SPE DISTINGUISHED LECTURER SERIES

is funded principally through a grant of the

SPE FOUNDATION

The Society gratefully acknowledges those companies that support the program by allowing their professionals to participate as Lecturers.

And special thanks to The American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME) for their contribution to the program.
Fluid Considerations from Initial Assessment to Production

A. (Jamal) Jamaluddin
WCP Marketing Manager - ARM
Saudi Arabia, Kuwait, Pakistan & Bahrain
Almost all technical and economic studies in the oil industry require an understanding of the reservoir fluids.
Fluids Characterization Strategy

- Real-Time Monitoring of Sample Representativeness & Real-Time Fluid Properties (Formation Tester Technology)…..
- Collect & Retrieve Representative Fluid Sample (Single-phase sampling)…..
- Measure Fluid Properties Onsite (PVT Express)…..
- Samples to the Laboratory for Detailed PVT & Flow Assurance Analysis…..
Downhole Fluid Characterization

- In-situ *mud filtrate* contamination monitoring
- Gas phase detection assures *sample capture* above the bubble point
- In-situ *gas-liquid-ratio* (GLR) measurements without any phase separation
- Main NIR absorption peak diagnoses the type of oil
  - Heavy Oil/Light Oil/Condensate/Dry Gas
Principles of Color Absorption and Molecular Vibration Absorption

The spectrum of crude oil is the sum of color and molecular vibration absorptions.

Color Absorption:
- Caused by electronic excitations
- Depends on the content of aromatic compounds
- Represents the heavy end of crude oil
- Decays exponentially as wavelength increases

Molecular Vibration Absorption
- Caused by the resonance of the chemical bonds in the molecule
- Occurs at certain wavelength
- Proportional to the component density
Clean-up Process Oil Based Mud: Colour Effects

\[ y = \frac{m_1 + m_2}{(m_0 - 276)^{5/12}} \]

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>OFA</th>
<th>Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td>695</td>
<td>17%</td>
<td>22%</td>
</tr>
<tr>
<td>940</td>
<td>13%</td>
<td>17%</td>
</tr>
<tr>
<td>1264</td>
<td>12%</td>
<td>13%</td>
</tr>
<tr>
<td>1681</td>
<td>9%</td>
<td>11%</td>
</tr>
<tr>
<td>2250</td>
<td>8%</td>
<td>10%</td>
</tr>
</tbody>
</table>

\[ y = m_1 + m_2/(m_0 - 276)^{5/12} \]

<table>
<thead>
<tr>
<th>m1</th>
<th>m2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4852</td>
<td>-4.8787</td>
</tr>
</tbody>
</table>
Engineer opened the bottle to correctly catch the hydrocarbon slugs, and closed the Exit port at the same time.

Pressure Behaviors are good.
Gas-Oil Ratio - Molecular Vibration

LFA GOR Measurement - Experiment and Field Data

- LFA experiment data
- LFA field data

Y = X
Component Fluid Analyzer - Results

Gas-Oil Ratio
Sm3/Sm3

<table>
<thead>
<tr>
<th>CFA</th>
<th>Offsh. Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td>1290</td>
<td>991</td>
</tr>
<tr>
<td>440</td>
<td>319</td>
</tr>
<tr>
<td>370</td>
<td>305</td>
</tr>
<tr>
<td>320</td>
<td>306</td>
</tr>
</tbody>
</table>

Composition (wt%)

- C1
- C2 - C5
- C6+
- water

Pressure Gradients
- 0.374 g/cc
- 0.599 g/cc
- 0.982 g/cc

Depth (m)
- 3660.0m
- 3668.2m
- 3675.1m
- 3685.6m
- 3700.0m

Pressure (bar)
- 377 - 381
Reservoir Fluid Phase Behavior & Sampling

Temperature

Pressure

Wax Boundary

Upper Boundary

Bubblepoint curve

Lower Boundary

2-Phase

Dewpoint curve

Critical Point
Representative Sampling

Single-phase vs. Conventional (Oil Reservoir)

- Reservoir Fluid
- Hydraulic Fluid
- Nitrogen Gas

PV \propto T

- Conventional Bottomhole Sampler
- Single-phase Bottomhole Sampler
Importance of Single-phase Sampling

Asphaltene Contents
- Conventional: 0.19% (w/w)
- Single-phase: 0.61% (w/w)

Asphaltene Precipitation Onset
- Conventional: 7,800 psi
- Single-phase: 10,000 psi
Single-phase Sampling Categories

✓ Cased Hole

- Single-phase Reservoir Sampler - On Wireline, Slickline or Coiled Tubing.
- SCAR – Single-phase sampling during DST

Single-phase Reservoir Sampler

SCAR: DST Conveyed Carrier
Single-phase Sampling Categories

- Open Hole/Cased Hole
  - Formation Testing Tools (MDT)
    - Multi Port Sample Reservoir (450 cc)
    - Single Phase Multi Chambers (250 cc)
    - Large Volume Chamber (1 & 2.75 gal Chamber)
On-Site Fluid Characterization:
PVT in less than 8 hours

- Measured Properties:
  - Saturation Pressure
  - GLR
  - Composition to C36+
  - STO: viscosity, density, RI
  - Reservoir Fluid Density
  - OBM Contamination

- PVT Prediction using Artificial Neural Network
  - Detailed PVT properties
Optical Signal (Bubblepoint for Oil)
Optical Signal (Dew Point for Condensate)
Data Comparison - Black Oil

- C1 Mole %: 42, 50
- C12+ Mole %: 43, 49
- OBM: 7.8, 6.7
- MW: 202, 197
- STO MW: 371, 368
- GOR scf/stbbl: 315, 328
- Psat bar: 202, 206

PVT Express Data vs LAB DATA
Data Comparison - Condensate

- **C1 Mole%**: PVT Express Data = 83, LAB DATA = 83
- **C12+ Mole%**: PVT Express Data = 1.25, LAB DATA = 1.2
- **MW**: PVT Express Data = 25, LAB DATA = 25
- **STO MW**: PVT Express Data = 170, LAB DATA = 153
- **GOR bbl/mmcf**: PVT Express Data = 45, LAB DATA = 56
- **Dew Pt bar**: PVT Express Data = 374, LAB DATA = 373
PVT Expert – Results

![Graph showing formation volume factor (FVF) vs. pressure (PSIA).]

- **Formation Volume Factor (FVF)**
- **Pressure (PSIA)**

Legend:
- **PVT XP FVF**
- **Lab FVF**
PVT Expert Results - Rich Retrograde Condensate
Real-Time/Onsite Fluid Characterization

Impact to Client

- Early assessment of commodity pricing ➔ Commercial value
- Better assessment of reserves/producibility
- Areal variation of fluid properties
- Compositional gradient
- Decision to take more samples or not?
- Design well testing program based on true fluid characteristics
  - With or without H₂S/CO₂
  - Flow specific zones or not
Flow Assurance: To Assure Flow and Maintain Production by Managing These Elements

- Asphaltenes
- Waxes
- Hydrates
- Emulsions/Slugs
- Scales
- Sulfur
Definitions & Phase Boundaries

Asphaltenes: Alkane insoluble components of oil & precipitate $\Delta (P, T \& x)$

Waxes: Normal paraffin from $C_{15}$ to $C_{75}$ and become solid $\Delta (T \& P)$

Hydrates: Gas hydrates are inclusion compounds & formed by water and small molecular gases ($C_1$, $C_2$, $C_3$, $CO_2$, $H_2S$) at low temperature and high pressure conditions.
Near-infra Red Technology for Onset of Asphaltene Precipitation
High Pressure Microscopy: OIL 3 @ 270°F

13,000 psi

Distance = 9.43 μm

11:02:48:02  50X Lens  10-05-00

13,000 psi & 270°F
Near-Infrared Scan & High Pressure Microscopy (South American Oil @ 310°F)
Asphaltene Clean Up
Impact to Client

- Before understanding the phenomenon
  - Chemical batch treatment: $750k/yr (non effective)
- After study
  - Asphaltene control: $250k/yr (continuous injection)
- OPEX reduction: $500k/yr
VOI: Surface Facilities

PROBLEMS:
- Solids in the feed tank/dehydration unit
- Sales oil was off pipeline spec of 0.5%
- Chemical/Filter disposal/Handling Off spec condensate: $400k/y
VOI: Surface Facilities Modification

BENEFITS

- No solids in the plant
- No off spec condensate handling < 0.5%
- Operating cost reduction: $250k/y
**Key properties of waxy crudes**

- **Highly Non-Newtonian**
  - (viscosity strong function of shear rate)

- **Mildly Non-Newtonian**
  - (viscosity dependent on shear rate)

- **Newtonian**
  - (viscosity independent of shear rate)

Temperature range: 15-25 °C

**Pour Point**

**Temperature**

**Cloud Point**

Temperature

- Oil B
  - 0°C (32°F)
  - WAT = 41°C (105°F)
  - 60°C (140°F)

- Oil A
  - 0°C (32°F)
  - WAT = 24°C (76°F)
  - 60°C (140°F)
Gas Hydrate Characterization

- Gas hydrates are inclusion compounds
- Formed by water and small molecular gases ($C_1$, $C_2$, $C_3$, $CO_2$, $H_2S$) at low temperature and high pressure conditions
- 2 types of structure (Pentagonal Dodecahedron)
- Can form in the subsea flow lines.
- One $m^3$ of hydrate can hold 160 $m^3$ of gas
- Visual technique used to detect the thermodynamic hydrate formation conditions
Artificial Lift Processes

Downhole Commingling

Gas Lift

Reservoir fluid/fluid or reservoir fluid/lift gas compatibility needs to be evaluated
Fluid Compatibility: @ 270°F & 8000 psi

0 mass % gas
Summary: Advanced Technology

- Downhole/Onsite Fluid Characterization
  - Early results can help make decision related to
    - Test or not to test wells/zones.
    - Complete or not to complete wells/zones.
    - Take samples for laboratory analysis.


- Modern laboratory techniques allow us to understand the fundamentals of fluids and assist us in designing optimum production & proactive solution strategies.