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13 Under balanced and managed pressure drilling and completion

13.1 General
This section covers requirements and guidelines for well integrity during underbalanced drilling/completion (UBD) and managed pressure drilling/completion (MPD) operations, using jointed pipe which can be rotated at surface, and the following systems:

- MPD: Systems manipulating annular pressure at surface to control and manage downhole pressures using static underbalanced fluid.
- UBD: Systems manipulating annular pressure at surface to control and manage downhole pressures and formation inflow rates used for drilling hydrocarbon bearing formations (i.e. not air drilling).

The purpose of this section is to describe the establishment of well barriers by use of well barrier elements and additional requirements and guidelines to execute underbalanced operations with hydrocarbons produced to surface and MPD operations in a safe manner.

The standard is written for MPD/UBD operations using a surface BOP. Operations that do not fit the prior description may be allowable, but are not governed by this standard.

13.2 Well barrier schematics
Well barrier schematics (WBS) shall be prepared for each well activity and operation.

Samples of well barrier schematics for selected situations are presented at the end of this section (13.8).

13.3 Well barrier acceptance criteria

13.3.1 General well barrier requirements in UBD and MPD
All well barrier elements shall be rated to withstand the maximum differential pressure expected for planned operation mode (UBD or MPD) including a predefined safety factor. The MPD/UBD system rating is given by the element with the lowest pressure rating which shall be protected by a pressure relief system.

MPD and UBD operations have common well barrier elements. These elements are listed in the respective EAC tables. In addition, the following apply:
a) A complete list of possible leak paths shall be made.

b) A risk assessment shall be done to assess common well barrier elements. As a minimum, well type (new/re-entry), status, certifying frequency, visual/mechanical surveillance and probability and consequence of failure of each elements should be addressed.

c) A system/equipment acceptance plan shall be made prior to installation.

13.3.2 UBD well barrier requirements

The primary well barrier during UBD operations is maintained by fluid column and pressure control.

The BHP and the reservoir influx shall be monitored and controlled by means of a closed loop surface system including an RCD, flowline, ESDV, choke manifold and surface separation system:

a) The RCD shall be installed above the drilling BOP and shall be capable of sealing the maximum expected wellhead circulating pressure against the rotating work string and containing the maximum expected shut-in wellhead pressure against a stationary work string.

b) The return flowline shall have two valves, one of which shall be remotely operated and failsafe close (ESDV). The flowline and the valves are included in the Well Barrier Element Acceptance Criteria table for UBD/MPD choke manifold and shall have a WP equal to or greater than the maximum expected shut-in wellhead pressure. The ESDV shall be proven to prevent overpressuring/flowing of the separation equipment in event of a downstream blockage.

c) Gas detection devices shall be installed to detect possible leaks from connections on the wellhead, high pressure riser and BOP.

d) A dedicated UBD choke manifold shall be used to control the flow rate and wellbore pressure, and reduce the pressure at surface to acceptable levels before entering the separation equipment. The choke manifold shall have a WP equal to or greater than the anticipated shut-in wellhead pressure. The choke manifold shall have two chokes and isolation valves for each choke and flow path.

e) A surface separation system shall be selected and dimensioned to handle the anticipated fluid/solids in the return flow. Plugging, erosion or wash-outs of surface equipment shall not impact the ability to maintain primary well control. Surface separation systems shall have documented capability and suitability for the area they are to be located. Specifications of surface separation equipment (i.e. separators, sample catcher system, flare systems) and support systems are not included in this NORSOK standard.

f) Snubbing facilities shall be used or the well shall be killed with a kill weight fluid prior to tripping pipe, if the shut-in or flowing wellhead pressure can produce a pipe light condition and a DIV, a retrievable packer system or similar shut-in device, is not in use or is not functioning as designed.

g) If the inflow potential exceeds the capacity of the surface equipment then the primary well barrier will no longer function as intended and thus the well shall be secured.

h) The UBD fluid system can consist of basic liquids such as seawater, fresh water, brine, crude or base oil, occasionally combined with gas injection. Weighting material requirement depends on the reservoir pressure and the degree of draw down desired. The selected UBD fluid shall be suitable for the application it is chosen for.

i) Circulating system and flow simulations; the control of BHP and the design of a suitable circulation system is very important in UBD operations. In the planning and design phase, multiphase flow modelling shall be done. The results of the modelling and other design parameters shall be used for equipment selection and in procedures prior to start of operations. Within these procedures the BHP operating envelope shall be set based on best available data. Optimal operating parameters for the execution phase shall be based on real time phase behaviour modelling and actual well and reservoir conditions. Dynamic simulators should as a minimum be used to model the effects of starting and stopping circulation and the fluid interaction during connections.

The elements in the secondary well barrier are the same in UBD as in conventional drilling:

j) A drilling BOP shall be installed for UBD.

k) Kill fluid of sufficient volume and density shall be available on site at any time to be able to kill the well in an emergency. 1.5 times the hole volume should always be available.
13.3.3 MPD well barrier requirements

The primary well barrier in MPD operations is maintained by a statically underbalanced fluid column with applied surface pressure. The BHP is controlled by means of a closed loop surface system and equipment providing back pressure.

a. The RCD shall be installed above the drilling BOP.

b. A dedicated MPD choke manifold shall be used to control the well bore pressure and reduce the pressure at surface to acceptable levels before entering the separation equipment or to the shakers. A manual MPD choke system is not accepted as a part of the primary well barrier.

c. Plugging, erosion or wash-outs of surface equipment shall not impact the ability to maintain well control.

d. The surface system shall be selected and dimensioned to handle the anticipated fluid/solids, including formation fluids if potential exists for influx removal with MPD.

e. Snubbing facilities shall be used in all pipe light scenarios. Alternatively, the well can be brought into hydrostatic overbalance or a qualified isolation well barrier element can be placed down hole prior to any probable pipe light scenarios.

f. During any tripping operation, the ability shall be in place to measure either positive backpressure if the RCD is installed, or verify level of liquid in the annulus when the RCD is not installed.

g. A stab-in safety valve for the pipe in use shall be available on the rig floor.

The secondary well barrier for MPD is the same as for conventional drilling.

h. A drilling BOP shall be installed for MPD operations

i. MPD manifold and flow path shall be independent of rig choke manifold, so the rig choke manifold is always available for well control operations.

The minimum requirement for operating parameters drilling window is:

j. A minimum kick tolerance shall be specified. Based on the MPD system’s capability of recognising small influxes and minimising influx volumes, the kick tolerance can be smaller than for conventional operations.

k. If MPD circulation path is not used while tripping in open hole the kick margin shall be as for conventional drilling. Max experienced pore pressure can be used, or if not known then the minimum BHP the section has been exposed to can be used.

l. The range of operating parameters shall be such that the MPD system is proved capable of operating for both planned operations and selected predefined contingencies, which shall be based on criticality and frequency of occurrence. As a minimum loss of rig power, choke plugging, change of RCD element and switch between MPD and well control mode (and vice versa) shall be included.

m. Stop criteria for lack of kick margin and/or being outwith of operating range shall be made. A contingency plan shall be in place and include actions to be taken if this occurs.

n. The minimum formation stress should be higher than the maximum estimated pore pressure in the section. If this guideline cannot be fulfilled it shall be documented that the risk of fracturing the formation is acceptable and contingency plan for potential scenarios shall be made.
### 13.4 Well barrier elements acceptance criteria

The following table describes requirements and guidelines which are additional to what is described in Section 15:

None. Additional requirements and guidelines have been included in the EACs.

### 13.5 Well control action procedures and drills

#### 13.5.1 Well control action procedures

Main operational risks shall be identified and contingency procedures shall be made, reflecting the actual equipment to be used and the well specific data.

The following table describes incident scenarios for which well control action procedures should be available. This list is not comprehensive and additional scenarios may be included based on the planned activities.

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Bottom hole or surface pressure and/or flow rates detected which could lead to the pressure rating of the RCD (static or dynamic) or the capacity of the surface separation equipment being exceeded.</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>NRV failure, influx into work string during making connection or tripping in live well.</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Leak in common well barrier element; Casing</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Leak in common well barrier element; Casing cement</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Leak in common well barrier element; WH, HP-riser &amp; BOP</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Gain while drilling, while pumping x-link pill and while out of hole</td>
<td>MPD only</td>
</tr>
<tr>
<td>7.</td>
<td>Erosion or wash out of choke.</td>
<td>Consider the case where isolation for repair of the choke cannot be achieved.</td>
</tr>
<tr>
<td>8.</td>
<td>Leaks at surface.</td>
<td>RCD, flowlines, manifold etc</td>
</tr>
<tr>
<td>9.</td>
<td>Plugging at surface.</td>
<td>Choke, flowmeter etc.</td>
</tr>
<tr>
<td>10.</td>
<td>Work string failure, washout or twist-off.</td>
<td>Consider pipe light scenario and contribution from additional NRVs in the drillstring. Evaluate risk for pipe failure based on well path/dog leg severity</td>
</tr>
<tr>
<td>11.</td>
<td>Emergency shut-in.</td>
<td>UBD only</td>
</tr>
<tr>
<td>12.</td>
<td>Emergency well kill and bullheading.</td>
<td>Including criteria for shut-in</td>
</tr>
<tr>
<td>13.</td>
<td>Lost circulation, on bottom and out of hole.</td>
<td></td>
</tr>
<tr>
<td>14.</td>
<td>H₂S in the well.</td>
<td></td>
</tr>
<tr>
<td>15.</td>
<td>Loss of rig power.</td>
<td></td>
</tr>
<tr>
<td>16.</td>
<td>Simultaneous kick and loss situation</td>
<td></td>
</tr>
<tr>
<td>17.</td>
<td>Stuck pipe.</td>
<td></td>
</tr>
<tr>
<td>18.</td>
<td>Failure of method to hold dynamic backpressure during connections.</td>
<td></td>
</tr>
<tr>
<td>19.</td>
<td>Rig movement</td>
<td></td>
</tr>
<tr>
<td>20.</td>
<td>Rig/platform alarm with mustering</td>
<td></td>
</tr>
</tbody>
</table>
13.5.2 Well control action drills
The following well control action drills should be performed:

<table>
<thead>
<tr>
<th>Type</th>
<th>Frequency</th>
<th>Objective</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure rating of the RCD (static or dynamic) exceeded.</td>
<td>Once per well with crew on tour.</td>
<td>Response training.</td>
<td>Before drilling out of the last casing prior to UBD/MPD operation.</td>
</tr>
<tr>
<td>The capacity of the surface separation equipment being exceeded.</td>
<td>Once per well with crew on tour.</td>
<td>Response training.</td>
<td>Before drilling out of the last casing prior to UBD operation.</td>
</tr>
<tr>
<td>Leaking NRV, influx into work string on making connection or tripping in live well.</td>
<td>Once per well with crew on tour.</td>
<td>Response training.</td>
<td>Before drilling out of the last casing prior to UBD/MPD operation.</td>
</tr>
<tr>
<td>Leak in RCD. Including stripping to change element.</td>
<td>Once per well with crew on tour.</td>
<td>Response training.</td>
<td>Before drilling out of the last casing prior to UBD/MPD operation.</td>
</tr>
<tr>
<td>Leak in equipment after RCD.</td>
<td>Once per well with crew on tour.</td>
<td>Response training.</td>
<td>Before drilling out of the last casing prior to UBD/MPD operation.</td>
</tr>
<tr>
<td>Leak in drilling BOP lower connector.</td>
<td>Once per well with crew on tour.</td>
<td>Response training.</td>
<td>Before drilling out of the last casing prior to UBD/MPD operation.</td>
</tr>
<tr>
<td>Choke drill.</td>
<td>Once prior to starting UBD/MPD operations with crew on tour.</td>
<td>Practice in operating the power choke with pressure in the well.</td>
<td>Before drilling out of the last casing prior to UBD/MPD operation.</td>
</tr>
<tr>
<td>Uncontrolled work string movement out of well.</td>
<td>Once per well with crew on tour.</td>
<td>Response training.</td>
<td>Before drilling out of the last casing prior to UBD/MPD operation.</td>
</tr>
<tr>
<td>H₂S drills.</td>
<td>Prior to drilling into a potential H₂S zone/reservoir.</td>
<td>Practice in use of respiratory equipment.</td>
<td>All relevant personnel to have necessary training if H₂S is known to be present.</td>
</tr>
<tr>
<td>Transferring between well control and UBD/MPD equipment</td>
<td>Once prior to starting UBD/MPD operations with crew on tour.</td>
<td>Practice in changing from UBD/MPD mode to standard well control mode (in case of a kick situation).</td>
<td>Before drilling out of the last casing prior to UBD/MPD operation.</td>
</tr>
</tbody>
</table>
### 13.6 Well control matrix

A well control matrix shall be prepared. Criteria for stopping operation and observe (yellow zone) and definition of well control incident including first action shall be included in the matrix. The well control matrix shall be well specific and based on the design limitations of the actual equipment that will be used during execution.

#### 13.6.1 Well control matrix for MPD operations

A well control matrix for MPD should be structured as follows:

<table>
<thead>
<tr>
<th>Surface Pressure Indicator</th>
<th>At Planned Drilling Back Pressure</th>
<th>At Planned Connection Back Pressure</th>
<th>≥ Planned Back Pressure &amp; &lt; Back Pressure Limit</th>
<th>≥ Back Pressure Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Influx</td>
<td>Continue Drilling</td>
<td>Continue Operation</td>
<td>Continue operation, adjust system to decrease WHP</td>
<td>Secure well, evaluate next planned action</td>
</tr>
<tr>
<td>Operating Limit</td>
<td>Continue drilling, adjust system to increase BHP</td>
<td>Continue operation, adjust system to increase BHP</td>
<td>Continue operation, adjust system to decrease WHP and increase BHP</td>
<td>Secure well, evaluate next planned action</td>
</tr>
<tr>
<td>&lt; Planned Limit</td>
<td>Cease drilling, adjust system to increase BHP</td>
<td>Adjust system to increase BHP</td>
<td>Secure well, evaluate next planned action</td>
<td>Secure well, evaluate next planned action</td>
</tr>
<tr>
<td>≥ Planned Limit</td>
<td>Secure well, evaluate next planned action</td>
<td>Secure well, evaluate next planned action</td>
<td>Secure well, evaluate next planned action</td>
<td>Secure well, evaluate next planned action</td>
</tr>
</tbody>
</table>

- Operating limit: A well specific limit below which drilling can continue
- Planned limit: A well specific limit above which MPD ceases and transitions to well control operations

If potential formation fluid is planned to be handled through the MPD equipment, the risk must be verified to be equal or lower than handling it through the rigs well control system. It shall be possible to transfer from MPD mode to conventional mode during a well control situation without increasing the risk compared to a conventional well control situation. Procedures to handle larger or unexpected volumes must be prepared before start operation. If formation fluid is planned to be circulated out using the MPD control system, real time pressure data should be available while the influx is circulated out.
A well control action matrix for UBD can be structured as follows:

<table>
<thead>
<tr>
<th>Surface Flow Rates</th>
<th>Range 1 (0-Q1)</th>
<th>Range 2 (Q1-Q2)</th>
<th>&gt; Q2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wellhead Flowing Pressure</strong></td>
<td>Continue Drilling</td>
<td>Adjust system to increase BHP</td>
<td>Secure well, evaluate next planned action</td>
</tr>
<tr>
<td><strong>Wellhead Flowing Pressure</strong></td>
<td>Continue Drilling</td>
<td>Cease Drilling</td>
<td>Secure well, evaluate next planned action</td>
</tr>
<tr>
<td><strong>Wellhead Flowing Pressure</strong></td>
<td>Secure well, evaluate next planned action</td>
<td>Secure well, evaluate next planned action</td>
<td>Secure well, evaluate next planned action</td>
</tr>
</tbody>
</table>

Where:
- \(P_1\) = Minimum separator pressure to ensure effective dumping of fluids.
- \(P_2\) = Planned operating pressure,
- \(P_3\) = Operating pressure limit,
- \(Q_1\) = Planned operating flow rate,
- \(Q_2\) = Operating flow rate limit

### 13.7 Other topics

#### 13.7.1 Procedures

MPD/UBD operations require procedures developed for the specific application of the method based on risk analysis and risk assessments. Procedures shall be developed for all critical activities.

The following operational requirements apply for MPD:

- a) During MPD operation slow circulation rate pump pressure measurements shall be done with the same interval as for conventional drilling.
- b) Dynamic flow checks shall replace standard flow checks. Dynamic flow checks are performed by stopping drilling and holding constant surface pressure while monitoring for gains or losses through the closed loop MPD system.
- c) If unexpected formation fluid is planned to be handled through the MPD equipment, well control procedures shall be made.
- d) Well/operation specific limitations shall be established and included in DOP’s, i.e. maximum and minimum BHP, kill rate, slow circulating rates, maximum tripping speed etc.

Amongst other, procedures should be developed for:

- e) kicking off the well (UBD only),
- f) making connections,
- g) live well tripping (UBD only),
- h) erosion monitoring,
- i) trapped pressure in equipment,
- j) communication interfaces,
- k) change out of RCD bearings/elements.

#### 13.7.2 Personnel training

The personnel involved in UBD and MPD operations shall be competent. Personnel in the process of becoming competent shall be supervised by competent personnel.
The following personnel shall complete a basic MPD/UBD course and a refresher course every second year:

- Assistant driller
- Driller
- Toolpusher
- Drilling supervisor
- MPD/UBD supervisor
- MPD/UBD operator
- Drilling engineer
- Drilling superintendent
- Rig manager
- Platform/Site manager

The above personnel (except Platform/Site manager) shall complete an installation specific course and a refresher course every second year.

The involved offshore personnel shall perform on site training before initiating the MPD/UBD operation, which shall include planned operations and contingencies. A plan shall be in place to ensure sufficient training for oncoming crews.

All the above training shall be documented.

MPD/UBD supervisor shall hold a valid well control certificate issued by a recognised international party (i.e. IWCF or IADC).

### 13.7.3 Data acquisition

Relevant real-time data shall be collected and displayed on screens on a continuous basis, including:

- a) annulus/choke pressure,
- b) standpipe pressure,
- c) active surface system fluid volume,
- d) drilling fluid pump rate,
- e) returned gas rate (UBD),
- f) returned liquid rate,
- g) gas injection rate (if any),
- h) surface equipment pressure,
- i) surface temperature,
- j) down hole pressure and temperature (in the BHA) (memory data should be recorded)

### 13.7.4 UBD Surface separation system

Surface separation systems shall have documented capability and suitability for the area they are to be located. Specifications of surface separation equipment (i.e. separators, sample catcher system, flare systems) and support systems are not included in this NORSOK standard.

### 13.7.5 Relief well

For wells drilled with UBD/MPD an evaluation of the validity of the current relief well strategy shall be included in the drilling program. It shall include an evaluation of whether the relief well needs to be drilled with UBD/MPD. If UBD/MPD is required the suitability of available rigs to drill relief wells in UBD/MPD shall also be included.

Examples of well barrier schematic illustrations

The following well barrier schematics are guidelines and describe one possible solution for how the well barrier envelopes with well barrier elements can be established and illustrate