Coiled-Tubing High Pressure Jet Drilling System

April 19, 2001

Dr. William C. Maurer
Comparison of Drilling Methods

- Conventional Drilling
- Motor/Jet Bit Drilling
- Rotary Drilling
- Motor Drilling
- Motor/Jet Bit Drilling

Drilling Rate (ft/hr)

0 200 400 600 800 1000 1200

Conventional Drilling
Motor/Jet Bit Drilling
Rotary Drilling
Motor Drilling
Motor/Jet Bit Drilling
High Pressure CT Drilling System (Single Flow)

- CT Reel
- Injector Head
- LP & HP Pumps
- Conventional Coiled Tubing
- Single Flow HP Motor (Solid Rotor)
- Single-Flow HP Bit
Project Participants

- Maurer Engineering - Motors and Bits
- Quality Tubing - HP Coiled Tubing
- Stewart & Stevenson - CT Rig
- BJ Services - Field Operations
- Marathon - Operator Requirements
- ARCO - Operator Requirements
HP Motor Design

Curtis Leitko
High Pressure CT Motor (Single Flow)

- Titanium Drive Shaft
- PDC Thrust Bearings
- PDM Multilobe Rotor/Stator (3 1/8”)
- Solid Rotor
- Filter
- High Pressure Jet Bit
- Radial Bearings/Flow Restrictors
- Solid Titanium Flexshaft
- Titanium Flexshaft
- Low Pressure
Thrust Load on Bearing

10,000 PSI

Seal
Housing
Thrust Bearing
Bit

34,000 lb
Force
Candidate Bearings

Ball Bearing

PDC Bearing
Bearing Load Comparison

100 Hours @ 300 rpm

Ball Bearing: 5600
PDC Bearing: 16,800
Motor Labyrinth Seals

- **Housing**: Fluid Flow
- **Shaft**: 5"
- **Upper Restrictor**: 5"
- **Lower Restrictor**: 5"
Motor Labyrinth Leakage

Four 5” Labyrinths
10,000 psi

Leakage Clearance (w) vs. Flow Rate (gpm)

- Leakage Clearance (w): 0.004" and 0.006"
- Flow Rate (gpm): 8.1 and 12.1

- 8.1 gpm for 0.004" leakage clearance
- 12.1 gpm for 0.006" leakage clearance

- Four 5” Labyrinths at 10,000 psi
Advanced Geothermal Turbodrill (AGT)
Planetary Gears

- Sun Gear
- Planet Gears
- Ring Gear
Turbodrill Performance

<table>
<thead>
<tr>
<th>Rotary Speed (RPM)</th>
<th>Torque (ft-lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>85</td>
<td>900</td>
</tr>
<tr>
<td>1100</td>
<td></td>
</tr>
<tr>
<td>7500</td>
<td></td>
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</table>

- With Gear Box
- Without Gear Box
HP Bit Design
High Pressure Jet Bit

High Pressure Jets
HP Coiled-Tubing Design

John H. Cohen
### Coiled Tubing Burst Pressure

*(100,000 psi yield)*

<table>
<thead>
<tr>
<th>CT Diameter (in.)</th>
<th>Wall Thk. (in.)</th>
<th>Burst Pressure (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>0.109</td>
<td>20,800</td>
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<tr>
<td>1.25</td>
<td>0.156</td>
<td>24,160</td>
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<tr>
<td>1.50</td>
<td>0.175</td>
<td>22,670</td>
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<tr>
<td>1.75</td>
<td>0.188</td>
<td>20,910</td>
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<tr>
<td>2.00</td>
<td>0.203</td>
<td>19,800</td>
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<tr>
<td>2.375</td>
<td>0.203</td>
<td>16,670</td>
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<tr>
<td>2.875</td>
<td>0.203</td>
<td>13,770</td>
</tr>
<tr>
<td>3.500</td>
<td>0.203</td>
<td>11,310</td>
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</table>
CT FATIGUE LIFE
(based on MEI CTLIFE model)

Fatigue Life (trips)

Internal Pressure (psi)

Qt-1000

1.75''

2.00''
Fiberspar Spoolable Products

- Production Tubing - *FS PT*
- Line Pipe - *FS LP*
- Coiled Tubing - *FS CT* (for Well Servicing)
First FS CT Field String

6500 Ft. Length, 1.5” OD
CT Burst Pressure

Burst Pressure (psi)

2.00 inch OD

- QT-1000
- Incoloy-625
- Composite
Hybrid Coiled Tubing

Composite CT

Steel CT
High Pressure Motor Tests

John H. Cohen
Mud Motor Dynamometer Test Stand
10,000 psi
CT High Pressure Jet Drilling Rate

Leauder Limestone 3-1/8” Bit

Drilling Rate

1800
1600
1400
1200
1000
800
600
400
200
0

Rotary
Conventional
High Pressure

Motor
Motor

150
300
1600
A Noble Drilling Corporation Subsidiary

DOE High-Pressure Coiled Tubing Drilling System

Phase III Commercialization

William C. Maurer
August 8, 2000
Objective: Field test and demonstrate prototype CT Drilling System

Start Date: Oct. 1, 2000
Phase III Budget: $3,152,498
DOE Phase III Funding: $1,585,556

Sub Contractors: BJ Services, Quality Tubing
Phase III Tasks

1. Conduct shallow field test
2. Modify system
3. Conduct deep field test
4. Develop Commercialization Plan
5. Write Final Report
Phase III Plans

- Shallow field tests: Catoosa
- Deeper field tests: Marathon Oil
- Commercial tests: BJ Services
High Pressure Bit

Conventional Coiled Tubing

High Pressure Motor

High Pressure Flow
Jet Slotting Stimulation

High Pressure Jets

Formation Damage

Slots

High Pressure Jets

ROCK
Formation Damage Mechanism
(*Timmerman, 1982*)

Pressure profile in the formation

\[ D_p^{\text{skin}} = \text{Pressure drop across the damaged zone} \]

Skin or zone of damage
"In most homogeneous matrix situations, the physical depth of solids invasion tends to be shallow (1-2 cm into the formation)"

(Bennion et al., 2000)
Well Bore Helical Slotting
Glacier Bluff Dolomite 10,000 psi Jet
Texas Cream Limestone 10,000 psi Jet
Cement Tubing High Pressure Jets Drilling Cement
CT Cement Cleanout Rates

- Low Pressure 10,000 psi

ROP (ft/hr):
- 0
- 60
- 1000

Low Pressure 10,000 psi

Maurer Technology
Cement Cleanout Assumptions

- Conventional ROP = 60 ft/hr
- Jet ROP = 600 ft/hr
- Conv. CT Rig = $10,000/day
- Jet CT Rig = $20,000/day
- Land Rig = $5,000/day
- Offshore Rig = $200,000/day
- Well Depth = 10,000 ft.

Conv. Land Cost = \( \frac{($10,000 + $5,000) \times 10,000}{60 \times 24} \) = $104,000
Cement Cleanout Costs
(Land Well)

Cost

Cleanout Costs ($1000's)

120
100
80
60
40
20
0

104

Cost

21

Conventional
Jet
Cement Cleanout Costs
(Offshore Well)

<table>
<thead>
<tr>
<th>Cost</th>
<th>Conventional</th>
<th>Jet</th>
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<tbody>
<tr>
<td>0.15</td>
<td>1.46</td>
<td>0.0</td>
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<tr>
<td>0.2</td>
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<tr>
<td>0.4</td>
<td></td>
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</tr>
<tr>
<td>0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.8</td>
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<tr>
<td>1.0</td>
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<tr>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.6</td>
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The diagram shows the cost comparison between conventional and jet methods for cement cleanout in offshore wells. The conventional method has a higher cost compared to the jet method.
Barite Scale Removal

- Tubing
- High Pressure Jets
- Barite Scale
High Pressure Jets

Jetting slots

Cleaning Slotted Liners

Open slots

Tubing

Plugged slots

High Pressure Jets

ROCK
Hole Reaming/Cleaning

- Predrilled Hole
- Reamed Hole
- High Pressure Jets
- Hole Guide
- Predrilled Hole

ROCK
Drilling (Horizontal)
Phase III Commercialization

- BJ Services
  - CT field operations
- Quality Tubing
  - High Pressure CT
- Marathon Oil
  - Field test sites
- Maurer Engineering
  - HP motor/bit development
The End

Visit our web site: www.maureng.com
### Potential Market

<table>
<thead>
<tr>
<th>Applications</th>
<th>Number Wells</th>
<th>Income Per Well</th>
<th>Annual Income</th>
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</thead>
<tbody>
<tr>
<td>Drilling</td>
<td>500</td>
<td>$100,000</td>
<td>$50 Million</td>
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<tr>
<td>Open-Hole Slotting</td>
<td>1000</td>
<td>$30,000</td>
<td>$30 Million</td>
</tr>
<tr>
<td>Cement Cleanout</td>
<td>100</td>
<td>$50,000</td>
<td>$5 Million</td>
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</tbody>
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**Total Income = $85 million/year**