Workshop on Multilateral and Extended Reach Wells

By

Jerome J. Schubert
Department of Petroleum Engineering, Texas A&M University

Final Workshop Report
Prepared for the Minerals Management Service
Under the MMS/OTRC Cooperative Research Agreement
1435-01-99-CA-31003
Task Order 85221
MMS Project Number 439

September 2003
FINAL REPORT
Workshop on Multilateral and Extended Reach Wells
MMS Project 439

Jerome J. Schubert

Executive Summary

OTRC is conducting a multi-year (2002 – 2004) research project entitled “Development and Assessment of Well Control Procedures for Extended Reach and Multilateral Wells Utilizing Computer Simulation” (MMS Project 440). Additionally, the MMS requested that OTRC provide a Workshop for MMS engineers to familiarize them with the current state of the art and practice for Multilateral and Extended Reach Wells.

Workshop materials were prepared that described
- state of the art and practice for drilling and completing multilateral and extended reach wells
- applications and economic benefits of multilateral and extended reach wells
- limitations for multilateral and extended reach wells

Steve Walls, Cherokee Offshore Engineering, Bjorn Gjorv, TAMU, and Jerome Schubert, TAMU prepared and presented the workshop materials.

Two one-day workshops were held at the
- Pacific Region Office for engineers and geologists from the Pacific and Alaska regions on November 21, 2002
- Gulf of Mexico Region Office for engineers from the Gulf regions on December 5, 2002

Agendas for the two Workshops are presented in the Appendix.

In the workshop held in the Pacific Region, there was more discussion on the topics presented in the morning session (definition of extended reach and multilateral wells, torque and drag, dual gradient drilling, and expandable tubulars) than was anticipated. The session on drilling fluids was also longer than expected. The additional time spent on these subjects resulted in a somewhat abbreviated discussion of some of the state of the art for ERD and ML wells.

Based on the experience and feedback from the Pacific Region workshop, the topics were rearrange for the Gulf of Mexico Region workshop. The discussion on torque and drag, dual gradient drilling, and high lubricity muds was shortened. Further, since representatives of Shell Oil Company and Enventure (the developers of Expandable Tubulars) were at the MMS offices on the same day, we decided to omit the presentation on expandable tubulars. These changes allowed us to spend more time on the state of the art and practice in multilateral and extended reach wells.

Based on the feedback from both workshops, the MMS engineers were well satisfied with the workshops.

The Workshop presentation materials are attached.
Agenda
Extended Reach and Multilateral Workshop
MMS Pacific Offices, Camarillo, CA
Presented by
Jerome J. Schubert, TAMU
Steve Walls, Cherokee Offshore Engineering
Bjorn Gjorv TAMU

8:30 am    Welcome and Introductions
9:00 am    Introduction to Extended Reach and Multilateral Wells
            Define ERD and ML levels
            How ML and ERD wells are drilled
            Economic benefits
            Technical difficulties
            Lost circulation and other well control problems
            Casing wear
            Torque and drag
            Cementing

10:30 am   Break
10:45 am   New drilling technologies that could enhance ML/ERD
            Dual Gradient Drilling
            Expandable tubulars

12:00 pm   Lunch
1:00 pm    New drilling technologies, continued
            High lubricity muds
            Hole cleaning
            State of the art in ERD
            State of the art in MLD

2:30 pm    Break
2:45 pm    Completion, workover, and fishing concepts
            Horizontal gravel-packed sand control completions
            Downhole completion tools for ER and ML wells

3:45 pm    Questions and discussion
4:40 pm    Adjourn
8:30 am  Welcome and Introductions
9:00 am  Introduction to Extended Reach and Multilateral Wells
  Define ERD and ML levels
  How ML and ERD wells are drilled
  Economic benefits
10:00 am Break
10:15 am New drilling technologies that could enhance ML/ERD
  Dual Gradient Drilling
  Expandable tubulars
  High lubricity muds
  Hole cleaning
  State of the art in ERD
  State of the art in MLD
Lunch
1:30 pm Completion, workover, and fishing concepts
  Horizontal gravel-packed sand control completions
  Downhole completion tools for ER and ML wells
2:30 pm Technical difficulties
  Lost circulation and other well control problems
  Casing wear
  Torque and drag
  Cementing
3:30 pm Questions and discussion
4:00 pm Adjourn
Workshop on Multilateral and Extended Reach Wells

Jerome J. Schubert, TAMU
Bjorn Gjorv, TAMU
Steve Walls, Cherokee Offshore Engineering

Workshop on Multilateral and Extended Reach Wells
- Sponsored by:
  - Minerals Management Service
  - Offshore Technology Research Center
  - December 5, 2002
  - New Orleans, Louisiana

Introductions
- Bjorn Gjorv, TAMU GAR
- Steve Walls, Cherokee Offshore Engineering
- Jerome Schubert, TAMU, PI

Outline
- Introduction to Extended Reach and Multilateral Wells
  - Describe ERD and ML levels
  - Application
  - Economic benefits
  - Examples

Outline, con’t.
- New drilling technologies that can enhance ML/ERD
  - Dual Gradient Drilling
  - Expandable tubulars
  - High lubricity muds
  - Hole cleaning
  - State of the art in ERD
  - State of the art in MLD

Outline, con’t.
- Completion, workover, and fishing concepts
  - Horizontal gravel-packed sand control completions
  - Downhole completion tools for ER and ML wells
Outline, con’t.

- Technical difficulties
- Lost circulation and other well control problems
- Torque, drag, and buckling
- Casing wear
- Cementing
- Questions and discussion
- Adjourn

Introduction to Extended Reach and Multilateral Wells

- Describe ERD and ML wells

David Knott
Senior Editor

BP Exploration Operating Co. Ltd. completed a well in U.K. Wytch Farm oil field with a horizontal reach of 10.1 km, setting a world record. The M-11 well was drilled from an onshore drill site into a reservoir that extends offshore and was brought into production on Jan. 12 at a rate of 20,000 b/d of oil.

Wytch Farm M11 Well
- Stepout (Horiz. Depart.) = 33,181 ft
- Exceeded previous record by 6,729 ft
- Measured Depth = 34,967 ft
- True Vertical Depth (at TD) = 5,266 ft
- Time to drill and case = 173 days
M11 is the 14th ERD well at Wytch Farm

REF: Anadrill Press Release 1-23-98

Overview cont’d
- One third of reserves are offshore under Poole Bay
- ERD project began in place of an artificial island in 1991
- Saved 150 million in development costs
- Development time saved - 3 years
- Scheduled with reach of 6.2 km
- Prod. before ERD project = 68,000 BOPD
- Prod. with 3 ERD wells = 90,000 BOPD

Multilaterals

Outline
- Figs. 3-6 Advertisements, PE Int.
- Figs. 7-9, OGJ, Dec. 11, 1995 p.44
- Figs. 10, 11, OGJ, March 16, 1998 p.76
- Figs. 12-17, OGJ, Dec. 1997, p.73
- Figs. 18-24, OGJ, March 23, 1998 p.70
- Oil & Gas Journal, Feb. 28, 2000, p.44
Fig. 1. The Multi-String Completion System provides segregated production and allows lateral re-entry using a dual bore deflector.
Multilateral Completions
Levels 1 & 2

Description
Open unsupported junction: Borehole mother-bore and lateral or standard line hung-off in either of the well bores.

Mother-bore cased and cemented
Lateral open:
- Lateral either blank-out or with standard line hung-off in open hole.

Multilateral Completions
Levels 3 & 4

Mother-bore cased and cemented
Lateral cased but not cemented:
- Lateral line anchored to mother-bore. It includes a liner hanger but is not cemented.

Mother-bore cased and cemented
Lateral open:
- Both bores cemented at the junction.

Pressure integrity at the junction:
Achieved with the completion

Pressure integrity at the junction:
Achieved with the casing

Downhole splitter:
Large main well bore with two smaller lateral bores of equal size

Window milling

Step 1
- Run multilateral packer on starter mill assembly

Step 2
- Set packer
- Commence milling window

Step 3
- Complete milling of window
ERD/ML Applications

- Attempt to reduce the cost per barrel of oil produced.
- Same or increased reservoir exposure with fewer wellbores
- Substantial increase in drainage area.
- Increased production per platform slot

ERD/ML Applications

- More reserves
- Production from natural fracture systems
- Efficient Reservoir drainage
- Exploiting reservoirs with vertical permeability barriers

ERD/ML Limitations

- Improving thin oil zone reservoirs production performance
- Increase ROI
- Reduce well cost
- Reduce time
- Reduce capital cost

Economic benefits
Complex well geometries boost Orinoco heavy oil producing rates
Oil & Gas Journal, Feb. 28, 2000

- Single horizontal lateral
- Gull-wing well
- Stacked multilateral
- Fishbone well
- Gull-wing, fishbone well
- Stacked fishbone well

~9°API oil. ∼1.2 × 10¹² bbls in place. ∼250 × 10⁹ recoverable
Unocal
- Dos Cuadras field – California
- Cost of a trilateral well - $2 million
- Cost of 3 conventional horizontals - $3 million

Texaco
- Brookeland field – Austin chalk
- Estimated savings of $500,000 - $700,000 per well as compared to two conventional horizontal wells of equivalent length

UPRC
- Austin Chalk – quadralateral
- Total cost for re-entry was $605,000 which is 20% less than the cost of two new dual lateral horizontals
Austin Chalk
- Changes from vertical to horizontal to ML led to reductions in development costs from $12/BOE to $5.75/BOE to $4.65/BOE

North Sea
- Reduced development costs by 23% and 44% respectively when horizontal and ML approaches are compared to vertical well development

Saih Rawl Shuaiba reservoir
- Dual lateral wells were drilled for water injection. Five wells completed successfully at 30% cost savings per dual well relative to two single laterals

Venezuela
- Level 3 Hook Hanger systems have yielded up to 900 bopd increase in production per well.
- Cost 1.58 times that of a single well
- But, Per-day increase in revenue, based on $20/bbl oil, is as much as $18,000/well

Deepwater Brazil
- ML costs an average of 1.43 times that of a single well
- While increased production, revenues and savings have amounted to as much as $10 million over conventional technology applied in the region

TFE - Argentina
- Table 1 – Comparison between platform, subsao and ERD (Hiba – Argentina)

Fig. 1 Location of the Hiba field (Tierra del Fuego – Argentina)
Fig. 2 ERD profile and casing strategy (Hiba field – Argentina – Work record)
New drilling technologies that can enhance ML/ERD

- Dual Gradient Drilling
- Expandable Liners
- High Lubricity Muds
- Hole Cleaning
- SOA in ERD and MLD

---

### Conventional Casing Seat Selection

```
<table>
<thead>
<tr>
<th>Depth</th>
<th>Frac Pressure</th>
<th>Max Mud Wt</th>
</tr>
</thead>
<tbody>
<tr>
<td>8,6 lb/gal</td>
<td>15.1 lb/gal</td>
<td>13.9 lb/gal</td>
</tr>
<tr>
<td>SMD</td>
<td>Conventional</td>
<td></td>
</tr>
</tbody>
</table>
```

```
<table>
<thead>
<tr>
<th>Depth</th>
<th>Min Mud Wt</th>
</tr>
</thead>
<tbody>
<tr>
<td>21,000 psi</td>
<td></td>
</tr>
</tbody>
</table>

```

### Wellbore Pressures

- Fracture Pressure
- Pore Pressure
- Sea Water Hydrostatic Pressure
- Conventional MUD Hydrostatic Pressure
**Wellbore Pressures**

- Seafloor Hydrostatic Pressure
- SMD
- Mud Hydrostatic Pressure
- Conventional
- Fracture Pressure
- Pore Pressure
- Sea Water Hydrostatic Pressure
- Depth
- MUD Hydrostatic Pressure
- Conventional

**Gaging Requirements - Conventional**

- Seafloor Hydrostatic Pressure
- SMD
- Mud Hydrostatic Pressure
- Conventional
- Fracture Pressure
- Pore Pressure
- Sea Water Hydrostatic Pressure
- Depth
- MUD Hydrostatic Pressure
- Conventional

**Expandable Tubulars**

- Ultimate Strength
- Yield Strength
- Stress
- Pressure

**Expandable Tubulars**

Well designs with the same production capacity using unexpanded and expanded tubulars.

---

Fig. 1—Cross-section of partially expanded pipe with mandrel.

Fig. 2—Expandable Tubulars are cold worked into the tubular's plastic region.

Fig. 3—Comparison of conventional and expandable tubulars with emphasis on the expandable tubulars.
High lubricity muds

Hole cleaning

State of the art in ERD

State of the art in MLD

Completion, workover, and fishing concepts

Horizontal gravel-packed sand control completions
Downhole completion tools for ER and ML wells

Technical difficulties
- Lost Circulation
- Well Control Problems
- Torque, Drag, and Buckling
- Casing Wear
- Cementing

Lost circulation and other well control problems
Steve Walls

Torque and Drag

Torque, \( T = \frac{F \times d}{12} \)

Drag (friction)
\[ F = \mu N = \mu W \sin I \]

Force to move pipe,
\[ F = \mu W \sin I \]

An approximate equation, with \( W \) in lbf and \( d \) in inches
Effect of Doglegs

1. Dropoff Wellbore

\[ T = \alpha T \]

Buckling

Torque \( N \Delta \theta \), \( \frac{2d}{\Delta \theta} \), \( \frac{2d}{\Delta \theta} \)\( W \sin \theta \), \( 2T \sin \frac{\theta}{2} \)

\[ N \sin \theta \leq 2T \sin \frac{\theta}{2} \] (10)

Figure 7: Schematic view of the small scale test loop.

Fig. 7: A schematic for coated tubing buckling in a vertical wellbore.
Sinusoidal Buckling Load

A more general Sinusoidal Buckling Load equation for highly inclined wellbores (including the horizontal wellbore) is:

\[ F_{cr} = 2 \left( \frac{EI_W}{r} \right)^{1.5} \]

Sinusoidal Buckling in a Horizontal Wellbore

When the axial compressive load along the coiled tubing reaches the following sinusoidal buckling load \( F_{cr} \), the initial (sinusoidal or critical) buckling of the coiled tube will occur in the horizontal wellbore.

\[ F_{cr} = 2 \left( \frac{EI_W}{r} \right)^{1.5} \]

Helical Buckling in a Horizontal Wellbore

When the axial compressive load reaches the following helical buckling load \( F_{hel} \) in the horizontal wellbore, the helical buckling of coiled tubing then occurs.

\[ F_{hel} = 2 \sqrt{2} \left( \frac{EI_W}{r} \right) \]
Helical Buckling in Vertical Wellbores:

The upper portion of the tubular in the vertical wellbore will be in tension and remain straight. When more tubular weight is slacked-off at the surface, and the helical buckling becomes more than one helical pitch, the above helical buckling load equation may be used for the top helical pitch of the helically buckled tubular.

General Equation

A more general helical buckling load equation for highly inclined wellbores (including the horizontal wellbore) is:

$$ F_{hel} = \frac{2 \sqrt{2} \sqrt{1.9\frac{EIW_c \sin \alpha}{r}}} $$

Buckling in Vertical Wellbores:

In a vertical wellbore, the buckling will occur if the tubulars becomes axially compressed and the axial compressive load exceeds the buckling load in the vertical section.

This could happen when we “slack-off” weight at the surface to apply bit weight for drilling and pushing the coiled tubing through the build section and into the horizontal section.

Helical Buckling in Vertical Wellbores:

A helical buckling load for weighty tubulars in vertical wellbores was also derived recently through an energy analysis to predict the occurrence of the helical buckling:

$$ F_{hel,b} = 5.55 (EIW_c)^{1/3} $$

Helical Buckling in Vertical Wellbores:

This helical buckling load predicts the first occurrence of helical buckling of the weighty tubulars in the vertical wellbore.

The first occurrence of helical buckling in the vertical wellbore will be a one-pitch helical buckle at the bottom portion of the tubular, immediately above the KOP.
Helical Buckling in Vertical Wellbores:

The top helical buckling load $F_{hel,t}$ is calculated by simply subtracting the tubular weight of the initial one-pitch of helically buckled pipe from the helical buckling load $F_{hel,b}$, which is defined at the bottom of the one-pitch helically buckled tubular:

$$F_{hel,t} = 5.55\left(\frac{EIW_e}{e}\right)^{\frac{1}{3}} - W_e I_{hel}$$

$$\geq 0.14\left(\frac{EIW_e}{e}\right)^{\frac{1}{3}}$$

Conclusions

1. When conducting drilling, well completion and wireline logging in horizontal wells using CT, helical buckling of the tubing in the vertical section of the horizontal wells will usually happen. How to reduce this buckling will be a significant challenge in developing and extending CT technology for horizontal wells.

Continue ...

2. The CT may buckle helically in the horizontal section when conducting the above operations, but it is seldom for the CT to buckle in the build section of a horizontal well.

Continue ...

3. The axial load distribution of helically buckled CT will be largely affected by the frictional drag generated by the helical buckling. The CT may be "locked-up" in a horizontal well when a large portion of CT is helically buckled, to the point where you can hardly increase the bottom load, such as the bit weight, by "slacking-off" weight at the surface, nor push the CT further into the wellbore.

Continue ...

4. The equations on tubular buckling and axial load distributions presented here make it possible to predict the actual bit weight/packer load, and the maximum horizontal section length, for drilling, well completion, CT wire logging, CT stimulation, and other CT operations in horizontal wells. Generally, larger size of CT will reduce the risk of helical buckling and the amount of resulting frictional drag.
Casing wear

Excess torque and drag
- Threaten the success of completion if it exceeds the capacity of the Drive system or drillstring.
- Can result in casing wear

Catenary wellbore

Non-rotating drillpipe protectors

Non-rotating drillpipe protectors

Table 1: Average Frictional and Stiction COF’s.

<table>
<thead>
<tr>
<th>RESULTS</th>
<th>Low Dog</th>
<th>Non-rotating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Sticking COF</td>
<td>0.11</td>
<td>0.14</td>
</tr>
<tr>
<td>Average Relativistic COF</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Rotary Steerable Systems

Remediation for Casing Wear

- Retrieve and replace
- Scab liners (tie back)
- Plastic liners
- Expandable cased-hole liners

Plastic Liners

Fig. 1. Flattening reduces application places a tight-fitting liner into the well. These capacities vary with the diameter, but in the case of the example above it is a standard plastic liner.

Fig. 2. Following devitrification, plastic liner is pushed into the wall with simple weights that are then released. The plastic “membrane” takes over and the plastic swells out against the steel pipe.

Fig. 3. As this sample pipe cross-section shows, a properly selected plastic, accurately downsized and successfully fitted, provides a tight-fitting liner that pushes out against the steel with a force that requires about 100 lbf/in.

to move; i.e., the liner is self-hanging.

Solid Expandable Tubulars
Cementing

Variables that affect liner cementing performance in deviated wellbores

Displacement flow rate

- Prodhoe Bay wells
  - 8-1/2" x 7" liner
    - Circulate at a velocity of 420-540 ft/min
  - 6-6/4" x 5-1/2" liner
    - Circulate at 600 ft/min
  - Cement slurry was displaced at 12 BPM

Cement slurry rheology

- Field results show more success with thinner cement slurries.
- This allows turbulent flow
- PV of 30-40
- YP of 3-5
- Results in a maximum swirl and turbulence

Turbulators placement

- Short 5 inch cylinders with spiral rigid vanes welded and positioned at approximately 30-45 deg.
- Forces the fluid to flow in a spiral pattern around the casing and wellbore.
- Two per joint is usually good
- Point in same direction

Centralization

- Must have enough centralizers to support the casing to centralize properly
Critical ERD Technologies

Critical Technologies for Success in Extended Reach Drilling (ERD) by Payne, M.L., Cocking, D.A., and Hatch, A.J.

Presented at the SPE ATCE, 1994, NO

Outline

- This paper discusses critical technologies for ERD.
  - Torque/drag
  - Drillstring design
  - Wellbore stability
  - Hole cleaning...

Outline - cont’d

- Casing considerations
- Directional drilling optimization
- Drilling dynamics
- Rig sizing

This paper is based on knowledge and experience gained from Wytch ERD project

Torque/Drag

- Optimization of directional profile
- Mud lubricity
- Torque reduction tools
- Modeling considerations

Optimization of directional profile

- Simple build and hold profile is not successful
  - High torque and drag
  - BUR = 4 deg./30 m from near surface
Directional profile - cont’d

- Pseudo-catenary profile is used
  - Initial BUR = 1.0 - 1.5 deg./30 m
  - Maximum BUR = 2.5 deg./30 m
  - BUR increase = 0.5 deg./400 m
  - Target angle = 80 - 82 deg.
  - Torque reduction
  - Easy to run or slide drilling assemblies

Mud lubricity

- It is important but complex.
- It affects torque and drag.
- WBM is used in the beginning.
- OBM is used after setting 13-3/8 in. casing.
- Oil-water ratio has a significant impact on lubricity. More oil means less friction.

Torque reduction tools

- Non-rotating DP protectors
  - Typically one on every other joint
  - Reduced torque ~ 25%
- Lubricating beads
  - Expensive for OBM
  - Reduced torque ~ 15%

Modeling considerations

- No torque/drag model is adequate for dynamic drilling conditions.
- Use MWD sub to measure downhole torque on bit and WOB.
- Using MWD data, estimate friction coefficients to monitor and predict downhole conditions such as torque/drag, wellbore stability, and hole cleaning.

Drillstring design

- Top-drive rotary system capacity
  - = 45 - 60 kips-ft
  - Useful only if the drillstring provides matching strength

Drillstring design for high torsional capacity

- Grade S-135 is conventional
- Grades up to 165 ksi are considered non-conventional and “high strength”
- High torque thread compounds
- High torque connections
  - Double-shoulder tool-joints
  - Wedge thread tool-joints
Hole stability for high hole inclination

- Use correct mud weight
- Stress data from:
  - Leak-off test
  - Extensometer
  - 4-arm calipers
- Chemical interactions between mud and formation also affect stability

Hole cleaning

- Flowrate is the primary hole cleaning tool - up to 1,100 gpm in the 12 1/4" hole
- Rheology
- Pipe Rotation
- Circulate cuttings out - prior to trip
- Monitoring of hole cleaning

Solids control

- Solids control in mud is essential for long MD holes where hole cleaning efficiency may tend to be low
- May need extra processes or equipments

Casing consideration

- Casing wear avoidance
  - Tungsten carbide protects the drillpipe well, but is hard in casing
  - Use of new generation of hard-metal, e.g. chromium-based metals
  - Use of alternative hard-facing materials
- Several casing running options

Casing running options

- Three primary considerations
  - Maximum available running weight
  - Frictional losses of running weight
  - Mechanical losses of running weight

Directional well planning

- Anti-collision considerations
  - It is necessary when well separation is small.
- Target sizing (ex. 200 m by 350 m)
- Profile planning (ex. pseudo-catenary profile)
Hydraulic consideration

- Proper selection of PDM rotor nozzles
- Bit nozzle selection
- Maximum bit pressure drop of 500 psi

BHA philosophy

- Change of one “primary” BHA component at a time.
- Use of steerable PDMs.
- Development of solid relationships with bit manufacturers and advancement of bit designs with those of the BHA.

Tortuousity considerations (dog-leg severity)

- Need to minimize slide interval and frequency
- Slide on 5-7 m increments to maintain low angular change

Emerging technologies

- Rotary-steerable system
- Azimuth control tool

Surveying

- MWD
- Gyro surveys for specific objectives:
  - Anti-collision requirements
  - To reduce lateral errors at target entry
  - Definitive survey at target entry

Drilling dynamics

- Torsional stick/slip vibrations cause chaotic bit and drillstring motion and adversely affect bit life, ROP, and rotary drilling capacity
- Rotary feedback system to reduce torsional vibrations
- Bit/BHA induced lateral vibrations
- Hole Spiral
Rig sizing

- Requirements depend on ERD project size.
- Proper rig and drilling equipment is critical.
- It is necessary to determine maximum anticipated drilling torques and margins.
- Rig power efficiency must be analyzed.

Conclusions

- Special rig configurations and drilling equipments are necessary to successfully pursue extreme ERD objectives.

Conclusions cont’d

- ERD operations require intense engineering focus on monitoring and analysis of field data and forecasting on future wells.
- High levels of team-based performance can be critical to ERD success.

Questions and discussion

The End
Thank you
Extended Reach Drilling

- Discussion of the State of the Art, Present Limitations, Completion, Fishing and Workover Tools & Techniques and Critical Safety Issues

Steve Walls

Definitions of ERD

- Throw ratio > 2:1
- HD/TVD
- ER Projects typically break into four groups:
  - Ultra Long ERD
  - Very Shallow ERD
  - Deepwater ERD
  - Small Rig ERD

General Limitations

- Traditional Challenges have been mostly overcome
- Remaining Ones are Toughest
  - ECD
  - Ultra Deep Casing Runs
  - Practices
    - Design
    - Implementation

ERD Performance

- ERD: Just reaching the objective
- Time & Cost Performance
- New Benchmarks
  - Fit-for-Purpose Solutions
  - ERD Solutions: Alternatives
    - Subsea Tiebacks
    - Another Platform
    - Increased Footprint

Ultra-Long ERD Wells

- Where are these wells being drilled?
  - US: GoM, California, ANS
  - West Africa, Canada, North Sea
  - China, Australia, New Zealand
  - SE Asia: Thailand, Malaysia, Indonesia
  - Russia
  - Argentina, Venezuela

Ultra-ERD Characterization

- Throw Ratios up to 6:1
- Build/hold to 80º
- Negative weight: ½ of the HD
- Special techniques: logs, casing
- Nuclear drilling
  - TDS-4 minimum, XT conn
  - 3 or 4 1600-hp pumps
  - 5.5", 5.875" drill strings
What Does It Take?

- Extensive Planning: 9-12 mo/well
- Lead Times (Drill Pipe 1 year)
- Rig Availability & Modifications
  - HP, HT, space, setback loads
- Training for THAT well
  - Office & Operations teams

Available Technologies

- Casing Flotation
- Downhole Adjustable Stabilizers
- Rotary Steerable Systems
- Walking PDC bits
- Mechanical torque/drag reducers
- Wireline tractors
- Hole condition monitoring systems
- HT top drives and tubulars

ERD Performance

- Case History: Real Learnings
  - 1992: 15980' MD
    - Drlg: 400 hrs   NPT: 175 hrs
  - 1994: 16018' MD
    - Drlg: 250 hrs   NPT: 50 hrs
  - 1996: 16400' MD
    - Drlg: 260 hrs   NPT: <10 hrs

CH 2: Best Performance

- Pre-1993
  - 16,000' MD: 70 days

- 1993-1994
  - 16,500' MD: 50 days

- 1995-1996
  - 16,500' MD: 35 days
  - 20,500' MD: 55 days
**Operational Training**

- **Before Training**
  - 14,500' MD: 60 days
  - 16,000' MD: 95 days
  - 17,800' MD: 108 days
- **Project-Specific Training**
  - 21,000' MD: 110 days
  - 22,000' MD: 108 days
  - 25,000' MD: 140 days
  - 24,000' MD: 93 days

**Deepwater ERD**

- Same considerations as Shallow
- ECD is primary limit
- Present wells
- Comfortably within 2.5:1 ratio
- 15,000’ step-outs, 6000’ TVD
- Primarily from SPARs
- Deepest WD to date: 5400’
- Record: 6000’ TVD, 21,000’ step-out (WD was 1200’)

**Small Rig ERD**

- Typical: ERD Rig  Small Rig
- DW: 2000 hp <1500 hp
- MP: 4000+ hp  2-3000 hp
- Circ: 7500psi  4000 psi
- TD: 60k ft.lbs  28k ft.lbs
- Mud: >3000 bbl  1000 bbl
- Setback: Plenty  Not Enough

**Finesse Drilling**

- Offshore California: 1999
- Small “workover” rig
- 5” drill pipe
- Portable top drive
- 2 850-hp mud pumps
- 750-bbl active mud system
- Not enough setback or casing storage

**Project Concerns**

- Setback Limits
  - Space and fingerboard size
  - Weight on sub and jacket
  - Pipe stretch exceeded head room
- Pipe Rack Storage
  - Casing run off the boat
  - Managing multiple strings
  - Simultaneous setback limits

**Operational Limits**

- Catheads, Iron Roughnecks (HT)
- Rig Power
  - Impossible to backream at TD
  - Max: Pumps, Top drive, Lifting
- Design Limits: Overpulls gone
- Mud systems: shipped whole mud
- Solids handling, small volume
- Circ: Flowrate, pressure limits
Project Results
- Record California Well
- 19,555’ MD
- 79º Tangent section, drop @ TD
- 3º/100’ build
- 16,000+’ HD
- 8,000+’ TVD

Completion Techniques
- Pre-Drilling Consideration
  - Well: designed for the completion AND future interventions
- Tubular logging, perforations
- 8500’ slotted horizontal liner
- Wireline, CT tractors
- Intelligent completions, particularly for multiple pay sections

Interventions
- Three Main Technologies
  - Jointed Tubing
  - Live Workovers (Snubbing)
  - Coiled Tubing Units
  - Wireline Options typically limited
  - Wheeled Tools, Tractors
  - Primarily are System Failures
  - Corrosion, Sand Control, failed packers (Annular pressure)

Interventions
- Three Main Technologies
  - Jointed Tubing
  - Live Workovers (Snubbing)
  - Coiled Tubing Units
  - Wireline Options typically limited
  - Wheeled Tools, Tractors
  - Primarily are System Failures
  - Corrosion, Sand Control, failed packers (Annular pressure)

Fishing Considerations
- Wellbore friction constraints due to tortuosity, wellbore stability
- Jar placement is of prime importance in ERD wells
- Computer program placement instead of rules of thumb
- Required at the start: Risk Management Analysis
  - Sidetrack Planning Team
  - Are the Take Points Firm?

Jar Placement
- Longitudinal Stress Wave Theory
  - Foundation of Jarring Programs
  - Impact and Impulse
  - Stress Wave Reflection
  - Jars need to be optimized for both down-hits and up-hits, depending on the anticipated problems
  - Two-piece jars can be useful

General Fishing Rules
- DLS>15º/100’: don’t operate jars in this environment due to stresses
- Jars below build/turn section: As much as 50% of the axial load can be lost due to wellbore contact
- Jars above build/turn section: Stress wave reflections are less, resulting in lower impulse.
  - Anticipate (experience)
Intelligent Wells

- Fundamental: downhole process control
- Realtime (or near-RT) surveillance, interpretation and actuation
- Accomplished through downhole measurement and remotely controlled zones (versus surface)
- "Dumb" wells: provide no data or control except through CT, wireline or jointed tubing interventions

Converging Technology

- Smart wells Just In Time
  - ERD-ML, Horiz Drlg achievements
  - Fewer but larger tubulars
  - Sand control & stim improvements
    - 50 bpm @ 15000 psi frac-pacs
  - Pre-completion of multiple pays
  - Draining multiple reservoirs
  - Co-mingled production

ABB Smart Well Concept

Schlumberger IRIS
(Intelligent Remote Implementation System)
**Future Intelligence**

- ADMARC system being tested

---

**Critical Safety Issues**

- Consider the Operations
- HP Circulating Systems
- Multiple handling of Tubulars
- Exposures to exotic fluids
- SBM BMP: compliance systems
- Storm planning, ops disruptions
- Rushed planning implications

---

**Summary**

- Viable ERD projects are now being undertaken from small rigs, in deepwater & with very long HDs.
- Current technologies answer most of the limitations of ERD. Those limitations which remain are very significant challenges.
- ERD through specific design and implementation practices is an absolute must.
LOC Control Techniques

Techniques to Control Lost Circulation in Drilling Through Under-Saturated, High-Permeability Formations

Steve Walls

What’s the Problem?

- Producing formations depleted from virgin pressures
- Wellbore stability, casing string designs may cause problem
- Trapped pressures in source rock require high MWs; lead to very high overbalances & Delta P
- Weakened rock matrices
- Synthetic Oil Based Muds

Problem Magnitude

- Losses may be almost inevitable
- Once begun, LOC very difficult to cure when drilling with SBM
- Typically, losses > 25 bbl/hr require a response from rig team
- @ $300/bbl, this could lead to a $180,000 mud loss in 24 hours
- Sen. Dirksen from Illinois

Response Strategies

- Systematic, Rigorous, Progressive
- Ramping-Up Approach
- Avoid the Problem
- Watch Indicators, React to Seepage Losses
- Manage ECD, Hydraulics, ROP
- Hole Cleaning Cycles
- Kick Tolerance Consideration?

Progressive Response

- Sweeps: CaCO₃, G-Seal, Master-seal, 50-70 bbl’s @ 50-80 #/bbl
  (Lower end to maintain drilling)
- High Fluid Loss Squeezes: Frac Attack, Gunk Squeezes can be placed through drill string usually
- Dia-SealM & Cement Squeeze: POOH required, TIH Oh
- Contingency string or live with the losses if you’re at a casing point

Working the Problem

- Early on, the loss zone(s) must be identified. Area knowledge?
- Resistivity Info (Invasion)
- Sand/Shale Interfaces
- At the Bit
- Casing Shoe or 1st Sand
- Rubble Zones (Sub-salt wells)
- Primary Cementing Considerations
Moving On
- After spotting pills, pull up, circ to ensure drill string is unplugged and free and monitor losses for 3-4 hours while well heals (and LCM migrates into position)
- If squeezing, use a 5-minute hesitation squeeze technique with no more than 50 psi increase per squeeze increment. Max 250-300

Continue to Monitor
- When LOC is healed, it’s usually a temporary fix, except in the case of Dia-SealM & cement squeezes
- Monitor returns at all times and be aware of positions of drill string tools such as stabilizers and bit
- If LOC occurs again, determine immediately if it’s a new zone or the problem you just fixed

Important Considerations
- Care and feeding of the reservoir
- Rock matrix is under-strength, in the case of prior depletion
- Use Risk Management matrix to systematically determine the proper response level
- DO NOT PRE-TREAT!
  - Causes the problem you’re trying to avoid

Summary Points
- Lost Circulation, particularly in SBM, can quickly add up to the loss of hundreds of thousands of dollars + severe reservoir damage
- Anticipate the problem (logistics)
- Systematic Response
- Intelligent Drilling with all the relevant data points. ECDs, a patient approach to solutions
Towards Better Hole Cleaning

High lubricity mud and the Use of Sweeps for Hole Cleaning: Understanding the Hole Cleaning Mechanisms

Steve Walls

Many Types of Systems

But Still 3 Foundations
- Water-Based (WBM)
- Oil-Based (Diesel) (OBM)
- Synthetic-Based (SBM)

Progressively higher costs and applicability as drilling severity increases, whether it’s HP, HT, ERD, Hole Stability or, as is most common, a combination of these

Water-Based Systems

- Benefit the most from lubricants
- Combinations of surfactants, mineral oil, snake oil
- Most successfully used in fit-for-purpose approaches, MLD
- Milne Point cocktail, ANS
- Highest Friction Factors of any system with the lowest $/bbl cost
- Drill-In Systems (Flo-Pro)

Diesel Oil Muds (OBM)

- Expensive, but very tolerant of contaminants and high temps
- Very stable, minor barite swap tendencies, Compressive
- Very good lubricity
- Serious Issues
- Exposures
- Discharges
- Disposal, Housekeeping

Synthetic Based (SBM)

- Most predominant usage in ERD, Deepwater & areas with hole stability problems
- Very expensive, high lubricity
- Two main types, esther & i-o
- EPA discharges & LC50 issues
- Require the use of a BMP & compliance engineer
- Problems with LOC

SBM Characteristics

- Compressible like OBM
- Lose density as temp rises
- Very subject to barite swap
- Need to be very careful to stabilize density in well before drilling after a trip
- Cuttings dryers, oil retention and monitoring with compliance engineer
Hole Cleaning

- Hole Sweeps
- Hole Angles <30º
  - Improve as well goes vertical
- Very low benefit >30º
- Mainly contaminate mud system and drive up rheologies, causing other wellbore problems
- Satisfy the Office (or Field)

Hole Cleaning Model

- Lore is full of references to chip velocity, annular velocity, hole cleaning profiles (plug to laminar to turbulent)
- All explained in vertical wellbores with concentric annuli
- Seen any of those around lately?

Real Wellbores Today

- Directional Wells, Eccentric Annuli
- Varying hole angles and turns
- ECD problems lead to controlled ROPs, minimum rheologies
- Cuttings fall to bottom of wellbore around drill string, particularly in angle building sections when there’s a high proportion of sliding vs. rotary drilling

Some Snapshots

- 0º – 30º
  - More traditional hole cleaning
- 30º – 50º
  - Cuttings dune, Avalanching
- 50º – 90º (and beyond)
  - Cuttings dunes slowly working up the wellbore
  - Picture a sweep in each annulus

How Does Hole get Cleaned?

- The real answer is that many times it doesn’t, resulting in stuck pipe, wasted time on trips, lost wells
- Drillers are Optimists
  - ERD: Exactly Reverse Direction
- Assume hole is NOT clean until it proves otherwise
- Torque, Drag, Circ Press, Cuttings

String Rotation

- This is the real key to hole cleaning
- Not just any rotation: low rpm is insufficient
- ERD Specialists have noted step changes at 120 rpm and again and 150-180 rpm, depending on drill string size
- Not a panacea if ECD is a problem
Patience

- Holes with extended 70º and above tangent sections rarely even begin to clean up until 2 bottoms up are observed
- Dunes are moving up the well and the hole will unload suddenly
- 4 bottoms up is typical, it can be more
- Torque/Drag analysis: condition

Drilling while Cleaning

- It's not impossible, but the mechanisms need to be understood as they apply to a given wellbore geometry
- Great advantage of rotary drilling vs. motor drilling is hole cleaning (plus the lower tortuosity and micro-doglegs from tool sets)
- Weighing cuttings

Summary Points

- Mud systems fit for purpose
- Understand Hole Cleaning mechanism through a given well
- Dubious value (& wasted money and time) of sweep combinations
- Designing the well to be cleaned
  - Drilling Clean (Motor Housings)
  - Tripping Clean (Hole Cleaning)
  - Casing Clean (Back Reaming)
**Introduction & Definitions**

- TAML: (Technology Advancement of Multilaterals) is the result of a group of operators with multilateral experience who developed a categorization system for multilateral wells based on the amount and type of support provided at the junction.

---

**Level definitions**

- **LEVEL 1**: Open hole junction
- **LEVEL 2**: Completed & centralizer multilateral / open hole / centralizer & lateral liner / anchor to lateral lifeline

---

**Level definitions**

- **LEVEL 3**: Centralized & cemented multilateral / open hole / centralizer & lateral liner / anchor to lateral lifeline
- **LEVEL 4**: Centralized & cemented multilateral / open hole / centralizer & lateral liner / anchor to lateral lifeline

---

**Level definitions**

- **LEVEL 5**: Centralized & cemented multilateral / open hole / centralizer & lateral liner / anchor to lateral lifeline

---

**Level definitions**

- The Downhole Splitter is regarded as a TAML Level 6 multilateral is a unique system and process that allows two distinct wells to be drilled, cased, and completed from a single surface conductor. When completed, each well can be produced, serviced, and worked over independently of the other.
Step one: Drilling the Lateral
- Starts with drilling out of lateral pre-milled window to create the lateral well bore.
- Once the lateral has been drilled, the whipstock is removed in preparation of running the lateral liner.

Step Two: Installing the Deflector
- The system deflector is then run into the lower latch assembly.
- This automatically orients the deflector towards the lateral window.

Step Three: Running the Lateral Liner
- A bullnose on the lateral liner deflects off of the deflector assembly and into the lateral well bore.

Step Four: Orienting the Liner Running Tool
- The liner running tool engages the upper orienting latch coupling.
- Drill pipe is rotated to engage the orienting latch assembly.

Step Five: Setting the Transition Joint Assembly
- The liner running tool strokes through the orienting latch assembly as the Transition Joint locks into a profile in the main casing.

Step Six: Removal of the Liner Running Tool
- The liner running tool is removed.
Example of completing a TAML Level 3 multilateral junctions.

Step Seven: Retrieval of the Deflection Tool

- The liner deflector can be retrieved, or it can be left in the hole.

Example of Artificial Lift in Multilateral Wells

Limitations and drawbacks

- Higher initial costs
- Complicated drilling, completion and production technologies
- Sensitive to poor vertical permeability
- Complicated and expensive stimulation
- Often slower and less effective cleanup
- Cumbersome wellbore management during production
- Technology still in development stage

Using Coiled Tubing for Multilateral Work-Overs

- A new bottom hole assembly (BHA) enables a new method to workover multilateral wells using coiled tubing.
- This BHA combined with a lateral entry guidance system (LEGS) makes it possible to perform workover treatment in wellbores that were previously impossible.

LEGS BHA Function

- Two modes of operation; circulating and navigating
- Can switch the mode of operation by pumping at a given flow rate through the BHA
- Circulating mode is used to deliver treatment fluids

Kick-off Assembly

- The Kick-Off Assembly pivots the wand about the base of the wand, radially outward.
The Sweep Assembly rotates the wand and the Kick-Off Assembly about its center axis, through a maximum of 360 degrees.

This figure shows a design of the LEGS BHA that will not permit the tool to be misguided by the entrance geometry of the junction.
Horizontal Gravel Packs

Outline
- Introduction
- Circulating path in a standard gravel pack
- Some history
- Project planning and execution
- Limitations of horizontal gravel packs in ERD wells
- Future challenges

Introduction
Gravel packing is a commonly applied technique to control formation sand production from open-hole oil and gas wells. In a gravel pack completion, a screen is placed in the well across the productive interval and specially sized, high permeability gravel pack sand is mixed in a carrier fluid and circulated into the well to fill the annular space between the screen and formation.

A basic gravel pack circulating path

Openhole horizontal gravel packing
- OHHGP has gained acceptance as a mainstay completion technique.
- Projected reliability and the potential to achieve significantly higher sustainable production rates have been the major drivers for pursuing this type of completion.
- Interval lengths in excess of 2500 feet are now fairly common, with the current record being 6,938 feet in a well completed in the North Sea by the Texaco North Sea UK Company.

Some history

The demand of new technology:

- Deepwater completions of high volume producers (>15,000 BOPD or >70 MMscf/D) in the GOM with a well life up to 15 years became a major challenge for the industry.
- Increased reliability was needed for the openhole screened completions, and OHHGP was the answer to the problems experienced. Some of the difficulties that were encountered will be discussed here.

Key issues in project planning and execution openhole horizontal gravel packs:

- Reservoir study
- Shale stability study
- Formation integrity test
- Gravel pack sand sizing
- Gravel pack screen
- Workstring design
- Well displacement
- Fluid loss control

Issues that can jeopardize performance of successful OHHGP

- Excessive fluid loss
- Varying hole geometry that could lead to premature pack termination
- Hole stability issues leading to hole collapse
- A narrow pressure spread between bottomhole pressure and fracture gradient

Limitations of Extended-Reach Horizontal Gravel Packs

- The Beta-wave (return gravel wave) placement pressure is the main factor in determining the maximum length of a horizontal gravel pack. This pressure is limited by the requirement to install the gravel pack without exceeding formation fracture pressure.

Beta-wave Pressure Control

- High Rate Well displacement to remove fluff
  - Circulating brine at high velocity provides optimum hole cleaning.
  - Ensures that drill solids and dynamic filter cake material (fluff) is circulated out.
  - The remaining filter cake should be thin and extremely durable.
Future challenges

- New invert gravel pack fluid that has the potential to save rig time by reducing costly OB to WB fluid swaps, and also eliminates the need for acid treatment after pack placement.
- Advancement in tool technology that reduce bottomhole circulating pressure during placement of the sand pack using the Alpha/Beta placement method.

Final comments

- In the future, the newly developed expandable screen systems may also provide an alternative to horizontal openhole gravel packing.
- In a demanding environment such as deepwater, technology must continue to evolve to meet the need for long term reliability and high productivity.
- It is difficult to say whether one of these technologies will emerge as the dominant technology.

Cont’d

- Advancements in tool technology that allow multiple functions during a single trip of the workstring.
- Advances in screen systems that provide the capability to isolate and pack around shale sections as well as the capability to place the gravel pack while encountering fluid loss.