Introduction

- Petrofac
- Formation Testers
  - Pretest Procedure
  - Pressure Interpretation
  - Older & Newer Tools
- Draw-Down Mobility
- Reservoir Quality
- Pressure Interpretation
- Pretest Acquisition & Quality Control
- Conclusions
- Questions & Discussion
Introduction to Petrofac

• We are an international service provider to the oil and gas processing industry.

• More than 13,000 people support our operations in 29 countries worldwide.

• We design, build, operate and maintain oil and gas facilities and our capabilities span the asset life cycle from concept through to decommissioning.

• Petrofac Engineering & Production Services (EPS) span Engineering, Operations & Maintenance, Asset Management, Well Engineering, Training, Late Life and Decommissioning.

• Our Engineering Services consultancy includes a Subsurface Consultancy team delivering:
  • Geoscience
  • Reservoir and production engineering

• We integrate our subsurface skills with wider Petrofac capabilities.

• We execute fast-track oil and gas projects, including greenfield developments, mid-life production enhancements and late-life field optimization.
FORMATION TESTERS

• PRETEST PROCEDURE
• PRESSURE INTERPRETATION
• OLDER & NEWER TOOLS
Formation Tester Pretest Procedure

- Tool positioned at depth of interest
- Pressure gauge stabilized (1)
- Mud pressure recorded (2)
- Packer seals against formation & probe extended to formation (3)
- Small volume of fluid is extracted and pressure draw-down (4)
- Formation pressure build-up (5)
- Formation pressure stabilized (6)
- Tool retracted (7)
- Mud pressure stabilized & recorded (8)
Pressure Interpretation

- Reservoir at original pressure

- Pressure points define a gradient consistent with formation fluid properties
  - Gas, Oil, Water

- Gradients consistent with PVT properties & water salinity

- Free-Water Level defined by intersection of water & hydrocarbon gradients

- Oil-Water Contact is above the Free-Water Level in a water-wet reservoir

- In a produced reservoir FTs may have different objectives
Older and Newer Tools

Older tools

- Strain Gauge
- Quartz Gauge if run
- Fixed draw-down volume
- 2 X 10cc
- 1 X 20cc
- Fixed draw-down rate
- Single Build-up

Newer tools

- Improved Strain Gauge
- Improved Quartz Gauge
- Variable draw-down volume
- Variable draw-down rate
- Multiple draw-downs
- Multiple build-ups

2 X 10cc DD

3 X 0.1cc DD
DRAW-DOWN MOBILITY  mD/cp
Draw-Down Mobility (mD/cp)

- Draw-down mobility calculated from:
  - Minimum DD pressure
  - Stabilized formation pressure
  - Pretest volume & rate
  - Filtrate viscosity
  - Probe diameter

\[ K_{dd} = C \cdot \frac{q \mu}{\Delta P} \]

\( K_{dd} \) = Drawdown Permeability in \( \text{md}/\text{cp} \)

- \( C \) = probe Constant
- \( q \) = fluid extraction rate
- \( \mu \) = fluid viscosity
- \( \Delta P \) = pressure drawdown
Draw-Down Mobility

880 psi DD
4 mD/cp mobility

100 psi DD
60 mD/cp mobility

4 psi DD
1200 mD/cp mobility

Reservoir Quality
Low – Medium - High

Petrofac
Draw-Down Mobility

Summary Plots: Old and New Tools

2 X 10cc DD

3 X 12cc DD

Final Pretest Expanded

3 X 5cc DD

1 X 20cc DD

Pressure (psia)

Time (sec)

Pressure (psia)

Time (sec)
### Summary Tables

<table>
<thead>
<tr>
<th>Depth</th>
<th>Formation Pressure</th>
<th>Mobility</th>
<th>Mud Pressure Before &amp; After</th>
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### Drawdown Mobility

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RESERVOIR QUALITY FROM MOBILITY
Reservoir Quality from Draw-Down Mobility

- ~150m TVDSS
- Multiple Sand & Shale Oil Reservoirs
- Oil-Based Mud
- Rotary Side-Wall Cores
  - Permeability (mD)
  - Porosity (v/v)
- Formation Tester data
  - Mobility (mD/cp)
Core Permeability and Draw-Down Mobility

- Core analysis from Rotary SWCs in a single well
- Limited core data
- Multiple reservoirs
- Core indicates a possible Poro-Perm trend
- Draw-Down Mobility from Formation Tester
- FT mobility shows a similar trend to core analysis

Core Data

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<th>Core Porosity</th>
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FT Data

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Core Permeability and Draw-Down Mobility

Three Wells

- Core and FT mobility data from three wells
- Z colour axis for well
- Rotary SWCs & conventional core
- Abundant Draw-Down Mobility data from FTs
- Better defined Poro-Perm trends using multiple well data
- Draw-Down Mobility and core shows similar trends
Core Permeability and Draw-Down Mobility

- Z axis colour is VSH
- Lighter points are cleaner & darker points are shalier
- Draw-Down Mobility and core shows similar trends
- Draw-Down mobility seems to be a reasonable proxy for permeability
- Check and calibrate against other methods such as Core, Well Test, NMR

Core Data

FT Data

Core Porosity

Log Porosity

Three Wells and VSH

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PRESSURE INTERPRETATION USING DRAW-DOWN MOBILITY
Formation Tester Pressure Interpretation – High Perm. Reservoir

- FT Pressures plotted against TVDSS depth
- Pressure gradients related to fluid type
- Intersection of hydrocarbon and water gradients identify the Free-Water Level
- Pressure gradient and positioning on FT points should be:
  - Guided by pretests with higher mobility and more reliable pressure data
  - Consistent with fluid PVT properties and water salinity
In lower quality reservoirs the pressure data may be more difficult to interpret:

- Insufficient build-up stabilisation time
- Super-charging of the formation
- Fewer valid FT points
- Pressure gradient and positioning on FT points should be:
  - Guided by pretests with higher mobility and more reliable pressure data
  - Consistent with fluid PVT properties and water salinity
PRETEST ACQUISITION & QUALITY CONTROL
Pretest Quality Control

Older generation FT tools:
- Fixed DD volume and rate

Newer generation FT tools:
- Allow multiple Draw-Downs with each Pretest
- Control of volume and rate
- Small pretest volumes:
  - Less drawdown
  - Faster buildup & stabilization
- Improved acquisition of valid pressure data in low perm formations
- Quicker surveys with better results due to more control on volume and rate

2 X 10cc pretest
3 X 0.11 cc pretest
Pretest Quality Control

- Poor buildup may be due to:
  - Poor reservoir quality
  - Failure to communicate with formation through mudcake

- Select a sufficient initial drawdown volume to ensure pressure communication is established with the formation:
  - 1cc to 2cc in low perm
  - 3cc to 7cc in high perm

- Drawdown rate is less sensitive:
  - 0.1 to 0.2 cc/sec in low perm
  - 0.5 to 1.0 cc/sec in high perm

- Volumes and rates are a guide and will depend on the formation, field engineer and local experience
Pretest Quality Control

- Mud hydrostatic pressure
  - Before and After the Pretest
  - Pressure difference may indicate insufficient stabilisation time

- Temperature Profile
  - Geothermal gradient
  - Fluid influx or losses

- Mud Weight Profile
  - Downhole direct measurement of MW
  - Mud quality

Mud Hydrostatic Before and After

- Mud hydrostatic pressure
- Before and After the Pretest
- Pressure difference may indicate insufficient stabilisation time
- Temperature Profile
- Geothermal gradient
- Fluid influx or losses
- Mud Weight Profile
- Downhole direct measurement of MW
- Mud quality
Pretest Quality Control

Mud Hydrostatic Before and After

- Mud hydrostatic pressure
  - Before and After the Pretest
  - Pressure difference may indicate insufficient stabilisation time
- Less than 1 or 2 psia is usually good
- More than a few psia may not be good
- Operational Issues
  - Hole conditions
  - Time available
  - FT conveyance
  - Wireline or Drillpipe
  - FT objectives

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FT Pressure (psia)
CONCLUSIONS

QUESTIONS & DISCUSSION
Conclusions

- Formation Testers
  - Pretest Procedure Wireline & LWD
  - Pressure Interpretation Fluid gradients and FWLs
  - Older & Newer Tools Pretest volume and Drawdown rate
- Draw-down Mobility Theory and calculations
- Reservoir Quality Mobility may be a useful proxy for permeability
- Pressure Interpretation QC using FT mobility and Mud Before & After
- Pretest Acquisition & QC Pretest Size and Drawdown Rate in Low and High perm formations

- Many more FT issues: objectives, planning, acquisition, data delivery, interpretation
- Local knowledge and Wireline or LWD field engineer experience
- Operational issues: Packers, probes, gauges, well conditions, depletion, time, cost, priority, log in/out
- Shared responsibility and collaborative effort between many parties
- Field Team (Engineer, Wellsite Geologist, Drillers) Client Office Team, Service Company Team
Questions and Discussion

Colour = Mobility

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<tr>
<th>MUD TVD</th>
<th>MUD HYDRO BEFORE</th>
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<th>Delta PSI</th>
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TVDSS (m)

FT Pressure (psia)

Core Data

FT Data

Core Permeability

FT Mobility

Core Porosity

Log Porosity

< 10% VSH
10 to 20%
20 to 30%
30 to 40%
40 to 50%
BACK-UP SLIDES
**Draw-Down Mobility**

- **Low**
  - 670 psi DD
  - 16 mD/cp

- **Medium**
  - 160 psi DD
  - 92 mD/cp

- **High**
  - 13 psi DD
  - 950 mD/cp

**Reservoir Quality**

- **Full Pretest**
- **Final Pretest**
- **Expanded**

**Pressure History**

- WW 2201.0 m in S-1201.0 m (residual)
Water Density and Viscosity vs Temperature, Pressure and Salinity

![Graph of water density and viscosity vs temperature, pressure, and salinity.](image)

Fig. 3 – Viscosity of sodium chloride solutions as a function of temperature and salinity (wt%) at 14.7 psia.

In general, brine viscosity increases with:
- Increasing pressure
- Increasing salinity
- Decreasing temperature

Pressure:
- 7,000 psi
- 1,000 psi
- 14.7 psi
Pressure Conversions

Pressure or Force per Unit Area

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<th>Multiply Number of to Obtain by Atmospheres(^1)</th>
<th>Bayes or Dynes per Square Centimeter(^2)</th>
<th>Centimeters of Mercury at 0ºC</th>
<th>Inches of Mercury at 0ºC</th>
<th>Inches of Water at 0ºC</th>
<th>Kilograms per Square Meter(^3)</th>
<th>Pounds per Square Foot</th>
<th>Pounds per Square Inch(^4)</th>
<th>Tons (short) per Square Foot</th>
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\(^1\) One atmosphere (standard) = 76 cm of mercury at 0ºC

\(^2\) Bar

\(^3\) To convert height h of a column of mercury at 0ºC to the equivalent height h\(_2\) at 0ºC, use h\(_2\) = h (1 - (m - h) / 1 + m), where m = 0.0001818 and f = 18.4 × 10\(^{-4}\) if the scale is engraved on brass; f = 8.5 × 10\(^{-4}\) if on glass. This assumes the scale is correct at 0ºC, for other cases (any liquid) see International Critical Tables, Vol. 1, 58.

\(^4\) 1 gram per square centimeter = 10 kilograms per square meter

\(^5\) psi = MPa × 145.038

\(^6\) psf = lb/ft\(^2\) × 144 = ft/lbf/10.72
Petrofac is an international service provider to the oil and gas industry. We have been supporting the industry for over three decades. More than 13,600 people assist our operations in 29 countries worldwide.

Our consultancy offering within Engineering Services supports clients in unlocking value from their assets through the provision of life cycle engineering support.

We tailor our solutions to deliver a truly differentiated outcome:

- Life of asset services, from pre-investment analysis to late life
- Broad technical capability, including subsurface and surface expertise
- Intelligent solutions that leverage the strength of Petrofac Group capabilities
- Responsive and flexible team that combines an innovative approach with practical knowledge of execution
- Cost and planning deliverables enhanced by real time operations and construction data sharing

We deliver these services on a standalone basis or as part of our wider service delivery, seamlessly integrating with capabilities from the wider Petrofac Group.

Our clients include independent oil companies (IOCs), national oil companies (NOCs), technology developers, construction companies, Government bodies and public sector institutions.

Our services encompass:

- Advisory services – surface and subsurface expertise supporting new and existing assets, mergers and acquisitions
- Field development planning – feasibility, concept and pre-front and engineering design (FF&E)
- Asset/facilities support
- Late life asset management – asset-life support services
- Process technology
- Renewable energy – offshore wind (fixed and floating)
Petrofac Engineering Consultancy

Technical assurance

Our ability to deliver across the value chain and to draw on a wide breadth of technical resources means we can deliver intelligent solutions that benefit from synergies within the Petrofac Group. We have a reputation for providing pragmatic and measured advice and have developed ‘trusted advisor’ status with our clients.

Our capability includes:
- Reservoir characterisation/geological modelling and reservoir simulation
- Operations support and production technology and chemistry
- Well engineering (including plugging and abandonment)
- Dynamic simulation and transient analysis
- Computational flow dynamics
- Vibration analysis
- Acoustic engineering
- Flow assurance
- Safety and environmental assessment, compliance and engineering
- Process and facilities design
- Subsea and pipeline engineering
- Advanced structural analysis
- Asset integrity assurance
- Asset management
- Cost estimating and planning

Advisory services

By integrating our technical capability, which spans both subsurface and surface domains, with the resources and know-how of the wider Petrofac Group, we provide a vital link between strategic level decisions and front line implementation. Our subsurface and surface expertise is also central to our modelling expertise, allowing us to deliver high-quality planning and forecasting.

Our subsurface skills span geoscience, petroleum engineering, production and well engineering. We use this expertise to identify uncertainties associated with oil and gas reservoirs and perform valuable analysis much earlier than traditional approaches. This front-end loading enables us to unlock significant benefits such as managing risk and reducing costs further down the line.

Field development planning

We have been delivering field development services for over 15 years and our project history spans onshore, offshore and subsea developments. This includes assets where a combination of onshore and offshore facilities and pipelines are required and those in challenging or remote environments.

The breadth of our experience means we are fully equipped to manage the challenges that can emerge during this early planning. Our study managers are experienced in identifying the key issues and developing the right solution. Their expertise covers reservoir, well engineering, facilities, pipelines and refining.

We manage the whole field development process, developing options suitable for further screening and detailing. Our solutions are enhanced by an ability to cost benchmark against data held by our construction and operations services. We use this data to inform our decisions.
- As probe is set, tool performs very small ~0.3 cc pretest
- Engineer then does one or more pretests with defined volume and rate
FT Pretest Drawdown

\[ P_{bu}(t) = P_f^* - \beta e^{\alpha t} \]

- \( P_{hyds} \)
- \( P_{dd\_start} \)
- \( P_{stop} \)
- \( \Delta P_{dd} = P_{stop} - P_{dd\_end} \)
- \( t = T - t_{dd\_end} \)
- \( \Delta t_{dd} \)
- \( t_{dd\_start} \)
- \( t_{dd\_end} \)
- \( T \)
- \( Q \)