Evolution Of Coiled Tubing Drilling Technology Accelerates

The technical feasibility and economic viability of coiled tubing drilling (CTD) has been proven, and the progress of this emerging technology is evident in the growing band of operating companies committing to multiwell CTD campaigns.

For many years the oil and gas industry has dreamed of using a continuous pipe, or tube, for drilling wells. Recent advances in coiled tubing (CT) technology have made this dream possible. Larger CT sizes and an understanding of the fatigue damage that results from bending and straightening the tube now enables CT to be safely and reliably used in new well and re-entry drilling applications.

The first coiled tubing drilling (CTD) attempts are believed to have been made in 1991 (Table 1). However, much earlier CTD efforts were made in Canada in the mid 1970s. The lack of activity between 1976 and 1991 indicates the technical and economic difficulties encountered in early CTD. However, the CTD success rate now is much higher, with success measured by the ability to achieve the operators' objectives.

Fig. 1. A dedicated coiled tubing drilling unit, such as that depicted by this artist's rendering, is now being jointly designed by Arco and Dowell for Alaska's Prudhoe Bay.

Coiled Tubing Drilling Rigs

Only a small percentage of the 550 CT units worldwide are suitable for immediate drilling. The equipment and practices that allow routine CT service operations to be completed on pressured wells also provide well control benefits for CTD operations such as drilling, tripping, and completing wells in underbalanced conditions.

One of the greatest advantages of CTD is improved

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productivity resulting from reduced formation damage.[1] When reviewing the technical advantages and disadvantages of CTD, it is important to keep in mind that underbalanced drilling provides an economic benefit that extends far into the lifetime of the well (Table 2). This economic advantage is potentially greater than most technical advantages of CTD and deserves special consideration during economic appraisals of modern drilling techniques.

While many believe CTD should be significantly less costly than conventional slimhole drilling, experience shows that in most applications, this is not the case. All but one of the CTD projects in Table 1 were completed onshore where the current daily rig costs are low. Despite the engineering and new equipment costs that burden any developing technology, CT has secured its place in the drilling market. Many believe CTD will become more economically competitive and eventually, more cost-effective than conventional drilling techniques.

Offshore, CTD operations will be quickly competitive because of reduced mobilization and demobilization costs.

The greatest disadvantage of CTD is the need for a downhole motor. In CTD attempts, 25% of the total job costs were related to downhole motors. Couple this with the reliability problems of early slimhole motors and tools, and it is evident that conventional rotary drilling retains some advantages in a competitive market.

When considering CTD, the advantages and disadvantages must be closely deliberated. If one advantage significantly impacts any aspect of the well to be drilled, then CTD may be a viable option.

Drilling And Completion Synergies

The advent of coiled completions–using a CT string as a completion tubular–supports and expands the potential for CTD in a variety of applications. Several coiled completions (up to $3^1/_2$ in.) have been installed as the primary production conduit.

Though the relationship between CTD and CT completions is obvious, the impetus to develop these services has come from different sources. Clearly, the benefits of aligning these technologies will be sufficient to overcome the technical difficulties that exist.

The design and construction of special equipment to run or retrieve jointed tubing or casing in association with CT services is under way with at least two units scheduled for delivery later this year. The ability to run and cement a casing string without a rig is beneficial. However, the ability to pull existing tubing and completion equipment, treat or workover as required, and have the flexibility to recomplete with coiled or jointed completions should significantly reduce overall costs.

Arctic CTD units are being built for operational flexibility in severe environments. Large capacity masts are designed to permit quick and easy interchange between

TABLE 1. KNOWN COILED TUBING DRILLING OPERATIONS.

Date	Location	Operator	Well bore	Deviation	CT size, in.	Hole size, in.
June 1991	Paris	Elf	Re-entry	Vertical	1.50	3.875
June 1991	Texas	Oryx	Re-entry	Horizontal	2.00	3.875
August 1991	Texas	Oryx	Re-entry	Horizontal	2.00	3.875
December 1991	Texas	Chevron	Re-entry	Horizontal	2.00	3.875
May 1992	Canada	Lasmo	New	Vertical	2.00	4.750
July 1992	Texas	Chevron	Re-entry	Horizontal	2.38	3.875
July 1992	Canada	Gulf	Re-entry	Horizontal	2.00	4.125
July 1992	Canada	Imperial	New	Vertical	2.00	4.750
July 1992	Texas	Arco	Re-entry	Horizontal	1.75	3.750
September 1992	Canada	PanCanadian	Re-entry	Vertical	2.00	4.750
October 1992	Canada	Canadian Hunter	Re-entry	Vertical	1.75	3.875
October 1992	Paris	Elf	New	Vertical	1.75	3.875
November 1992	Canada	Gulf	Re-entry	Vertical	2.00	4.750
November 1992	Austria	RAG	Re-entry	Vertical	2.00	6.125
December 1992	Alaska	Arco	Re-entry	Deviated	2.00	3.750
January 1993	Canada	Petro Canada	Re-entry	Vertical	2.00	3.875
February 1993	Holland	Shell-NAM	Re-entry	Horizontal	2.00	4.125
February 1993	North Sea	Phillips	Re-entry	Deviated	1.75	3.750
February 1993	Canada	Petro Canada	Re-entry	Horizontal	2.00	4.750
March 1993	Alaska	BP	Re-entry	Deviated	2.00	3.750*
April 1993	California	Berry	New	Vertical	2.00	6.250
April 1993	California	Berry	New	Vertical	2.00	6.250
May 1993	Alaska	Arco	Re-entry	Deviated	2.00	3.750
June 1993	Alaska	Arco	Re-entry	Deviated	2.00	3.750*

*Underreamed

Fig. 2. Upon recompletion, NAM's Berkel No. 5 well produced eight times more oil on natural flow than it produced previously with the assistance of a beam pump.

drilling, service, and completion modes of operation.

CTD Progress

As CTD techniques have been tried and proven, several case histories are emerging as milestones. A recent re-entry drainhole declared successful was the Berkel No. 5 well drilled by Nederlandse Aardolie Maatschappij (NAM) in The Netherlands (Fig. 2). Drilled in 1978, the well had an "S" profile with a maximum inclination of 52° at 2,919 ft and a final deviation at a 5,756-ft TD and 18° inclination.[2]

As part of a research project in February 1993, NAM planned to drill a medium radius, 4$^1/_8$-in. horizontal drainhole 100 ft above the oil/water contact. This entailed milling a window through a 5-in. liner and a 7-in. casing, drilling the buildup section through an overlying shale, and entering the reservoir from the side below a gas cap. Since milling a window with CT had been performed only once before, and in this instance both a liner and casing string were to be cut, a decision was made to mill the window using a workover rig employed to pull the completion. A modified whipstock, mud motors, and hydraulic thruster were used to simulate CTD operations using the workover rig.[3]

Before drilling began, a bit and bit sub were accidentally dropped in the well bore. They were successfully fished using an overshot and bent sub oriented by a low-speed mud motor and conveyed on CT. Drilling began at 4,523 ft, just below the window cut in the casing and liner. A total of 1,053 ft of 4$^1/_8$-in. hole was drilled, of which 722 ft intercepted the reservoir and 492 ft were horizontal. Build rates of up to 34.2°/100 ft were achieved, and a maximum inclination of 96° was recorded.

The hole was accidentally sidetracked from the low side when running in after changing from a buildup to a drilling assembly. This was corrected and the well path subsequently maintained within acceptable tolerances. Drilling was completed and total depth declared at 5,576 ft after a motor twisted off.

Upon recompletion, the Berkel No. 5 well produced eight times more oil on natural flow than it produced

TABLE 2. ADVANTAGES AND DISADVANTAGES OF CTD.

ADVANTAGES

Underbalanced drilling and improved well control
- Full pressure control possible throughout drilling operations.
- Underbalanced tripping, drilling, and completion reduces formation damage and permits faster penetration with reduced risk of differential sticking.

Continuous drillstring
- Allows continuous circulation while tripping.
- Eliminates joint related problems and allows faster tripping.
- No pipe handling, which improves safety and reduces noise.
- Reduced environmental impact. No spillage at joints.
- Simplified automation, reduced manpower.

Compact unit and equipment configuration
- Reduced drill site size and associated costs.
- Reduced mobilization and demobilization costs.

Wireline inside the CT drillstring
- Allows highspeed telemetry for measurement and logging while drilling (MWD, LWD).
- CT protects wireline and simplifies operations through simultaneous spooling of tubing and wireline.
- Electrically operated directional control is possible.

DISADVANTAGES

Drillstring cannot be rotated
- Downhole motors required, even for vertical wells.
- An orienting tool is required for steering.
- Higher friction with the borehole wall.

Limited to slimhole applications
- Largest hole to date is 6$^1/_4$ in., larger holes technically are feasible.
- Small hole size limits the number of casing strings and liners that can be run.

Wireline inside the CT drillstring
- Fatigued or damaged sections of CT cannot be removed from the drillstring.

New technique
- Currently in the learning curve.

TABLE 3. CTD APPLICATIONS
Re-Entry CT can re-enter existing wells, set a whipstock, mill a window in the existing casing or liner, and drill into the reservoir (usually horizontal, although several have been vertical). Drainholes deeper than 1,400 ft have been drilled. Multiple drainholes extended from a single well bore are under consideration.
Combination Drilling Conventional rotary drilling equipment is used to drill upper zones and set casing. The zone(s) of interest then are drilled using CTD techniques in underbalanced conditions. The capability of drilling multiple deviated well bores with minimal formation damage will improve production potential for such wells. The overall economics of single well completions and field development using this technique is attracting much attention.
Disposable Exploration And Observation Wells Inexpensive small holes are drilled to obtain formation or reservoir data for exploration or delineation. Typically, these wells are plugged and abandoned when sufficient data has been acquired to monitor reservoir parameters during subsequent production.
Production And Injection Wells Under the right reservoir and production conditions, a small hole is drilled and a CT string cemented in place to provide a small diameter, inexpensive well for production or injection.

previously with the assistance of a beam pump.

Shallow Delineation Wells

Two shallow delineation wells drilled in California (Berry Petroleum Co.'s BY20 and BC4) in April 1993 further demonstrate the ability of CTD to quickly produce an accurately placed well bore. These vertical wells were drilled using CT after a rathole rig had set 7-in. casing at 80 ft (Fig. 3).

A test project run prior to the CTD operations indicated unintentional deviation may be a problem when using downhole motors run by a workover rig. During the test, deviation as high as 6° was experienced in depths less than 1,000 ft. Consequently, two deviation surveys were planned for the first well drilled by CTD.

Well BY20 was drilled in 37 hours. However, this included time for deviation surveys, which reduced the average rate of penetration (ROP) to 32 ft/hr. The 6¼-in. hole drilled from the 7-in. casing shoe to total depth at 1,250 ft presented no deviation problems. The maximum recorded deviation was 1° with the deviation at total depth being ½°.

Well BC4 was drilled, without any deviation surveys, in 21 hours. With a 1,500-ft TD, the average ROP was 68 ft/hr. Again a 6¼-in. hole was drilled using a 4¾-in. motor. Subsequent logging operations showed the same minimal deviation as the first well.

Caliper log data indicated minimal well bore washout and the well bore was judged to be in better condition than a recently completed, conventionally drilled wellbore. Both wells were logged and had sidewall cores retrieved. With all objectives met, both wells were classified successful with tentative plans made for an additional CTD project.

CTD In The Arctic

Although many operating companies are investigating CTD, Prudhoe Bay operators and their alliance partners in Alaska are taking steps to evolve this relative novelty into a routine operation. The economic and logistic constraints associated with arctic operations demand that Prudhoe operators cannot wait for the technology to be developed elsewhere in the world.

Economic drilling opportunities in the region will expire by 1998 unless alternative methods are available to reach undeveloped reserves. New wells cost an average of $2.5 million, and rig-based sidetrack operations run $1.7 million or more. With CTD sidetracks predicted to cost $500,000, several hundred infill locations could be accessed economically resulting in an increased recovery of several million barrels of oil from known reserves.

Throughout the 1980s, Prudhoe Bay pioneered much of the work in CT cement squeezes. Nowhere in the world could the cost of conventional treatments, or the number of candidate wells support such a commitment to an innovative technology. Similarly, in the 1990s, CTD would appear to fit an equivalent category, with technology development setting the stage for intense CTD in the region over the next few years.

The completion advantages of CTD wells also are under scrutiny, with several drilling and completion options being investigated. Arco already has used 3½-in. coiled completions to flow test exploration wells, and several 2⅜-in. production strings (some equipped with gas lift mandrels) also have been run in North Slope wells (Fig. 4). The development of reliable, large-diameter coiled completions has opened a range of possibili-

Fig. 3. Berry Petroleum Co.'s BY20 and BC4 wells show CTD's ability to quickly produce an accurately placed well bore.

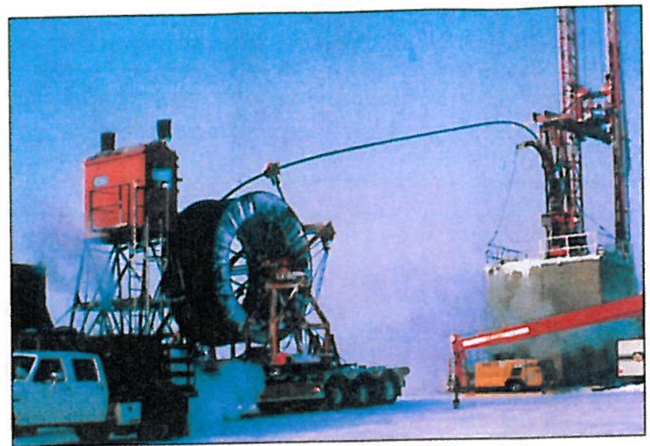

Fig. 4. The development of reliable, large-diameter coiled completions, such as Arco's 3½-in. coiled completion, will significantly impact the drilling, completion, and economics of future wells.

ties, which will significantly affect the drilling, completion, and most importantly, the economics of many future wells. ●

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