Transportation of waxy crudes in multiphase pipelines

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Outline of presentation

- Flow assurance
- Phase behaviour
- Solids precipitation
- Wax deposition
- Prevention and mitigation solutions
- Rheology and gelling of waxy crudes
Fluid and flow assurance

**Phase behaviour**

- Bubble point
- Production gas
- Hydrates (H)
- Wax (W)
- Asphaltenes (A)

**Scale**

**Asphaltenes**

**Corrosion**

**Fluid behaviour and control**

**Wax**

**Emulsions**

**Hydrates**

**Fluid flow**
Concept choice: Field development solutions
"The ability to produce and transport multiphase fluids from reservoirs to processing plants in economically and technically feasible way"
Multiphase flow engineering

- Pipeline dimension (sizing)
- Pipeline pressure drop (capacity)
- Undesirable phenomena
  - Slugging
  - Flow restrictions etc.

Flow assurance = Minimization of undesirable phenomena

Fluid mechanics: Governed by Newton

Fluid rheology: Governed by the fluid

Flow assurance: Governed by us!
Composition of petroleum fluids

- Enormous range and variety of components with regard to boiling point, molecular weight, polarity and carbon number
- Thousands of components from methane to large polycyclic compounds with atmospheric equivalent boiling points higher than 800°C
- Molecular weights range from 16 g/mole up to several thousand g/mole
- Carbon numbers from 1 to at least 100 (for heavy oils probably about 200)
Heavy and waxy crudes
Typical phase envelope of a reservoir oil

- Tc; Pc
- Cricondenbar
- Bubble point line
- Dew point line
- Liquid
- Gas

Temperature (deg C)

Pressure (bar)
Phase envelopes of complex mixtures

![Graph showing phase envelopes for different mixtures including 98% C1, 95% C1, 93% C1, Texas gas cond., N. Sea gas cond., Near-crit. gas cond., N. Sea volatile oil, N. Sea black oil, N. Sea asphaltic oil, N. Sea heavy oil, and critical points.]
Hydrate and wax phase boundaries

![Graph showing hydrate and wax phase boundaries with temperature (°C) on the x-axis and pressure (bar) on the y-axis. The graph includes saturation curve, wax phase, hydrate phase, critical point, and reservoir conditions.](image)
Complex phase behaviour
Secondary solid and liquid phases

![Complex phase behaviour diagram with labels for hydrates, asphaltenes + liquid, wax, single-phase liquid, and gas phases.](chart.png)
Compact hydrate plug
Ref. Kværner report on cold spots in Kristin X-mas tree and choke module
Wax ’slug’ in pig trap at Statfjord B
**Wax ’porosity’**

*Composition of wax deposit from Snorre-Statfjord pipeline*

<table>
<thead>
<tr>
<th></th>
<th>Sample no. 1</th>
<th>Sample no. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content (wt%)</td>
<td>8.88</td>
<td>0.03</td>
</tr>
<tr>
<td>Wax content (wt%)</td>
<td>Not purified</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>45.3</td>
<td>47.3</td>
</tr>
<tr>
<td>Purified</td>
<td>26.8</td>
<td>32.8</td>
</tr>
<tr>
<td>Dry solid content (wt%)</td>
<td>80.7</td>
<td>82.0</td>
</tr>
<tr>
<td>Ignition residue /dry (wt%)</td>
<td>0.1</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>“Organic” content /dry (wt%)</td>
<td>99.9</td>
<td>100</td>
</tr>
<tr>
<td>Ignition residue 950 °C /dry (wt%)</td>
<td>0.1</td>
<td>&lt;0.02</td>
</tr>
</tbody>
</table>

 Cá. 45% wax
 Cá. 55% non-wax
Wax precipitation curve

Waxy crude oil

Norne crude at 1 bar

Temperature (°C)

Wt% solid wax

0 1 2 3 4 5 6 7 8

-20 -10 0 10 20 30 40 50
Wax deposition test with Snøhvit oil-condensate mixture: \textit{Effect of }dT/dr (\Delta T)\textit{ }

\begin{itemize}
  \item Oil 10\(^\circ\)C
  \item Oil 8\(^\circ\)C
  \item Oil 6\(^\circ\)C
  \item Oil 4\(^\circ\)C
  \item Wall 4\(^\circ\)C
\end{itemize}

\textbf{Conclusion}: Wax deposition vanishes when there is no temperature difference between the oil and the wall (even if the oil temperature is far below WAT.)
Wax deposition profile in Kristin-Njord Y pipeline (60% porosity, 600h simulation)

Kristin-NJ/DR Wye
- wax deposition and temperature profile after 600 h
Wax (or other deposits) may give severe increase of pressure drop due to increased roughness.

**Effect of roughness on pressure drop in turbulent single phase flow**

\[
L=10\text{ km}, \quad Q=10,000\text{ m}^3/\text{d}, \quad D=254\text{ mm}, \quad \rho=800\text{ kg/m}^3
\]

- **Viscosity = 2 cp**
- **Viscosity = 100 cp**
Veslefrikk to Oseberg
38 km pipeline
Effect of roughness factor

Simulation:

Case B, Pressure drop and wax volume
10200 Sm$^3$/d from field 1 and 24000 Sm$^3$/h from field 2

- Pressure drop with roughness factor 0.15
- Pressure drop with roughness factor 0
Cooldown with different overall U-values

Source: McKenchie (2001)
Methods for controlling wax deposition

- Pipeline insulation
  - External insulation coating on single pipes
  - Pipe-in-pipe systems
- Pigging
- Chemicals
  - Inhibitors
  - Dispersants
  - Dissolvers
- Hot oil flushing
- Heating
  - Bundles
  - Electric heating (primarily hydrate control)
Wax management!
Waxy oils

- Newtonian (at \( T > \text{WAT} \))
- Shear-thinning (at \( T < \text{WAT} \))
- Time-dependent (thixotropic')
- Thermal- and shear-history dependent
- Yield stress (at \( T < \text{PP} \))
- Viscoelastic (at small deformations)

\[
\eta = \text{constant} \\
\eta = f(\gamma) \\
\eta = f(\gamma, t) \\
\eta = f(\gamma, t, \text{TH}) \\
\eta = '\infty'
\]
Rheology depends on composition and fluid history!

Maximum pour point condition

Minimum pour point condition
Yield stress from controlled stress flow curve

Tyrihans Sør crude oil

Notice difference between thermally pretreated and non-pretreated oil!
Restart of gelled oil pipeline

**Single phase**

- \( P_{\text{restart}} \) → Gelled oil → \( Q(t) \)

**Multiphase**

- \( P_{\text{restart}} \) → Gelled oil → Void → Gelled oil → \( Q(t) \)
Restart pressure vs. static yield stress
Pipeline length = 8 km     Safety margin = 50%
Effect of ‘good’ pour point depressant on wax crystal aggregation

Maximum pour point

No thermal conditioning:
Chaotic soup of wax crystals

Conditioned at 80°C:
Aggregates
Wax-free oil

Treated with 200 ppm PPD:
Ordered aggregates
Wax-free oil

Minimum pour point
Integrated Production Umbilical (IPU)

- 8” Flowline
- Thermal Insulation
- Heating lines
- Signal/Power cables
- Hydraulic/injection lines
- HV-power cables
Pour point

- The lowest temperature at which an oil will flow under standard test conditions (ASTM D-97).

- Not a well-defined rheological property, but indicates gelling temperature in pipeline shut-down situations.

- Follow-up with yield stress measurements if PP>0°C.

- Large effect of thermal history.

- Standard thermal pre-treatment (conditioning).

- Typically 4-5 wt% solid wax at minimum pour point.

- Large effect of dissolved gas.
Non-Newtonian viscosity model

Range 0-10% wax

*Pedersen and Rønningen (1999)*
Multiphase technology and flow assurance
Integrated approach for wells, flowlines and facilities

Added value due to
- increased recovery by using multiphase pumping and/or subsea separation
- reduced downtime caused by flowline plugging (hydrates, waxes) and slugging
- tailor-made separation process based on actual fluid properties
- optimal hydrate and wax control strategies based on LCC
- optimal thermohydraulic flowline design using state-of-the-art tools
- increased flowline capacities by using flowimprovers
- reduced chemical usage and emissions by using heated flowlines and low concentration inhibitors
- simplified satellite tie-in solutions by using multiphase meters

Wellbore hydraulics
Transient pipeline thermohydraulics
Sampling - Laboratory testing
Mobile Test Unit (MTU)

Chemical Injection Package

Process
- Separator
- Slug catcher

Fluid properties
Rheology

Emulsion control
Corrosion control

Scale control
Asphaltene control
Wax control
Hydrate control

Multiphase equipment
- Multiphase meter
- Multiphase pump