Drilling Motors for 300°C Geothermal Wells

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Geothermal Application

Step 1: Locate Site
Characterize and Select Site
Drill and Log Exploratory Well

Steps 2-3: Create Reservoir
Drill Injection Well
Stimulate/Create Reservoir
Drill Production Well

Steps 4-5: Operate System
Complete and Verify Circulation Loop
Install Operating Equipment
Objectives

- Drilling system (Bit, Drilling Fluid, Mud Motor) specifications:
  - 300°C temperature
  - 25ksi pressure
  - 10km depth
  - Water based muds
  - 50 hour mission
  - Steerable
  - Drill through granite formations
Typical Drilling Assembly

- Top Sub
- Power Section (Rotor & Stator)
- Flex Shaft
- Upper Bearing Unit
- Stabilizer
- Lower Bearing Unit
- Bit Box
- Tricone Rolling Cone Bit
- Adjustable Kick Off
Drilling Motor Parameters

- 6-3/4” OD
- Low speed 5/6 lobe ratio
- 4000 ft*lbs torque
- Flow rate ~250-650 gpm
- 100 RPM
- 50,000 lbs WOB

- Address elastomers not suitable to 300°C
  - Seals
  - Stator
  - Adhesives and lubricants

- Ability to machine metal stators
- Crucial machining of rotors considering tight gap with stator
Sealing Technology

- Current design elastomers would not survive 300°C

- Solutions
  - Metallic Bellows used in drill bit pressure compensator
  - FFKM O-rings used in mud motor
Stator Material Solution

- Development of a metal to metal power section
  - Metal stator

- Several heat treatment techniques analyzed
  - Entire stator heat treated
  - Sections cut and tested for uniformity
Rotor Coatings

- Since metal to metal contact occurs, rotors must be coated to prolong drilling operation
- Coating applied to coupons and analyzed for:
  - Hardness
  - Adhesion
  - Erosion
  - Microstructure
  - Abrasion
- Over 40 coatings tested
  - HVOF
  - Thermal Spray
  - Electro Plating
  - PACVD
Rotor Scanning Technology

- Rotors scanned before and after coating
  - Check for straightness after machining
  - Diameter variation along rotor
  - Uniform application of coating thickness
Testing

- High temperature test stand needed to test the durability and performance of metal to metal rotor/stator combination
- Performance mapping
  - Power output of metal-metal vs. rubber stator motor
  - Power output as function of gap
  - Power output as function of wear
- Find ideal combination of the different coating and heat treatment options

- Stand designed for smaller sized rotor stator for ease of handling
- Opposite operation of mud motor: operates as a pump
- Test stand specifications:
  - 300°C temperature
  - 4-3/4” size rotor/stator
  - Water and lubricant fluid to circulate (no solids)
Test Stand

Concept

Actual
Rotor/Stator Test Stand Results

- All stators with same heat treatment
- >10 different rotor coatings
- Baseline test with elastomer stator
- Performance test at room temperature
- Endurance test at high temperature

Test Conclusions
- Smaller rotor stator gap better performance
- Better efficiency for metal-metal vs elastomer stator
- Rougher surface texture impacts coating life
Flow Loop Results

- Entire motor assembly flow tested at room temperature
  - Flow range: approximately 250-750 gpm
  - Water/lubricant only

- Max torque achieved ~7000 ft*lbs (limited by flow loop capability)
- Efficiency ~30% where conventional motors 40-60%
- Durability test at 660 gpm started to lose speed 5rpm/20hrs

Coating wear on lobes
Field test results

- 2 runs at Baker Hughes drilling platform facility in Oklahoma
- Unable to run at 300°C
- Demonstrate functionality

Run 1
- Vertical only
- 2 motors with different rotor coatings
- Drilled through granite
- 1st motor operated for 17.5 hours and drilled 197 feet
- 2nd motor operated for 5 hours and drilled 41 feet
- Upon inspection, some coating chipped away
  - Change in stator profile startup should fix chipping issue
Field test results Run 2

- Main concept to demonstrate steering
- 11 hours of drilling through granite
- BUR (Build Up Rate) of 6°/100ft
- Testing concluded due to rig time

Motor w/Adjustable Kick Off
Going forward

- Ready for upcoming geothermal well
  - 3 prototypes assembled
  - Tricone bits
  - Drilling fluid
- More coated rotors to test in high temperature stand
- Stator profile changes
- Bit design changes
- Improvements in rotor machining
- 300°C MWD directional system

Thank you!