Technologie Forage – Puits HPHT

JL Bergerot – Paris La Defense – 08/02/2012
HP/HT Exploration history

A continuous deepening Exploration since XIX\textsuperscript{th} century

(Source : I.H.S. 2009  Onshore Canada & US excluded)
Still “major fields” discovered below 5000 m burial

(Source: I.H.S. 2009  Onshore Canada & US excluded)
Deep Exploration history

With depth go increasing pressure and temperature TOTAL on the leading edge

From I.H.S. 2005 (excluding onshore Canada & US)
Within TOTAL, are considered HPHT, high pressure and high temperature wells with:

- an expected wellhead shut-in pressure exceeding 10000 psi (690 bar) and
- a bottomhole temperature (static or dynamic) higher than 150°C (300°F).

• National rules and regulations will apply whenever they are more stringent
  – Norway: not « and » but « or »
HP/HT current industry limits

**Exploration limits are more extreme than Development limits**
Current HP/HT development limits overview

Platform and onshore are more advanced than subsea
HPHT challenges

- HP/HT domains determined by technology breakthrough (Elastomer, Electronics, drilling mud, subsea development, steels ….)

- Temperature has the major impact in HP/HT environment

- Absolute pressure generally a secondary issue.

  …but relative pressure (i.e. difference between pore pressure and fracture gradient) is a key parameter…
Temperature factor

Why is temperature critical for the well architecture?

- **Temperature has a greater effect on equipment than pressure (P)**
  - T will stay while P may decline quickly
  - Elastomers and even steels suffer when T increases
  - Electronics do not survive long at very high T
  - Thermal cycling in production may cause fatigue and failures

- **In HPHT, the Joule-Thomson effect worsen the conditions**
  - Bottomhole temperature in production is higher than initial static reservoir temperature

*Accurate temperature prognosis is a must in HPHT well design (maxi and all along the well path)*
Production profile

Building several flowing profiles with different productivity scenario to get the more demanding conditions

XMT qualified 204°C
Packer qualified 232 °C

Modeling of flowing conditions essential to get the limits
A complex question in HTHP

Numerous parameters
- Environment conditions have to be evaluated: pH, level of stress on the steel, temperature, salinity of formation water...
- It is necessary to check that anticipated well conditions are within the special grade properties

Some testing may be required to the anticipated conditions:
- Long process => increased timing
- Fine tuning of properties => tailor made grade
- Higher cost

The metallurgy needs to be verified by Experts
Pore Pressure Prediction

- Accurate pore pressure prediction is vital for safe well planning and execution
- Error margins on prediction must be highlighted to plan for mitigation
- In HPHT, very often if not always, pressure ramp-up is very sharp, so attention must be paid to:
  - the depth of the ramp-up (time–depth conversion)
  - the slope of the ramp-up

An incorrect prediction can jeopardise well objectives
Field example of a MWW prognosis in HPHT

The Mud Weight Window is often very narrow
Actual use of the MWW during the drilling activity

<table>
<thead>
<tr>
<th>Fracture Pressure</th>
<th>Uncertainty in FP</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESD = Equivalent Static Density</td>
<td>Supercharging 7/8 points</td>
</tr>
<tr>
<td>ECD = Equivalent Circulating Density</td>
<td>Margin to Supercharging 2 points</td>
</tr>
<tr>
<td>Safe Working zone</td>
<td>Annular Friction Gel Breaking Swab &amp; Surge 6/7 points</td>
</tr>
<tr>
<td></td>
<td>Compressibility 1 points</td>
</tr>
<tr>
<td></td>
<td>Safety Factor 2 points</td>
</tr>
<tr>
<td></td>
<td>Uncertainty in PP</td>
</tr>
<tr>
<td>Pore Pressure</td>
<td>Total = 20 points</td>
</tr>
</tbody>
</table>

The Mud Weight Window is not available in its entirety.

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Supercharging/ballooning effect

- When drilling and circulating, mud ECD forces some mud into formations via fractures or fissures
  - Supercharging/ballooning

- When pumping is stopped, pressure losses disappear and fractures and fissures close and the formation give the fluid back into the hole making the well flowing
  - Breathing

Don’t mix wellbore breathing and influx or kick
When there is no mud weight window?

Differentially depleted layers
Kick - Losses

No MWW

Shale and depleted layers
Instability - losses
HPHT challenges

- Complex well architecture and reduced operational windows demand
  - Rigor
  - Good transverse cooperation
  - Comprehensive planning and preparation
  - Advanced technology

It is not and will never be a routine job,

and it becomes even more difficult when pressure decreases ….
Why drilling HPHT infill wells: the stakes

- Increase the reserves (recovery factor).
- Accelerating the delivery (drainage).
- Replace failed wells
  - Loss of casing integrity
  - Sanding problems
- Development of new HP fields
  - Phased development
Why is HPHT infill drilling challenging?

- Drilling infill wells in Highly Depleted Reservoir is a strong challenge.
  - inability to achieve reliable wells on some fields (loss of 3 wells due to liner full collapse, 1st infill stopped due to a technical difficulty)
  - serious troubles on a field depleted by 140 bars only.

- Very rapid and important depletion is usual on HP/HT fields
The compaction

Surface Subsidence

Shear

Arching

Expansion

Low $\sigma_h$ zone

Sheared Casing

Reservoir Compaction

Compression

Compression

Hight $\tau$ zone

$\Delta z$
The mud weight window issue

- For initial wells, the cap rock and the reservoir are on the same pressure gradient
- \( FP > PP \) 
  A mud weight window exists
Original undepleted drilling

- Cap Rock
- C Sand
- B Sand
- A Sand

- Initial State
- Pore Pressure
- Mud Operating Window
- Frac Gradient

Existing well design
Evolution with depletion

- **High pressure Cap rock:** Remains at virgin pressure
- **Low pressure reservoir:** FP decreases with PP

mud weight Window disappears
Infill drilling – ‘high’ depletion levels

Where to place this shoe?

Drill Above Frac gradient?

Additional casing strings?

Cap Rock

Time

Pore Pressure

Mud Operating Window

Frac Gradient

C Sand

B Sand

A Sand
Uncertainties

- **Geo-mechanical uncertainties**
  - Evolutions of stresses with depletion
  - Frac pressures in the reservoir (Initiation and propagation)
  - Minimum mud weight for bore hole stability in the cap rock

- **Geological uncertainties**
  - Formation tops accuracy prediction
  - Presence of gas layers in the cap rock

- **Reservoir uncertainties**
  - Absolute level of depletion
  - Pressure profile within reservoir
    - No pressure measurements after production starts
    - PLT data not always available
Technology is KEY to overcome the issues

**the needs:**
- An intermediate mud weight to drill in the cap rock until the top reservoir is identified
- Mechanical back-up solutions
- A low mud weight in the reservoir

**the technology contribution:**
- Customized drilling fluids
- Stress caging techniques
- High temperature, high collapse resistance tubulars (expandables, drilling liners)
- Gas management with Managed Pressure Drilling (MPD) techniques
The results from 3 Elgin Franklin wells

- All technologies prepared (base case and contingency) have been used and implemented successfully
  - Expandable installed and achieved positive sealing
  - Successful liner drilling, cementing and packer setting
  - Reservoir drilled with ~760 bars overbalance using “designer mud” (world record)
  - Managed Pressure Drilling techniques deployed on last 2 wells allowing an efficient gas management

- Well were completed and produced without significant formation damage
CONCLUSIONS

- HP/HT and Deep E&P have significantly increased since the last decade.
- It is and will remain a major E&P future challenge in conventional HC.
  - Malaysia, Azerbaidjan, Egypt, UK, …
- The infill well success has opened new perspectives in the HP/HT domain:
  - Insurance that wells that fail in future can be replaced, thus securing production over the life of field.
  - On a wider perspective, phased HP/HT field developments can be contemplated. This will impact HPHT field economics by allowing a reduction in pre-investments.
- TOTAL ability to operate HPHT fields is the result of close to 50 years of operations.
- Future exploration/production of deeper horizons will need new technologies in all the E&P domains:
  - Combined HPHT Deep water fields,
  - Maturing HPHT fields
  - Higher temperatures
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BACK-UP
2 different architectures

Option 1

Option 2

First option
Stress caging then
reservoir at low MW.

Contingency
Run expandable -
Penetrate reservoir
below frac P - Drilling
liner - reservoir at low
MW

Drill reservoir
with low mud
weight

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Stress caging: how does it work?

- Drilling in reservoir with EMW > Pfrac
- Fracture is opened
  - Fluid + solids + pressure penetration
- Fracture is plugged
  - Prevents further fracture propagation
  - Well bore is strengthened by the local increase of compression stress
- Too high overbalance means
  - Large fracture
  - Difficulty to plug frac
  - Inability to prevent frac propagation
Mechanical back up

High Collapse Expandable Liner
- Specially designed and qualified for:
  - High temperature operation
  - High collapse capability
- Elastomer instead of cemented

Drill down liner
- To enter reservoir and case off cap rock/reservoir transition
- Liner in place if any problems (losses leading to cap rock collapse)
MPD use

Operation
- Apply back pressure while drilling
- Detect a downhole gas ingress by comparing inflow & outflow
- Choke well until outflow = inflow
- Bleed down tight layers by accepting successive gas ingress by opening the choke, taking acceptable volumes choke back and circulate gas out

Principle
- Precise measurement of flow out and MW out
- Semi-closed system for safer handling of gas at surface
- ECD management through surface back pressure