Achieving Exceptional Reliability through Key Initiatives on the Enabling Drilling Technology of the Continuous Circulation System:

Principles That Have Allowed for a Near Perfect Operating Performance
Operating Performance

Connection time

%99.93

Number of connections

%99.95
Maintaining and Achieving Success

+ CCS Overview
+ Philosophy & Principles of Design
+ Training, Implementation, & Tracking
+ Testing
+ Reliability Statistics & Case histories
+ Summary Comments
What is the CCS?

“A system that allows leaving the mud pumps on to maintain continuous down hole circulation throughout the drilling process while making connections with jointed pipe.”
System Components and Layout

- CCS Main Unit
- Mud Diverter
- Skid
- Top Drive Interface
- Control Container
- Control Panel (HMI)
CCS Specifications

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

**ECD Management** - Narrow pore/frac pressure gradient drilling
- Mitigate influx/well bore ballooning effects
- HPHT & UBD Operations

**Time** - Reduce drilling duration & program disruption
- Shorter Total Connection Time (Bit off Bottom to Bit on Bottom)
- Eliminate changing mud weights while tripping in Open Hole
- Fewer stuck pipe incidents

**Quality** - Improve hole condition & ability to step-out in ERD wells
- More effective solids control (eliminates slugs of solids & solids break out)

**Well Control/Safety** - Maintain required OB criteria while circulation
- Reduced likelihood of kicks on connections
Complex 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
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
- Redundant network
Test Fixtures: Ram Rubber
Test Fixtures: Tool Joint Torque Testing
Pipe Dope Retention Tests
Training School

**Comprehensive, dedicated school**
- Required for all service technicians
  - Refresher every two years
- Electrical schematic reviews
- System hardware and software updates
- Lessons learned review

**Selective process**
- Service Engineers are top performers in the field or have gone thru NOV Technical College
Competency Training

Qualification Process
- The qualification process includes educational, training, and evaluation activities.

Assessment Process
- Determine
- Record
- Report

Continued Shop and ON the Job Training
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 Facilities

Houston
Norway
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 Drive 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?
Records & Reporting

Daily Record & Report for client and service contractor → NO Secrets
Daily Logs
## Consumables

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

### Table: RH & POOH With 5" VAM EIS Drill Pipe

<table>
<thead>
<tr>
<th>Date</th>
<th>Connection Depth (BD)</th>
<th>Connection Depth (Reference)</th>
<th>Connection Type (RH or POOH)</th>
<th>Connection Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/21/2020</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Connection Depth (BD):**
- **Connection Depth (Reference):**
- **Connection Type (RH or POOH):**
- **Connection Number:**
- **Number of connections made:**
- **Stripping length:**
- **Preventative consumable replacement schedule:**
- **Full complement of spares:**
Real-time Monitoring
### End of Well Report

#### Table: Equipment Description - Pressure Vessel's

<table>
<thead>
<tr>
<th>Item #</th>
<th>Activity</th>
<th>Required</th>
<th>Yes/No</th>
<th>Inspection Report</th>
<th>Complete d By</th>
<th>Date Completed</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1</td>
<td>Open pressure vessel doors.</td>
<td>✓</td>
<td>✓</td>
<td>BR &amp; MG</td>
<td>19/12/06</td>
<td></td>
<td>Upper doors can only be opened once snubber has been raised 3&quot;</td>
</tr>
<tr>
<td>6.2</td>
<td>Remove ram blocks from ram shafts, remove ram rubbers from ram blocks,</td>
<td>✓</td>
<td>✓</td>
<td>BR &amp; MG</td>
<td>19/12/06</td>
<td></td>
<td>Ref MTS 073, Issue 1, Rev E</td>
</tr>
<tr>
<td></td>
<td>dress any damage to blocks using a file.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.3</td>
<td>Inspect ram shafts for damage &amp; any leakage.</td>
<td>✓</td>
<td>✓</td>
<td>BR &amp; MG</td>
<td>19/12/06</td>
<td></td>
<td>Photographs to be taken</td>
</tr>
<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>✓</td>
<td>BR &amp; MG</td>
<td>19/12/06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.5</td>
<td>Remove wear ring retaining side pads.</td>
<td>✓</td>
<td>✓</td>
<td>BR &amp; MG</td>
<td>19/12/06</td>
<td></td>
<td></td>
</tr>
<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>✓</td>
<td>BR &amp; MG</td>
<td>19/12/06</td>
<td>6 x 7/16&quot; UNC x 2&quot; L6 jacklind bolts red, 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 seat for erosion.</td>
<td>✓</td>
<td>✓</td>
<td>BR &amp; MG</td>
<td>19/12/06</td>
<td></td>
<td>Photographs to be taken</td>
</tr>
<tr>
<td>6.8</td>
<td>Grease wear ring seating area in upper pressure vessel, grease lower wear ring &amp; raft wear ring in upper pressure vessel, raft wear ring retaining side.</td>
<td>✓</td>
<td>✓</td>
<td>BR &amp; MG</td>
<td>19/12/06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.9</td>
<td>Grease seal seat area in upper pressure vessel, grease upper seal seat &amp; raft seal seat to upper pressure vessel.</td>
<td>✓</td>
<td>✓</td>
<td>BR &amp; MG</td>
<td>19/12/06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.10</td>
<td>Grease cartridge seal seating area &amp; raft pressure vessel door cartridge</td>
<td>✓</td>
<td>✓</td>
<td>GT</td>
<td>30/12/06</td>
<td></td>
<td></td>
</tr>
<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>✓</td>
<td>GT</td>
<td>30/12/06</td>
<td></td>
<td></td>
</tr>
<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>✓</td>
<td>GT</td>
<td>30/12/06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.13</td>
<td>Refill rare 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>✓</td>
<td>GT</td>
<td>30/12/06</td>
<td></td>
<td>Ref MTS 073, Issue 1, Rev E</td>
</tr>
<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 fer</td>
<td>✓</td>
<td>✓</td>
<td>MH &amp; GW</td>
<td>06/01/08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.15</td>
<td>Removes J-Plates from pressure vessel and clean all mud residue from behind the J-plate, inspect all door rollers for freedom of movement, replace</td>
<td>✓</td>
<td>✓</td>
<td>GT</td>
<td>30/12/06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.16</td>
<td>Refill all J-Plates to pressure vessel</td>
<td>✓</td>
<td>✓</td>
<td>GT</td>
<td>30/12/06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.17</td>
<td>Refill lockbar locking bolts into lockbar holder assembly, check security of lockbar safety clip</td>
<td>✓</td>
<td>✓</td>
<td>MH &amp; GW</td>
<td>06/01/08</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Tracker

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

- Inspections
- Upgrades
- Repairs
- Installation & Commissioning
- Other interactions between NOV and our customers
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
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
<table>
<thead>
<tr>
<th>Task</th>
<th>Operator</th>
<th>Date</th>
<th>Well</th>
<th>Number of Connections</th>
<th>Rig</th>
<th>Days on rig floor</th>
<th>Av. Total Connection Time (mins)</th>
<th>Av. CCS Operating Time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BP Americas</td>
<td>07/03 to 08/03</td>
<td>Oklahoma Jacobs 9-22</td>
<td>72</td>
<td>Helmerich &amp; Payne Flex III</td>
<td>14</td>
<td>15</td>
<td>13</td>
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<tr>
<td>2</td>
<td>ENI Italia</td>
<td>03/05</td>
<td>Italy Monte ENOC 10</td>
<td>82</td>
<td>Pergamine 7 land rig</td>
<td>11</td>
<td>18</td>
<td>14</td>
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<tr>
<td>3</td>
<td>ENI/ Petrobel</td>
<td>06/05 to 11/05</td>
<td>Egypt PFMD-1</td>
<td>521</td>
<td>Maersk Endurer Jack-up</td>
<td>173</td>
<td>27</td>
<td>14</td>
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<tr>
<td>4</td>
<td>Statoil Hydro</td>
<td>12/05 to 03/06</td>
<td>N.Sea Kristin S-2H</td>
<td>151</td>
<td>Scarabeo 5 Semi</td>
<td>66</td>
<td>19</td>
<td>13</td>
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<tr>
<td>5</td>
<td>Statoil Hydro</td>
<td>06/06</td>
<td>Norway Ulling</td>
<td>31</td>
<td>Ullrig test rig</td>
<td>9</td>
<td>16</td>
<td>13</td>
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<td>6</td>
<td>Statoil Hydro</td>
<td>09/06</td>
<td>N.Sea 34/11-A-02</td>
<td>4</td>
<td>Kvitebjorn Platform.</td>
<td>57</td>
<td>57</td>
<td>13</td>
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<tr>
<td>7</td>
<td>ENI / Petrobel</td>
<td>09/06 to 01/07</td>
<td>Egypt PFMD-2</td>
<td>48</td>
<td>Maersk Endurer Jack-up</td>
<td>145</td>
<td>18</td>
<td>13</td>
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<td>8</td>
<td>Statoil Hydro</td>
<td>03/07 to 07/07</td>
<td>N.Sea A-13</td>
<td>225</td>
<td>Kvitebjorn Platform.</td>
<td>136</td>
<td>22</td>
<td>12</td>
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<tr>
<td>9</td>
<td>Statoil Hydro</td>
<td>10/07 to 11/07</td>
<td>N.Sea A-12</td>
<td>127</td>
<td>Kvitebjorn Platform.</td>
<td>35</td>
<td>26</td>
<td>12</td>
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<td>10</td>
<td>Statoil Hydro</td>
<td>02/08 to 03/08</td>
<td>N.Sea Kristin N-2H</td>
<td>147</td>
<td>Scarabeo 5 Semi</td>
<td>15</td>
<td>22</td>
<td>13</td>
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<tr>
<td>11</td>
<td>Unit 3 FAT</td>
<td>06/08</td>
<td>Norway FAT</td>
<td>93</td>
<td>Test Rig</td>
<td>5</td>
<td>18</td>
<td>N/A</td>
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<tr>
<td>12</td>
<td>Statoil Hydro</td>
<td>10/08 to 11/08</td>
<td>N.Sea A-3</td>
<td>126</td>
<td>Kvitebjorn Platform.</td>
<td>63</td>
<td>25</td>
<td>12</td>
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<td>13</td>
<td>Statoil Hydro</td>
<td>Current</td>
<td>N.Sea A-9</td>
<td></td>
<td>Kvitebjorn Platform.</td>
<td></td>
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<tr>
<td><strong>Totals</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>1627</strong></td>
<td></td>
<td></td>
<td><strong>729</strong></td>
<td><strong>Av. 24</strong></td>
</tr>
</tbody>
</table>
Real Numbers

Connection time
%99.93

Number of connections
%99.95
CCS ECD Management

Normal Connections...

ECD less than frac pressure
Mud Weight less than pore pressure

Connection
Mud Weight
Pore Pressure

ECD (Mud Weight plus friction)
Frac Pressure
Static Head
Dynamic Head

Static Head
Mud Weight
ECD
Unlabeled
Exposed formation
Cased uncased
BOP stack
Top Drive
CCS ECD Management

ECD less than frac pressure
Mud Weight less than pore pressure

Connection
Mud Weight
Pore Pressure

ECD (Mud Weight plus friction)
Frac Pressure

Static Head
Dynamic Head
CCS ECD Management

Result...

ECD less than frac pressure and greater than pore pressure

Mud Weight

Pore Pressure

ECD (Mud Weight plus friction)

Frac Pressure

No Kick
No Ballooning
Summary

Philosophy
Principles of Design
Training, Implementation, & Tracking
Testing
Reliability