Coiled-Tubing High-Pressure Jet Drilling System

by

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INTRODUCTION

High drilling costs are a major constraint on the development of marginal oil and gas reserves in the USA. New drilling technology is needed to significantly reduce drilling costs and increase oil and gas recovery.

In a typical well, approximately 50 percent of the expenditures go toward making the hole and 50 percent toward completing the well (i.e., casing, cementing, logging, artificial lift, etc.). Therefore, techniques that will double the drilling rate have the potential to reduce overall well costs by up to 25 percent.

Developing a technique to significantly increase drilling rate therefore is of paramount importance, because no other development, except slimhole drilling, has the potential to make such a significant reduction in drilling cost.

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OBJECTIVE

Coiled-tubing (CT) rigs utilize continuous tubing to rapidly reel bits, motors, and other tools in and out of wells. They significantly reduce drilling, completion and workover costs in many areas and are ideal for underbalanced drilling since they can be reeled in and out of the well under pressure. CT has reduced squeeze cementing and workover costs by as much as 70 percent at Prudhoe Bay and other areas.

A major limitation of CT drilling is the relatively low power output of the slimhole motors due to their small diameters. For example, a 6¾-inch PDM motor delivers 130 to 170 horsepower compared to only 20 to 30 horsepower for a 2⅞-inch motor.

On another recent DOE project, Maurer Engineering developed high-power PDM motors that deliver twice as much power as conventional motors and drill twice as fast. The goal of this CT project is to further increase the drilling rate of these high-power motors to significantly reduce slimhole drilling costs.

APPROACH

In the 1970s and 1980s, Exxon, Shell, Gulf Oil and FlowDril demonstrated that high-pressure jet bits operating at 10,000 to 15,000 psi can drill many formations 2 to 3 times faster than conventional bits (**Figures 1** and **2**). These systems were not commercialized because of difficulties in pumping the high-pressure fluids to the hole bottom through conventional threaded drillpipe.

In the 1980s, Maurer Engineer developed a high-pressure motor on a DOE project that operated reliably at pressures up to 10,000 psi (**Figure 3**). The jets on the high-pressure bits drilled grooves in the rock which were easily removed by the PDC bit cutters (**Figures 4** and **5**).

These high-pressure motors drilled Berea sandstone at rates in excess of 1,000 ft/hr compared to 230 ft/hr for conventional motors and 100 ft/hr for rotary bits (**Figure 6**).

The approach being taken on this project is to develop a high-pressure slimhole motor for use on CT to overcome the drillpipe tooljoint leakage problems encountered with the earlier jet drilling systems.

PROJECT DESCRIPTION

Three types of downhole motors were evaluated for use with this system. PDM motors were selected over turbine and vane motors because they can be readily adopted for high pressure, they are widely used worldwide, and there are PDM motor maintenance facilities available worldwide.

Two basic high-pressure CT systems were evaluated on this project. With the *single-flow* system (**Figure 7**), high-pressure (HP) fluid (10,000 psi) is pumped down a single CT string to power the motor and deliver HP fluid to the bit nozzles. This system is preferred for smaller diameter holes (5" and smaller) due to its simplicity, higher reliability, and compatibility with existing equipment.

With the *dual-flow* system (**Figure 8**), two concentric strings of CT are used to deliver both low-pressure (LP) (2,000 psi) and HP fluid (10,000 psi) to the hole bottom. High-pressure fluid is pumped down the inner tube to the jet nozzles and LP fluid is pumped down the annulus between the concentric tubes to power the downhole motor (**Figure 9**).

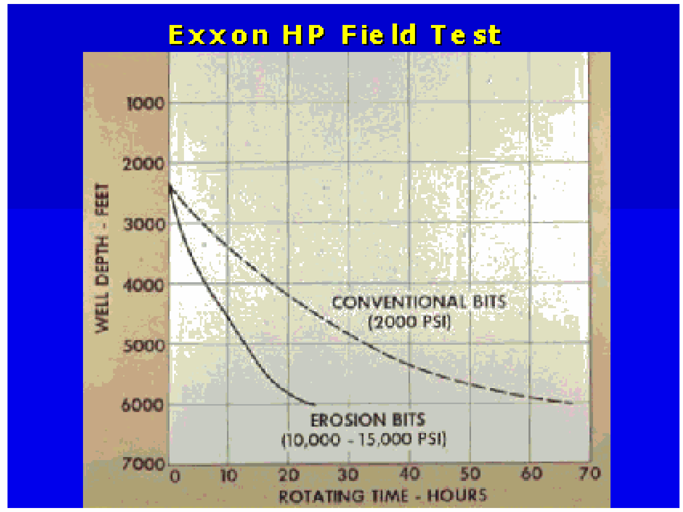
Concentric CT, currently used with insulated steam injector CT (**Figure 10**) and other applications, is preferred with larger diameter wells (over 5") where additional flow rate is needed to effectively clean the hole.

With the *single-flow* system, a conventional PDM motor was modified for HP operation by increasing the outer housing wall thickness to increase burst pressure, and increasing the thrust bearing capacity to handle high hydraulic downthrust loads (**Figure 11**).

With the *dual-flow* system, two hollow titanium flexshafts and a hollow motor rotor are required to transfer the HP fluid from the inner CT to the HP bit nozzles (**Figure 12**).

A *modified dual-flow system* bypasses LP fluid to the wellbore annulus above a *single-flow* HP motor to improve hole cleaning.

Figure 1



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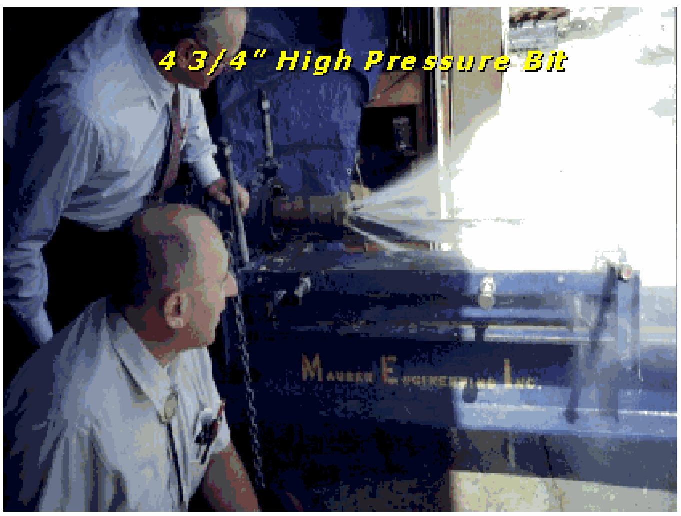
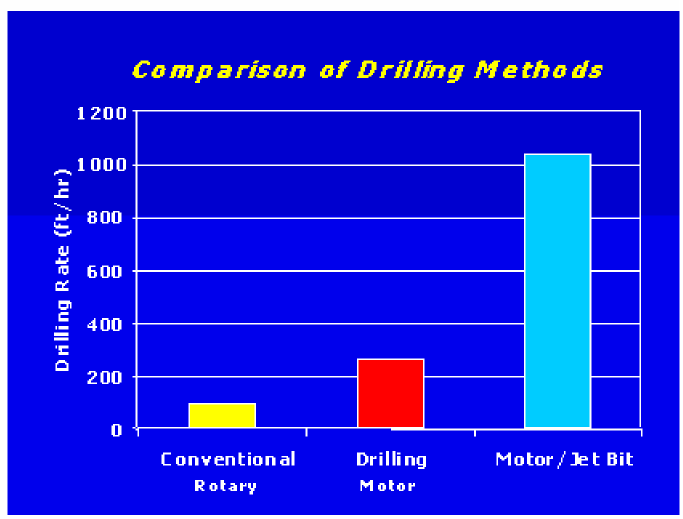


Figure 3

Figure 4

Figure 5



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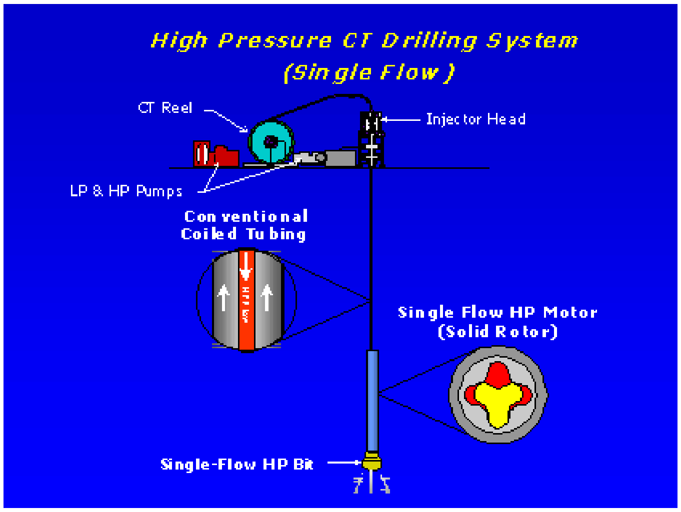

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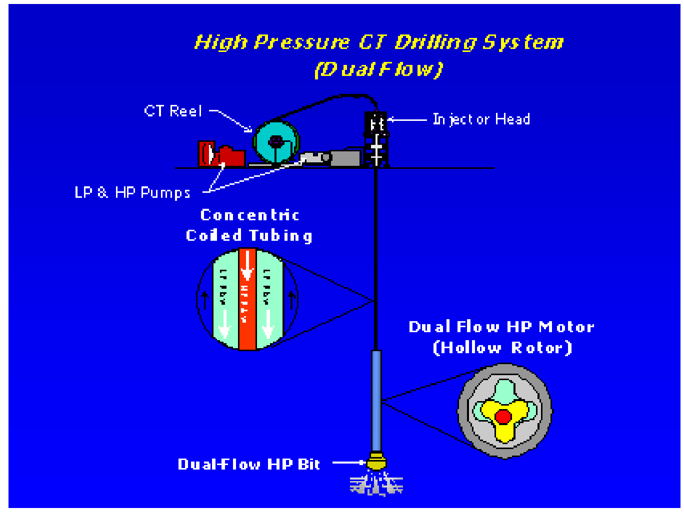

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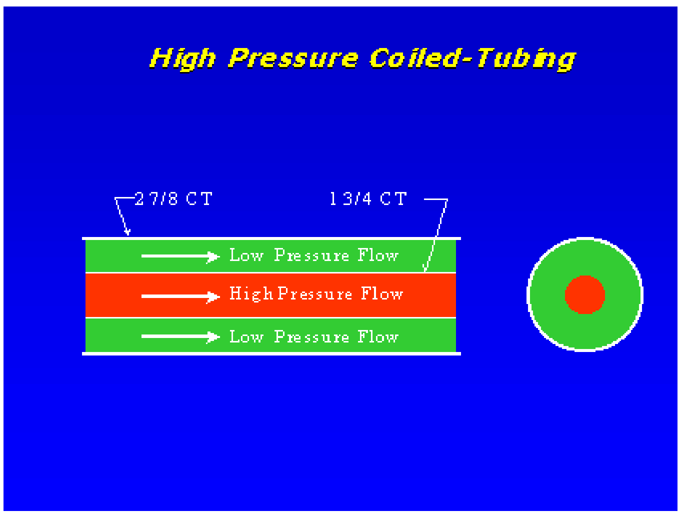

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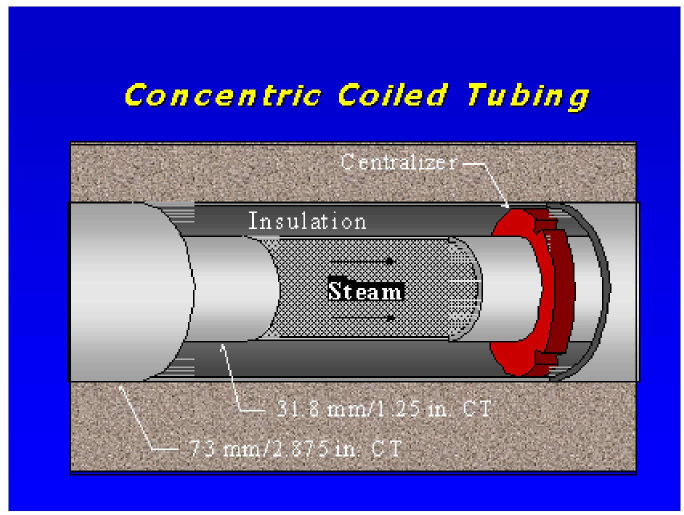

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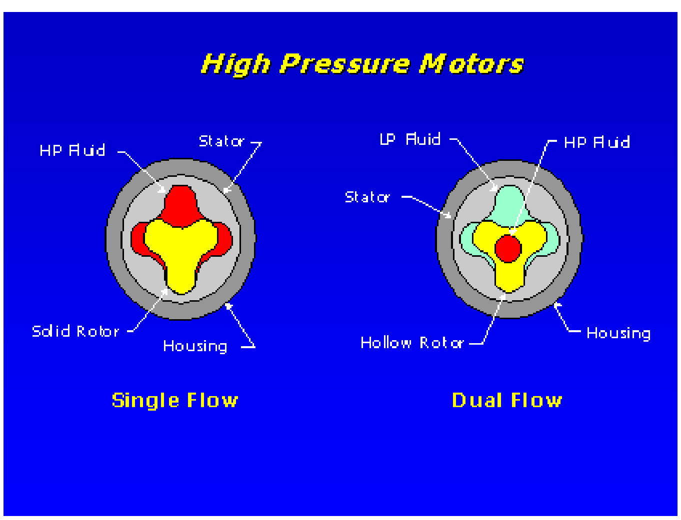


Figure 11

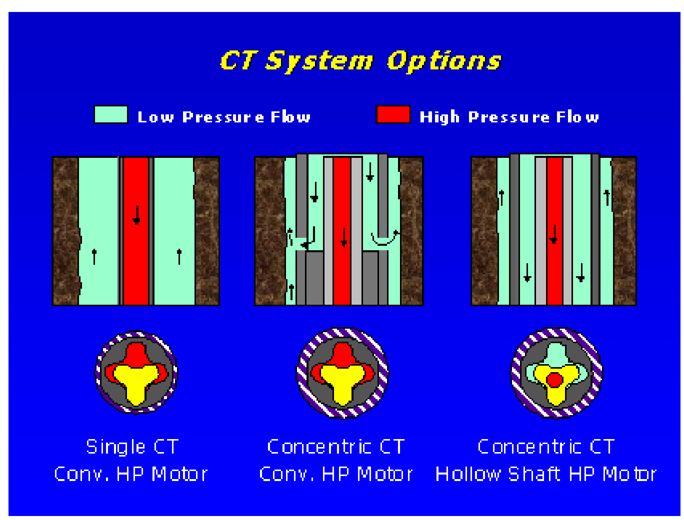


Figure 12

The Phase I Advisory Committee recommended that the *single-flow* system be developed during Phase II for use in smaller diameter holes (5" and smaller) due to its simplicity, lower cost and higher reliability. The more complicated *dual-flow* system shown in **Figure 8** will be developed later, once the *single-flow* system is commercialized.

PROJECT ACCOMPLISHMENTS

The high-pressure (HP) motor and HP CT rig components have been designed and the HP CT motor is now being assembled (**Figure 13**).

The HP motor (10,000 psi) utilizes several advanced features including special PDM rotors and stators that operate at high pressure, high-capacity titanium driveshafts and flexshafts, PDC thrust bearings (**Figures 14** and **15**), and labyrinth seals that control leakage at pressures up to 10,000 psi (**Figures 16** and **17**).

The prototype motor is being tested on HP drilling and dynamometer test stands at the Drilling Research Center (DRC) in Houston. These test stands were previously used to test DOE high-power motors.

Conventional CT is available with burst strengths in excess of 10,000 psi and can be used with this CT drilling system (**Figure 18**). Two-inch diameter CT (0.203" wall), which has a burst strength of 19,800 psi, was selected for use with the *single-flow* system. This size CT is a good compromise because it allows adequate flow rates to power the motor and provide good hole cleaning without producing excessive pressure drop inside the CT (**Figures 19** and **20**).

Fatigue failures are a problem when CT is cycled with high internal pressure (**Figure 21**). For example, with 12,000 psi internal pressure, 2 inch QT-1000 CT will fail after 16 cycles. This is adequate for initial field testing, but longer CT life will be needed when this system is commercialized.

QUALITY TUBING is testing Incoloy-625 CT that increases the fatigue life from 16 to 72 cycles and FIBERSPAR SPOOLABLE PRODUCTS is testing carbon fiber composite tubing with a fatigue life in excess of 2,000 cycles (**Figure 22**). The burst strengths of these new materials are considerably higher than conventional steel CT (**Figure 23**).

High-pressure drill bits were designed for use with these systems. The *single-flow* system utilizes bits with only HP nozzles whereas the *dual-flow* system utilizes bits with both LP and HP nozzles (**Figure 24**).

The HP bits will utilize PDC and roller cutters to mechanically remove the rock weakened by the HP jets. This allows these bits to conventionally drill through hard formations that cannot be eroded by HP jets, and eliminates the need to pull the HP bits when hard streaks are encountered.

Exxon utilized HP bits with diamond, drag and roller cutters so the bits could be optimized for all types of rocks ranging from soft shales to hard dolomites (**Figure 25**).

The HP roller and PDC bits shown in **Figures 26** and **27** were designed during this project. PDC bits have the advantage that they allow the HP jets to be distributed across the entire hole bottom to cut multiple grooves in the rock.

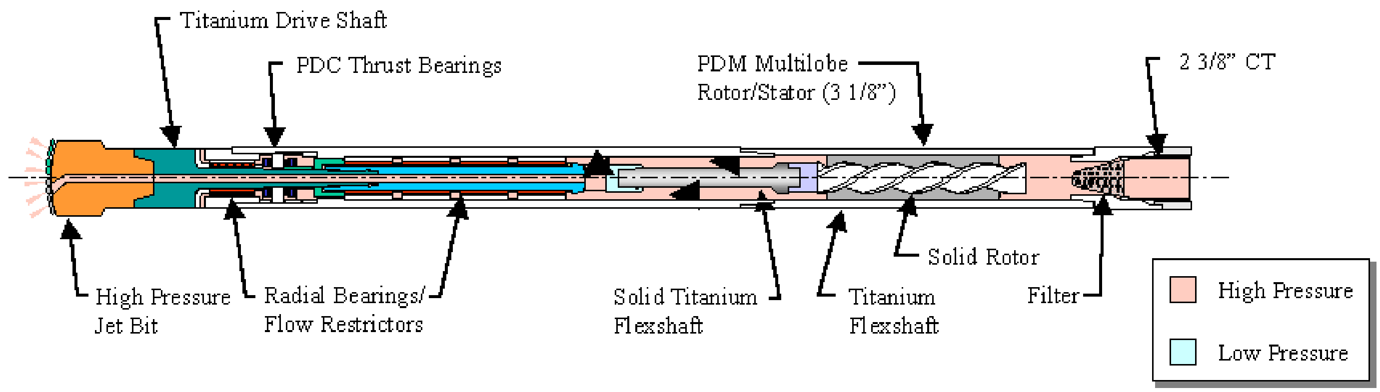
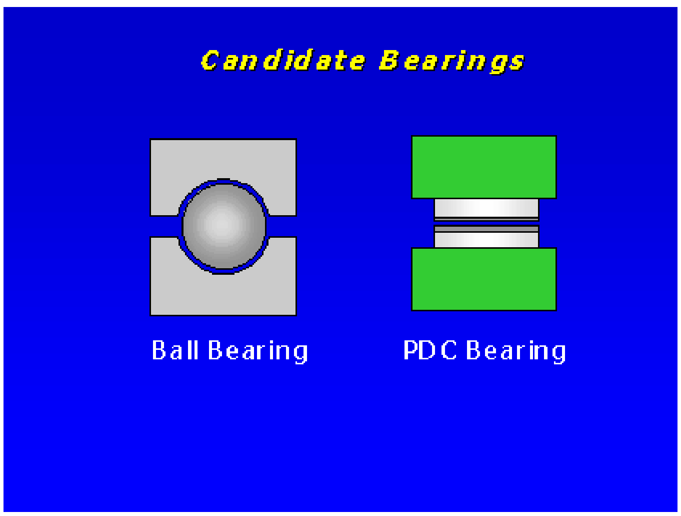


Figure 13. High Pressure CT Motor (Single Flow)



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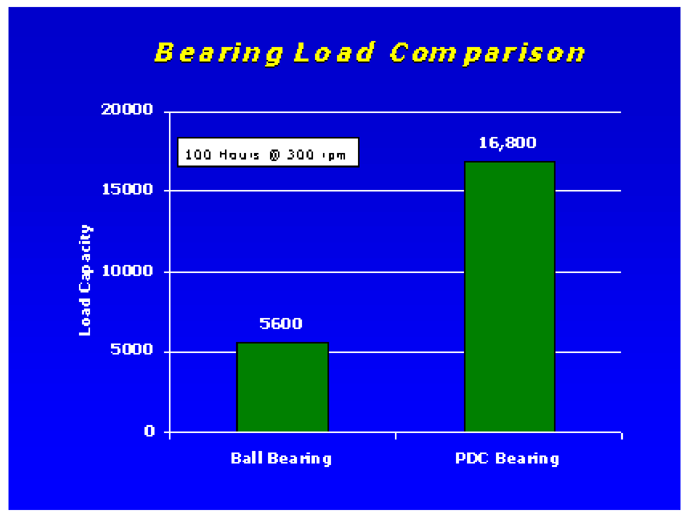

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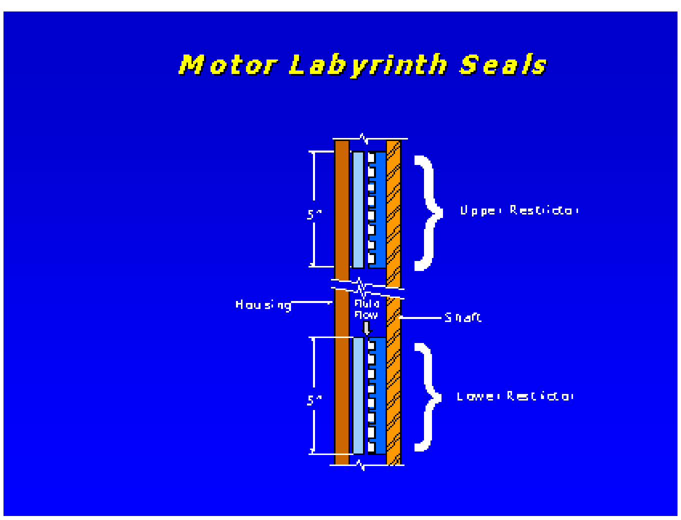

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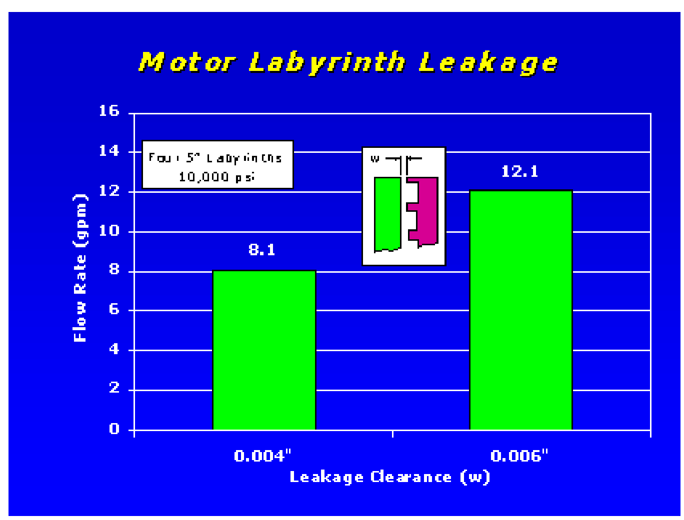
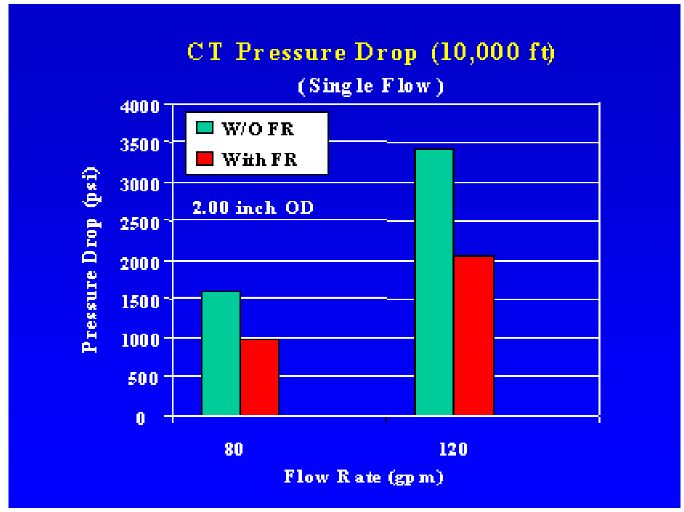


Figure 17

Coiled Tubing Burst Pressure
(100,000 psi yield)

CT Diameter (in.)	Wall Thk. (in.)	Burst Pressure (psi)
1.00	0.109	20,800
1.25	0.156	24,160
1.50	0.175	22,670
1.75	0.188	20,910
2.00	0.203	19,800
2.375	0.203	16,670
2.875	0.203	13,770
3.500	0.203	11,310

Figure 18



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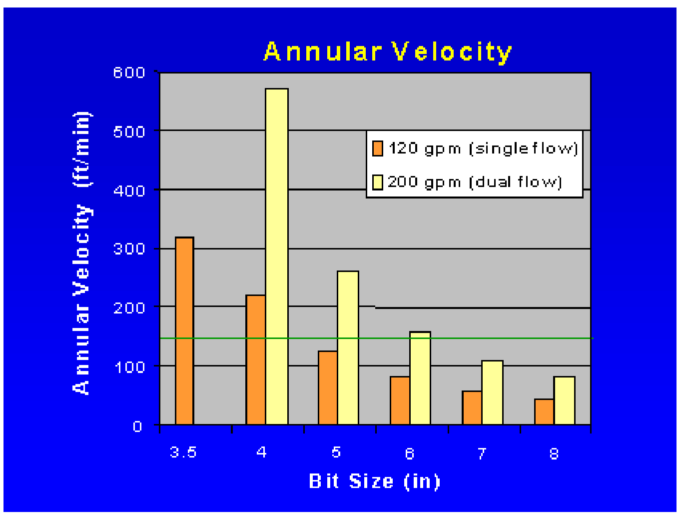

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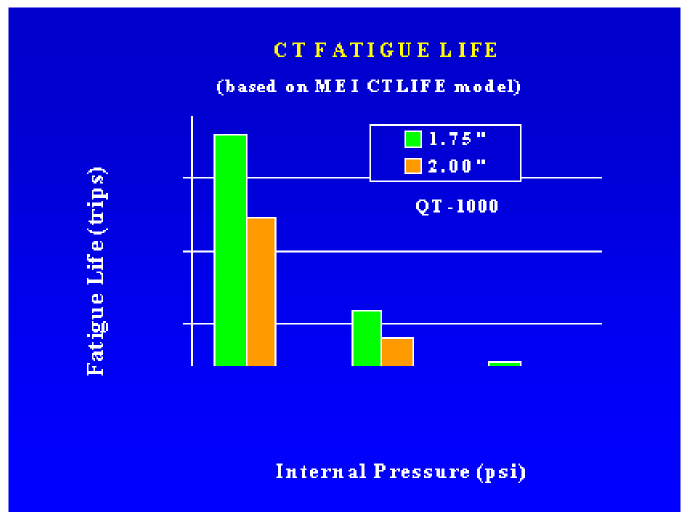

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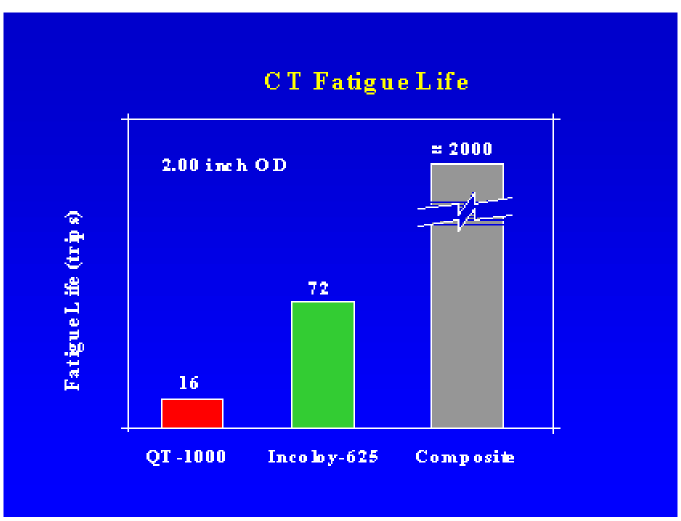

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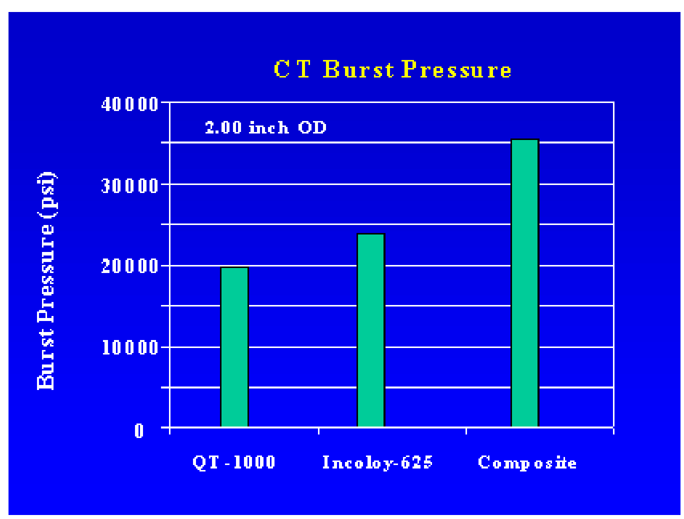

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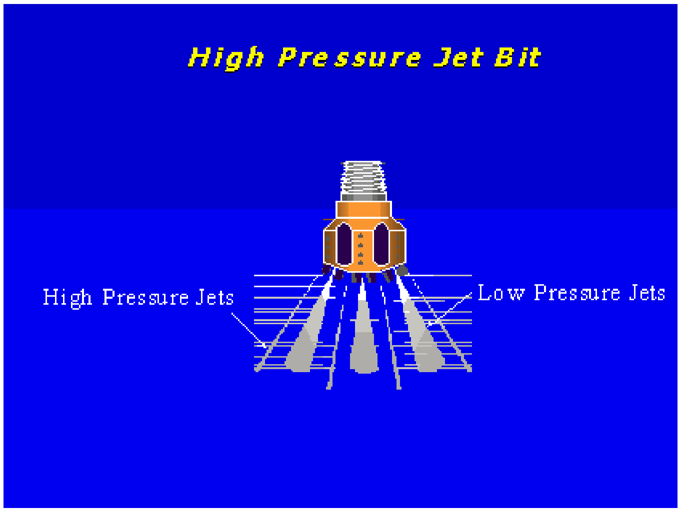

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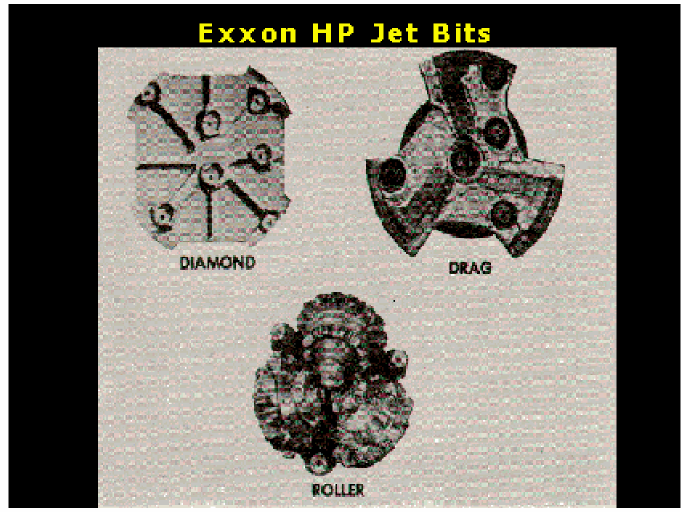


Figure 25

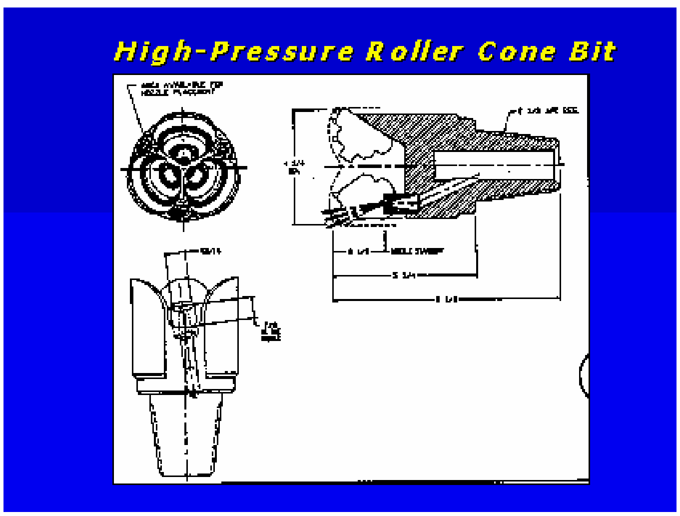
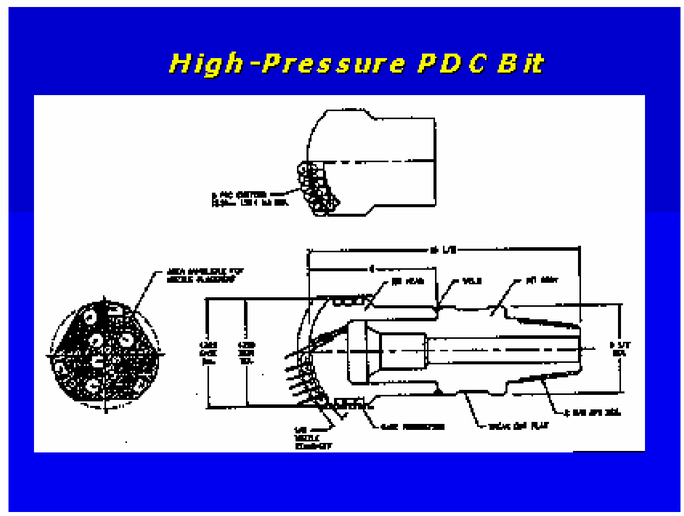


Figure 26



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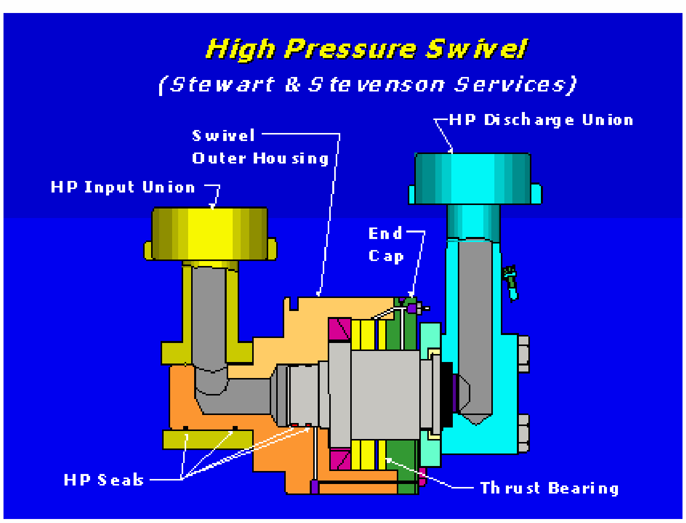

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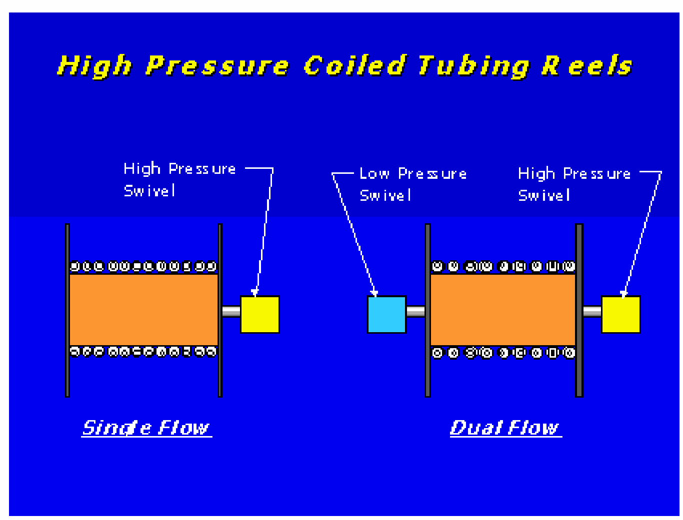

Figure 29

With roller bits, the HP nozzles must be placed on the edge of the bit (due to space constraints) to cut large grooves at the gauge of the hole. Exxon field tests showed that both types of bits are effective, but that PDC bits are preferred in small-diameter holes (3 to 5 inch).

HP bits designed by Exxon, Shell, Gulf and FlowDril performed well in the field and were very reliable, so developing reliable HP bits for use as with this HP CT drilling system will not a major technical problem.

Stewart and Stevenson developed a HP swivel (15,000 psi) for use with the system (**Figure 28**). The *single-flow* system utilizes a HP swivel on one end of the reel shaft to transmit HP fluid to the inside of the CT (**Figure 29**).

With the *dual-flow* system, a conventional low-pressure (LP) swivel will be used on the opposite end of the reel shaft to transmit LP fluid to the annulus between the concentric CT strings. A dual-pressure swivel (LP and HP) could also be used on one end of the reel shaft with the *dual-flow* system.

APPLICATIONS AND BENEFITS

The high-pressure CT drilling system should drill 2 to 4 times faster than conventional drills and reduce hole-making costs by up to 50 percent and overall well costs by 25 percent. This CT drilling system will find application in slim hole and underbalanced drilling and operations.

FUTURE ACTIVITIES

Following Phase II laboratory tests, the HP CT system will be tested including the HP motor, the HP swivel developed by Stewart and Stevenson and the HP CT developed by Quality Tubing. The system will then be commercialized following full-scale field testing.

ACKNOWLEDGMENTS

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