significant reduction in tensile strength, burst and collapse resistance.

Running slowly into the fill can clean out almost any form of granular material in a well, including under-displaced frac proppant with coiled tubing while pumping a special clean-out fluid. Regarding clean-out fluid, foam is not recommended for deviated wells, and it is generally considered less efficient in straight holes due to its high viscosity and low pump rate. Various combinations of a thick gel, water, nitrogen and flowing the well itself can enable fill clean-outs in most wells. Polymer gel characteristics, low viscosity at high shear rates, make them very suitable for clean-out fluids.

Downhole motors attached to the end of coiled tubing can be used to drill through cement, debris, etc. This is generally a quicker and cheaper alternative to workover rigs. For coiled tubing drilling, two major types of bits exist: diamond PDC and tungsten carbide (TC: splatter-welded). Tri-cone roller bits are generally not suitable for coiled tubing drilling because of the high rotational speed of the motors. Experience has shown that TC mills perform best when milling out tools and cement. Great care should be exercised when selecting a motor as too much power can have an adverse effect on the string, especially when drilling/milling in large tubulars where correct stabilization may be difficult. Motors with medium-stall torque are preferred over

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SPEAKERS:

Reeled Through Tubing Operations
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Slim-hole Drilling and Completion Technology
William McDonald, Maurer Engineering, Inc.

Available Slim-hole Logging Technology
Gary Kuecker, Baker Atlas

Near Wellbore High Energy Gas Fracturing
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high-stall torques. Stabilizers fitted to the top of the motor are always recommended.

Grifco outlined generic procedures and experience-based insights for coiled tubing operations for: (1) cutting tubing, (2) underreaming, (3) bridge plug operations, (4) packer operations, (5) gas lift operations, (6) cementing operations, and (7) acidizing operations.

Slim-Hole and Coiled Tubing Drilling. By using slim holes, operators can reduce well costs 40 to 70%, plus reduce environmental costs and concerns. Tools and equipment exist and operations can be performed safely. Experience indicates that slim holes do not usually restrict production. Slim holes were used as early as 1960 in the U.S. Over 1,300 wells were drilled in the 1,000 to 3,000 ft range in Kansas, Texas and Canada using slim-hole 2 ½- to 2 7/8-in casing and 1-in EUE hollow sucker rod tubing. Operators realized a 40 to 50% reduction in tubular costs and 17% cost savings overall.

There are several documented examples from later slim-hole drilling programs. Conoco used slim-hole drilling in Indonesia in the 1983 to 1986 time frame, realizing cost reductions of 65 to 73%. In the early 1990s, Oryx realized 50% cost savings in an eight-well, slim-hole re-entry program. In Thailand, Unocal used slim-holes in its Gulf of Thailand operations in 1999, realizing over 40% savings. Productivity of Unocal's slim-hole wells has exceeded that experienced with conventional wells. Pemex realized 30% cost savings in a late 1990s slim-hole drilling program. But success is not guaranteed. In a three-well slim-hole drilling program in Wyoming's Powder River basin, Domain Energy successfully completed slim-hole wells, but twist-off's due to stabilizer torque problems eliminated any cost savings.

There have been sufficient slim-hole drilling programs to establish the following. Areas that are not concerns include logging, perforating, tubing buckling and sticking, wellhead design, and BHA design. Concerns, which experience indicates can be solved, still include: (1) casing program, (2) drillstring torsional strength, (3) fishing and milling, (4) lost circulation, (5) bit design and reliability, (6) downhole motors, (7) cementing, (8) stimulation, and (9) workovers.

Since initial application in the 1960s, coiled tubing usage has increased to the point that there are now 750 units worldwide with 50% of those being in North America. Despite the potential for coiled tubing failure, there are few pipe failures reported. The most common coiled tubing applications are clean-outs, stimulations, profile modifications, perforation or logging operations, artificial lift and sand control. Data, cited for different applications, confirm that savings from 20 to 90% are being realized. Drilling with coiled tubing really began in the early 1990s. Through 1999, about 1,200 wells had been drilled using coiled tubing.

Arco alone has drilled about 140 wells with coiled tubing, primarily in Alaska. For 100 wells drilled in the 1993-1999 time frame in Prudhoe Bay, production averages 1,400 bopd and Arco reports a success rate of 90%. Since Arco continues to apply coiled tubing drilling in more challenging applications there (harder, longer reach targets), well costs have risen from $990M in 1995 to $1375M in 1999. Even with successes, there have been problems and coiled tubing drilling is not widely used. There are fewer than 20 coiled tubing units worldwide capable of coiled tubing drilling, and they are primarily being used in Alaska, Oman, Canada, the North Sea and Venezuela. But coiled tubing drilling will increase as technology advancements continue and become accepted.

Composite spoolable products, especially Fiberspar, are seeing increased application for production tubing, line pipe and coiled tubing. Attractions include their inherent corrosion resistance and, in some applications, quick and easy installation. Halliburton Energy Services has used Fiberspar coiled tubing rigs to cleanout CO_2 injection wells for Altura and Phillips in West Texas/New Mexico. Ease of installation makes Fiberspar line pipe products very attractive. Runs of 3,000 ft have been made in a matter of minutes. Fewer fittings and field connections make installations more reliable. Altura has used 40,000 ft of Fiberspar products in a West Texas waterflood installation.

Slim-Hole Logging Tools. Logging tools with diameters in the 3.62- to 5-in range are considered slim hole, while smaller tools are considered ultra slim hole. In addition to expected tools (gamma ray, porosity logs, caliper, etc.), Baker Atlas offers special slim-hole tools, including acoustic borehole imaging logs, reservoir performance monitor (RPM), and measurement while drilling (MWD) and logging while drilling (LWD) tools. The acoustic borehole-imaging tool, which provides 360-degree coverage and is useful for identifying fractures, can be used in oil-based muds. Baker's RPM tool is a multi-detector pulsed neutron instrument that can operate in multiple modes, including: (1) carbon/oxygen, (2) pulsed neutron decay, (3) holdup imaging, (4) activation water flow, and (5) radioisotope monitoring. In different ways, these modes assist in defining reservoir conditions that control reservoir performance. Slim-hole LWD tools include multiple propagation resistivity, density/neutron, and Navi185 directional/gamma ray. Slim-hole multiple propagation resistivity tools, which measure eight resistivities with separate depths of investigation, are quite useful for geosteering, as they can provide real-time data enabling horizontal wells to stay "in zone." Operators are encouraged to contact logging service companies about the latest advances applicable to their situation.

Near Wellbore High-Energy Gas Fracturing. Geotec Inc. has collaborated in bringing Russian-developed technology, caseless charge-powdered pressure generator or PGDBK, for near wellbore stimulation to North America. A PGDBK generator is a cylindrical shaped powder charge that is lowered to the appropriate depth in the wellbore via wireline or tubing. Upon receiving an electrical signal, the generator ignites almost instantaneously along its length, creating high pressure and temperature. This is a deflagration process and not an explosion. The generator disintegrates completely and the well is ready to be returned to production within hours. The design, number of charges, and type of tamp fluid depend upon geological and reservoir conditions, number and thickness of pay zones, and well configuration. Well depth should be at least 2,000 ft, and depths to 22,000 ft are possible. Temperature and pressure ratings are 400 ^{O}F and 14,500 psi respectively.

Well productivity is enhanced through mechanical, thermal and chemical actions. Mechanical action occurs due to rapid gas expansion after ignition. This expansion overloads void spaces and fractures, overcoming the rock's tensile strength to create several residual fractures of diverse orientation. Fractures extend 30 to 60 ft from the wellbore. The pulsating action of the pressured gases erodes the fracture surfaces, causing the fractures to remain unhealed. After the gas is expended, a backpressure surge action cleans out precipitates and allows easy flow through pore channels and perforations. Thermal action, reaching up to 1400 ^{O}F, reduces fluid viscosities and melts paraffin/asphalt/resins to keep flow channels open. Combined, the mechanical and chemical actions create eroded and plasticized walls. Proprietary chemicals are used to reduce the surface tension between oil and water, increasing the relative permeability to oil.

Parameters considered during treatment design are depth, pressure, temperature, lithology, quality of cement bond, and casing integrity and yield strength. Gauge rings must be run to ensure clearance for the generator and recommended logs (GR, CLL, CBL, and pressure/temperature). Generators are run at speeds not exceeding 300 ft/min, and wells are tamped with clean fluids compatible with the reservoir. Planned perforations are made and the charge ignited. Temperature logs are usually run after treatment to determine effectiveness.

There is an extensive treatment database, over 30,000 wells within CIS countries. Claimed success rate in oil wells is 70% and 90% in gas wells. Duration ranges from several months to years, and treatments have lasted for 5-7 years in some fields in CIS countries. There is a growing database of applications in the US. The percentage of wells by basin for the Powder River, Anadarko, and Austin Chalk Trend is 40, 35, and 25%, respectively. Carbonate, sandstone, chert and dolomite formations have been stimulated. Most of the treated formations are in the 4,000 to 8,000 ft range. Data were reported for 14 marginal wells in the U.S., most producing from 1 to 4 bopd. For this group of wells, production increases of 250% or more were noted.

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