

## Reservoir Drilling Guidelines

Drilling long horizontal wells (ERD) through depleted reservoirs to intersect possible compartmentalised 'virgin' reservoir pressure sections create a number of challenges. Typically the margin between the frac and pore pressure is reduced significantly.

Risks identified;

- Faulting; Crossing faults could result in lost circulation.
- Clay (in)stability; it is well known that a clay formation such as the Kimmeridge clay formation requires a certain mud density and mud rheology to maintain borehole stability
- Lost Circulation; it is a well known phenomena that if the pore pressure is reduced that this will correspond to a reduction in fracture pressure. This is a major problem while drilling (severely) depleted reservoirs.
- Differential sticking; The mud density required to stabilise the Kimmeridge Clay formation will cause a considerable overbalance within the reservoir (Brent) formation. Especially if this is depleted.

From the 4 main risks discussed above can be seen that these risks cannot be assessed in isolation.

### Key Issues.

The key issues for these hole sections are:

- Barite sag
- Induced Lost Circulation
- Pore Pressure Prediction
- ECD Management
- Formation Strength and kick tolerance
- Borehole Ballooning and Flow Back

#### *Barite Sag.*

This occurs when Barite settles towards the low side of the hole, resulting in a significant variation in mud density. If sag occurs, there is the potential to create lost circulation, well control incidents, ECD fluctuation, torque & drag difficulties, logging difficulties and poor cement jobs. It is a slow process, not usually becoming apparent until the mud has been static for a considerable period of time (after trips, logging or running casing). As the sags occurs, it results in a zone of lighter mud (possibly up to 1 ppg less than normal) above a zone of heavier mud (possibly up to 1 ppg above normal). As the hole is circulated, the lighter mud is seen in the returns before bottoms up, followed by the mud at a density above the nominal. As the light mud is displaced from the hole it is replaced with mud at the correct density. The extra density of the heavy mud now just below surface can be sufficient in wells where the pore pressure and fracture pressure are close together, to increase the bottomhole pressure up to the fracture pressure resulting in a loss of returns.

#### *Induced Lost Circulation.*

Considering the close proximity of the formation pore pressure and fracture pressure it is important to be aware of the potential to induce lost circulation so measures can be taken to avoid it.

Induced lost circulation can be caused by:

- Surge pressures while running in hole.
- High initial pump pressures and the ECD required in breaking circulation. It is recommended to rotate the string prior to starting the mud pumps in order to break the gels. The pumps can then be started and slowly brought up to speed. Note however, that if the mud density is approaching the fracture pressure, consideration should be given to stopping rotation after breaking the gels, then establishing circulation slowly, then starting rotation again.
- Barite sag
- Higher annular mud density after a trip (weighted slug, cooler mud etc.)
- Increasing rotational speeds can induce losses – the drillstring rpm should be increased in stages.

#### *Pore Pressure Prediction and Kick Detection*

Considering the degree of uncertainty over the pore pressure profile in this well, accurate pore pressure monitoring and prediction are vital in drilling the well successfully. Monitoring and plotting a combination of a number of trends and indicators, together with geological information provides the best means of interpreting any pore pressure changes. This can be achieved by combining real time drilling parameters (Dxc exponent plot, normalised drilling rate, torque etc) with the data transmitted by the LWD / MWD tools (pressure, resistivity, gamma ray etc) and all surface measurements (gas levels, temperature, mud density, mud temperature, mud salinity, cuttings shape etc).

The table below details the methods used for detection of abnormally pressured zones while drilling and classify them on the basis of their reliability;

Detection parameter reliability	Real time methods	'Lag Time' Methods
Reliable	Drilling rate Corrected 'd' exponent Normalised drilling rate Drag while making trips or connections Flow measurement Pit levels LWD	Gas: <ul style="list-style-type: none"> <li>• Connection gas</li> <li>• Background gas</li> <li>• Reservoir gas</li> </ul>
Moderately Reliable	Bottomhole settling of cuttings (fill) Torque	Shale density Shale factor Abundance and size of cuttings Cuttings shape
Not Very Reliable	Pump pressure	Mud temperature

Plotting the normalised ROP, results in a dulling trend line for the bit, any deviation from this trend line indicates either a lithology change or a change in formation pressure.

Monitoring and interpretation of gas data is fundamental in detecting abnormally pressured zones. All gas sensors must be fully operational while drilling the 8-1/2" and 6" hole sections. Increasing back ground gas levels reflect an increasing hydrocarbon content of the formations, so may also be an indicator of increasing pore pressure in a transition zone.

### *Borehole Ballooning and Flow Back*

Borehole ballooning is the supercharging of the formation when the pumps are on and the later 'flowback' from the well when the pumps are shut off. Borehole ballooning should not be confused with 'drainback' from the flow line.

Wells where there are close tolerances between mud density and fracture gradient are prone to borehole ballooning.

### **Procedures & Recommendations.**

- Ensure a clean PWD reading is taken in the shoe before the annulus is loaded with cuttings and define a clean hole ECD. This needs to be done at different flowrates with and without rotation.
- Ensure that the maximum ECD's recorded while drilling are not exceeded while circulating the hole.
- No mud pit transfers or bleeding in of mud into active system to take place without informing the Driller.
- The Driller must record the standpipe pressure and SPM prior to shutting down the mud pumps.
- Drill with constant parameters if possible.
- ROP will be limited by the requirement to have no more than 1 connection gas (or dummy connection gas) in the hole at any time. Make dummy connections as required to monitor increasing pore pressure, thus ensuring that there is only one connection gas in the annulus any time.
- In the event that there is a shut down for any reason, circulate the 'connection' gas out of the hole before recommencing drilling operations.
- Closely monitor hole conditions. Update drilling trends sheet every stand and report any changes to the Drilling Supervisor. Drilling parameters optimised to reduce bit bounce and BHA vibration.
- The ECD should be monitored closely using the PWD sub data.
- Losses; contingency lost circulation pills have been developed, for varying loss rates, and the materials identified must be held on the rig. Details are contained in the Mud Programme.
- Closely monitor for any indications of a differential sticking tendency if pore pressures are lower than prognosed.
- Monitor ECD values recorded and transmitted by the PWD sub.
- Surge pressures are as important at connections as whilst tripping in.
- Stop drilling whenever increasing mud density. Mud density increases should be made in small increments of no greater than 0.2 ppg. Excessive mud density could lead to losses, sticking and flowback.
- Have a 'wild' single on the catwalk ready to be picked up in case of tight hole or stuck pipe.

*Drillers Summary Sheet of Operational Practices*

<b>Operations Guide</b>	<b>Potential Risks</b>	<b>Procedures</b>
Normal pump rate	Fracture the formation	<ol style="list-style-type: none"> <li>1. Minimise the circulating time at low pump rates</li> <li>2. Do not exceed the maximum pump rates for ECD limitation</li> <li>3. Maximum pump rates to be known in relation to applied ECD and rotational speed</li> <li>4. Be aware of cuttings loading vs ROP</li> </ol>
Breaking circulation (After static for >1 hour)	Fracture the formation Barite sag	<ol style="list-style-type: none"> <li>1. Rotate the string to break the gels</li> <li>2. Maximum initial rotary speed to be slow (10 – 20 rpm)</li> <li>3. Start the pump at as low as practical speed whilst picking up the string</li> <li>4. Stop pipe rotation if required</li> <li>5. As soon as returns are observed, increase pump rate in steps to the designed drilling rate at 50 gpm/min in 6" hole and 100 gpm/min in 8-1/2" hole increments</li> </ol>
Breaking circulation (After static for <1 hour)	Fracture the formation Barite sag	<ol style="list-style-type: none"> <li>1. Rotate the string to break the gels (10 – 20 rpm)</li> <li>2. Start the pump at as low as practical speed</li> <li>3. Stop pipe rotation if required</li> <li>4. As soon as returns are observed, increase pump rate in steps to the designed drilling rate at 50 gpm/min in 6" hole and 100 gpm/min in 8-1/2" hole increments</li> </ol>
Reaming up / down	Fracture the formation Surging / Swabbing	<ol style="list-style-type: none"> <li>1. Pump rate is to be controlled</li> <li>2. Maximum reaming down speed minutes per stand</li> <li>3. Maximum reaming up speed minutes per stand</li> <li>4. Maximum pipe rotary speed to be in line with hole cleaning recommendations</li> </ol>
Running in hole	Surging Swabbing	<ol style="list-style-type: none"> <li>1. Follow the tripping speed recommendations</li> <li>2. Pick up string slowly</li> <li>3. Build up to the recommended tripping speed slowly</li> </ol>
Pulling out of hole	Swabbing	<ol style="list-style-type: none"> <li>1. Follow the tripping speed recommendations</li> <li>2. Pick up string slowly</li> <li>3. Build up to the recommended tripping speed slowly</li> </ol>