Achieving exceptional reliability thru key initiatives on an enabling drilling technology

Principles that have allowed for a near perfect operating performance of the Continuous Circulation System
Maintaining and Achieving Success

- Continuous Circulation System Overview
- Philosophy and Principles of Design
- Training, Implementation and Tracking
- Testing
- Reliability Statistics/Case histories
- Summary Comments
What is the CCS

A system to allow leaving the pumps on and maintain continuous down hole circulation throughout the drilling process including making & breaking drill pipe connections while making connections with jointed pipe.
Components of the CCS

Pipe Guide

Snubbing Head

Snubber Slips

Torque/Spin Gear

Upper Pipe Ram

Blind Ram

Lower Pipe Ram

Mud Valves

Snubbing Cylinders

Lower Slips
Components of the CCS
Rig Layout
Rig Layout

CCS Main Unit
Rig Layout

Mud Diverter Skid
Rig Layout

Top Drive Interface
Rig Layout

Control Container
Rig Layout

Control Panel (HMI)
System Components and Layout

CCS Main Unit

Mud Diverter Skid

Top Drive Interface

Control Panel (HMI)
CCS Specifications

- Working Pressure: 5,000 psi
- API Bore size: 9"
- Drill pipe size range: 3-1/2" to 5-7/8"
- Torque capacity: 70,000 ft-lbs
- Mud circulation: 1000 gpm
Philosophy of Design

Jet Engine Reliability

Zero interrupted Circulation Event
Principles of Design

• Redundancy where Practical
  – Personnel
  – Valves
  – Hydraulic Pumps
  – Multiple Operational modes

• Use of Field proven Technology
  – BOP’s
  – Slips
  – Rams

• Profibus communications network
  – Redundancy where Practical
Test Fixtures: Ram Rubber
Test Fixtures: Tool Joint Torque Testing
Pipe dope retention tests
Training School

- Comprehensive dedicated school 80 hours
  - All service technicians must attend
    - Must attend every two years refresher
  - Electrical schematic reviews
  - System Hardware and Software updates
  - Lessons Learned Review

- Selective process
  - Service Engineers are top performers at the NOV training center
Competency training

THE QUALIFICATION PROCESS
– The qualification process includes educational, training, and evaluation activities.

THE ASSESSMENT PROCESS
– Determine
– Record
– Report

Continued Shop and ON the Job Training
Complicated Tool

- The CCS is a tool fit for Purpose
  - Complicated tool
    - Snubbing
    - Iron rough neck
    - Mud flow management
    - Pressure containment
    - String hang-off
  - Complicated Controls
    - Electronic / Hydraulics
  - Complexity has lead to an evolutionary design improvement process
Records & Reporting

• Daily Record & Report for client and service contractor

NO Secrets

Daily Report        Issues Log        Maintenance Log
Real-time Monitoring

Client Engineers Office

Mobile Engineer (SME)  e-Hawk SERVICE CENTER

Client Rig

International Assistance

NOV Subject Matter Expert (HOME)
Function Acceptance Test

• Performed prior to shipment of equipment to job site
  – Full Report made and reviewed with focus on fixing all issues
  – Customer witnessed
• On site after rig commissioning
  – Performed in non critical section of Well
    • FAT specific procedure completed
Test fixtures

• Norway

• Houston

• Egypt
Maintenance between Jobs

5 year overhaul
• Thorough between well maintenance
  – Rebuild all valves
  – Fully lubricate all moving components
  – Replace the BOP wear sleeves
  – Monitor fluids
  – Monitor corrosion
  – 3rd party review of electrical components
  – Outfitted with all new replacement parts
    • Consumables
## Consumables

- **Tracking**
  - Number of connections made
  - Stripping length
  - Preventative consumable replacement schedule
  - Full complement of spares

## Connection Details

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<thead>
<tr>
<th>Connection Number</th>
<th>Connection Start Time</th>
<th>Connection End Time</th>
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<td>124</td>
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<tr>
<td>10</td>
<td>124</td>
<td>124</td>
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</table>

## Routine Maintenance

- **SNUBBER TOP HAT CAP BOLTS**
  - Visually checked after connection

- **SNUBBER TOP HAT CAP BOLTS/SNUBBER SLIP ENGAGE CYLINDERS**
  - Checked after connection

- **TORQUE RINGS & SEAL SEATS**
  - Removed, cleaned, and refitted after connection

- **Wear rings & seal seats**
  - Removed, cleaned, and refitted after connection

- **DP SLIPS & DIES**
  - Changed after connection

## Weekly Checks

- As per MTS 095 completed

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**Contact Information**

- **E-Hawk** Tel: +1 713 980 8516
- **Houston Tech Support** Tel: +1 832 657 7329
- **Montrose Tech Support** Tel: +14 1674 677222

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**Notes**

- **Check Fill Orifice Bean for Wear**
  - Every 30 connections

- **Check HPU Pressures/Temperature**
  - Every hour, record same on HPU Pressure/Temperature Record Sheet

- **Check Torque on SnuBBer ‘Top Hat’ Cap Bolts (1200ft/lbs) when UPRs are changed out**

- **Check Torque on SnuBBer Slip Engage Cylinder Base Retaining Bolts (400lb) = 15 Connections**

- **Check Torque on SnuBBer Top Hat Cap Bolts (1200lb) = 25 Connections**
  - When UPRs are changed out

- **Check Torque on SnuBBer Slip Engage Cylinder Base Retaining Bolts (400lb) = 15 Connections**

- **Check**
  - Fill Orifice Bean for Wear = 25 Connections

- **Remove & Inspect/Clean Upper/Lower & Middle Wear Rings & Seal Seats (if operations permit) = 100 Connections**
  - If slip dies to be renewed = 150 Connections
# End Of well Report

<table>
<thead>
<tr>
<th>Item #</th>
<th>Activity</th>
<th>Required</th>
<th>Yes/No</th>
<th>Inspection Report</th>
<th>Completed By</th>
<th>Date Completed</th>
<th>Comments</th>
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<tr>
<td>6.1</td>
<td>Open pressure vessel doors.</td>
<td>✓✓</td>
<td>BR &amp; MG</td>
<td>18/12/08</td>
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<tr>
<td>6.2</td>
<td>Remove ram blocks from ram shafts, remove ram rubbers from ram blocks, dress any damage to blocks using a file.</td>
<td>✓✓</td>
<td>BR &amp; MG</td>
<td>19/12/08</td>
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<td></td>
<td>Ref MTS 073, Issue 1, Rev D</td>
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<td>6.3</td>
<td>Inspect ram shafts for damage &amp; any leakage.</td>
<td>✓✓</td>
<td>BR &amp; MG</td>
<td>19/12/08</td>
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<td></td>
<td>Photographs to be taken</td>
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<tr>
<td>6.4</td>
<td>Remove pressure vessel door cartridge seal carriers for inspection/cleaning, inspect springs for any damage, replace as required, clean all mud residue from seating area.</td>
<td>✓✓</td>
<td>BR &amp; MG</td>
<td>19/12/08</td>
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<td></td>
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<td>6.5</td>
<td>Remove wear ring retaining side pads.</td>
<td>✓✓</td>
<td>BR &amp; MG</td>
<td>19/12/08</td>
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<tr>
<td>6.6</td>
<td>Remove lower wear ring from upper pressure vessel, clean all mud residue from seating area &amp; wear ring, inspect wear ring for erosion.</td>
<td>✓✓</td>
<td>BR &amp; MG</td>
<td>19/12/08</td>
<td></td>
<td>6 x 7/16” UNC x 2” LG jacking bolts reqd, photographs to be taken</td>
<td></td>
</tr>
<tr>
<td>6.7</td>
<td>Remove upper seal seat from upper pressure vessel, clean all mud residue from seating area &amp; seal seat, inspect seal seal for erosion.</td>
<td>✓✓</td>
<td>BR &amp; MG</td>
<td>19/12/08</td>
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<td>Photographs to be taken</td>
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<tr>
<td>6.8</td>
<td>Grease wear ring seating area in upper pressure vessel, grease lower wear ring &amp; refit wear ring in upper pressure vessel, refit wear ring retaining side pads.</td>
<td>✓✓</td>
<td>BR &amp; MG</td>
<td>19/12/08</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>6.9</td>
<td>Grease seal seat seating area in upper pressure vessel, grease upper seal seat &amp; refit seal seat to upper pressure vessel.</td>
<td>✓✓</td>
<td>BR &amp; MG</td>
<td>19/12/08</td>
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<tr>
<td>6.10</td>
<td>Grease cartridge seal seating area &amp; refit pressure vessel door cartridge seals.</td>
<td>✓✓</td>
<td>GT</td>
<td>30/12/08</td>
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<tr>
<td>6.11</td>
<td>Rotate all pressure vessel door lock bars checking for freedom of movement, remove all mud residue from lock bar grooves.</td>
<td>✓✓</td>
<td>GT</td>
<td>30/12/08</td>
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<tr>
<td>6.12</td>
<td>Check pressure vessel doors for sagging, re-shim doors if required once doors are closed</td>
<td>✓✓</td>
<td>GT</td>
<td>30/12/08</td>
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<td></td>
<td></td>
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<tr>
<td>6.13</td>
<td>Refit ram block assemblies to ram shafts, lubricate all ram blocks using grease, lightly lubricate external of cartridge seals, lightly lubricate lockbar grooves on pressure vessel doors, close pressure vessel doors.</td>
<td>✓✓</td>
<td>GT</td>
<td>30/12/08</td>
<td></td>
<td>Ref MTS 073, Issue 1, Rev D</td>
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<tr>
<td>6.14</td>
<td>Once pressure vessel doors are closed &amp; lock bars locked, remove all pressure vessel lockbar locking bolts from lockbar holder assembly for inspection/replacement</td>
<td>✓✓</td>
<td>MH &amp; GW</td>
<td>06/01/09</td>
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<tr>
<td>6.15</td>
<td>Remove J-Plates from pressure vessel and clean all mud residue from behind the J-plate, inspect all door rollers for freedom of movement, replace as required</td>
<td>✓✓</td>
<td>GT</td>
<td>30/12/08</td>
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<tr>
<td>6.16</td>
<td>Refit J-Plates to pressure vessel</td>
<td>✓✓</td>
<td>GT</td>
<td>30/12/08</td>
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<tr>
<td>6.17</td>
<td>Refit lockbar locking bolts into lockbar holder assembly, check security of lock bar safety clip</td>
<td>✓✓</td>
<td>MH &amp; GW</td>
<td>06/01/09</td>
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</tbody>
</table>
Rig Survey

- Comprehensive pre-installation Rig Survey

Rentals CCS Pre - Survey Information

Introduction: The information requested below is required to confirm how CCS will be integrated into the existing rig systems and prepare NOV Engineering for a rig site survey.

1) Drill Pipe:
   a. Size?
   b. Type?
   c. Length?
   d. Make up torque and expected down hole make up?

2) When continuous circulation is needed, what is the lightest the drill string is expected to weigh?

3) What is the stand pipe size and pressure rating?

4) Rig Specific Data
   a. What type of rig is it? Jack-up, etc.
   b. Who is the classification authority (i.e. ABS, Lloyds Register, etc.)

5) Does the bottom-hole assembly utilize filters or screens?

6) Is High-Speed internet available?

7) Rig Floor Equipment:
   a. Top Dive Make and Model?
   b. Derrick height?

8) What is the stand pipe size and pressure rating?

9) What is the expected flow rate?

10) Drilling Program:
    a. Estimated hole depth and length?
    b. Estimated well bore pressure?
    c. Mud type and weight?
    d. Estimated job duration?
    e. Is H2S expected?
    f. Is the well considered to be HPHT?
Daily Logs

StatoilHydro 13 November 2008

Company: Daily Logs
Norwegian Sector, North Sea

Operations @ 06:00
Current MD: Inclination:
5726 mtr 4232 m

Standby for CCS connection. Assisted with PCWD operations. 0:17
Pumped OOH to 5450 m with 2 x wet CCS connections. Reamed & re-logged 8 1/2" open hole to TD with 10 wet CCS connections. Circulated BU and displaced well to 1.97 sg Cs/K mud. Pumped OOH from 5726-5650 m. Assisted with PCWD operations.

OPERATIONS DETAIL

CCS
RIG
CCS wet connection POOH
Pumped OOH with BHA from 5517m with 1100 lpm, SPP 212 bar, PWS choke 36 bar, EMW 1.94 sg. Standby for CCS connection. Assisted with PCWD operations. 0:19
6:00
Down-linked and reset Sonic/Minitron tools. Took survey to check sonic tool.

CCS Wet connection # 101 POOH
CCS Wet connection # 102 POOH
CCS Wet connection # 103 RIH CCS Wet connection # 104 RIH CCS Wet connection # 105 RIH

Reamed 8 1/2" hole from 5450 - 5570m with 1000 lpm, SPP 190 bar, 80 rpm, torque 36-38 kNm, PWS choke 38-39 bar, EMW 1.94 sg. Continued to ream 8 1/2" hole from 5450 - 5570m with 1000 lpm, SPP 190 bar, 80 rpm, torque 38-40 kNm, PWS choke 37-39 bar, ROP 60 m/hr, EMW 1.94 sg. Standby for CCS connection. Assisted with PCWD operations.

CCS Wet connection RIH

Continued to ream & re-log 8 1/2" hole from 5570 - 5721m with 1000 lpm, SPP 190 bar, 80 rpm, torque 38-40 kNm, PWS choke 37-39 bar, ROP 60 m/hr, EMW 1.94 sg.

CCS Wet connection RIH

SAFETY ISSUES
Operations Issues:

Pipe Dope Type:
Pump OOH to 5450 m. Rig down CCS from well centre. Resume POOH according to HPHT procedure. Commence final rig down of

<table>
<thead>
<tr>
<th>Part #</th>
<th>Start</th>
<th>Received</th>
<th>Qty Due/Date</th>
<th>Used</th>
<th>Qty Used/Date</th>
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<tr>
<td>5&quot; NC50 VAM EIS</td>
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<th>Start</th>
<th>Received</th>
<th>Qty Due/Date</th>
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<td>2 x Ram Rubbers, part # 20011625</td>
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</table>

HCU Pressures/Temp:
Pump # 1:
2800 psi

Pump # 2:
3000 psi

Pump # 3:
3100 psi

Break Torque:
58kNm/42,778 ftlbs

Mud Pump Rate:
600 - 1000 lpm

Bit:
8½" LM 6360 D1

ECD:
Not Applicable

ROP:
60 mtr/hr

Mud Type:
Cs/K mud

Losses:
0 m³

Gains:
0 m³

Frac Pressure:
1.89g/cm³

Programme:
0 m³

BHA:
NB Stabilizer w/float, Float Sub, ARC, MWD Power Pulse, 3 Joints HWDP, Jar, 6 Joints HWDP

Last Casing:
9 7/8 @ 5454m MD (4002.6m TVD)

* CCS NPT:
0 hrs

** Cumulative NPT:
0 hrs

CCS Personnel on Site last 24 hours 06:00 - 06:00

Engineering Supervisor On-Call Dayshift 06:00 - 18:00
Engineering Supervisor Name: David Bissett
Engineering Supervisor Signature:

Nightshift 18:00 - 06:00
Engineering Supervisor Name: Angus Fraser
Engineering Supervisor Signature:

Pipe dope type: API 13A

Date: 14 November 2008

Customer Name: Jon Ross

Customers Signature:
Tracker

Within Tracker, "Tickets" are entered and assigned to NOV personnel to log and track customers requests for the following tasks:

Inspections, Upgrades, Repairs, Installation and Commissioning and other interactions between NOV and our customers.
Dedicated Support Structure

- 24/7 On-call Engineering Support
- Dedicated supporting management
- Committed Operators
  - Operators with tool experience from the tool’s inception
- Full time engineering staff
- Full NOV corporate support
How are we ultimately judged

- Graded on
  - Interrupted circulation Events
  - NPT
Case History

- ECD less than frac pressure
- Mud Weight less than pore pressure
- ECD (Mud Weight plus friction)
- Frac Pressure

Depth: exposed formation, cased, uncased

Pressure: static head, dynamic head

Mud Weight

Pore Pressure
Case History Without CCS

- Top Drive
- BOP stack
- Cased Uncased
- Exposed Formation
- Pore Pressure
- Frac Pressure
- Mud Weight
- ECD (Mud Weight plus friction)
- Static Head
- Dynamic Head
- Connection

ECD less than frac pressure
Mud Weight less than pore pressure

ECD (Mud Weight plus friction)
## History

<table>
<thead>
<tr>
<th>Job</th>
<th>Operator</th>
<th>Date</th>
<th>Well</th>
<th>Connections</th>
<th>Rig</th>
<th>Average Connection time (Min)</th>
<th>Total NPT (Hr: Min)</th>
<th>Lost Circulation NPT (HR:MN)</th>
<th>Lost Circulation Event</th>
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<td>BP</td>
<td>07/03 to 08/03</td>
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<td>Trial</td>
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<td>Maersk Endurer</td>
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<td>Statoil Hydro</td>
<td>12/05 to 03/06</td>
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| Totals | | | | | | | | | 
|--------|------------------|------------------|--------|-------------|-------------------|-------------------------------|---------------------|-----------------------------|------------------------|
|        | 1756             | 23 Min           | 64 Hrs | 3 Min       | 1                 |
Summary

• Philosophy
• Principles of Design
• Training, Implementation and Tracking
• Testing
• Reliability