Pipelines & Flow Assurance
Flow Assurance Wax Study on the Ravn Field Production System

**Wood Group Kenny:**  Hooman Haghighi, Jamie Littler, Fujiang Zhu, Temitope Solanke

**Wintershall:**  Leif H. Blidegn, Amir Mofidi
Agenda

- Introduction to the Risks of Wax Deposition
- Fluid Tuning
- Ravn Field Overview
- Results of In-field and Export Lines
- Conclusions and Recommendations
Wax deposition risks

Wax is long-chain simple hydrocarbons.

- Long Chain n-paraffin
- Branched chain paraffin
- Cyclo-paraffin (Naphthene)

Wax deposition can cause:

- Reduction in flow area
- Change in wall friction
- Blockage of the pipeline

These pictures are from public domain.
Wax management

Maintain the system temperature above the wax appearance and/or fluid pour point.

- Insulation
- Displacement with stabilized crude, diesel or condensate
- Active heating of the pipeline

Physical removal of wax

- Periodic scraping of the wax layer via pigging operations.
- Heating

Chemical treatment

Blideng et al. (2011), Running-in a new Platform, 22nd International Oil Field Chemistry Symposium
Wax deposition (Molecular Diffusion)

- Molecular Diffusion is the dominant wax deposition mechanism
- Radial diffusion of dissolved wax molecules in the oil
- Concentration gradient between dissolved wax in the turbulent core and the wax in solution at the pipe wall
- Dissolved wax diffuses towards the wall where it precipitates
Wax testing

- There are a few lab techniques available for wax measurements:
  - Viscosimetry
  - Cold finger
  - Differential Scanning Calorimetry (DSC)
  - Cross Polarization Microscopy
  - Filter Plugging
  - Fourier Transform Infrared Spectroscopy (FTIR)

Wax Appearance Temperature (WAT):

The temperature below which the paraffin's start to precipitate as wax crystals is defined as crude cloud point or WAT.

Pour Point:

The temperature at which oil sample movement stops is defined as the crude oil pour point.
Wax properties

<table>
<thead>
<tr>
<th>Lab Data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>WAT [°C]</td>
<td>27.5</td>
</tr>
<tr>
<td>WDT [°C]</td>
<td>55</td>
</tr>
<tr>
<td>Wax Paraffinic content [wt%]</td>
<td>2.625</td>
</tr>
</tbody>
</table>

Note 1: C17+

- Hayduk Minhas correlation was used to calculate the diffusion Coefficient (9.78E-08 cm²/s)
- Wax Inhibitor from lab test was shown to reduce the deposition rate by 40-80% (40% has been assumed as a conservative approach in this study)
**Viscosity tuning**

- A shear-thinning behaviour of the fluid has been observed at low temperature.
- The shear rate has been identified to represent the actual flowing condition (for each flow rate) and viscosity has been tuned based on the selected shear rate.

**Shear Rate Calculation-Catcher**

<table>
<thead>
<tr>
<th>Shear Rate Calculation-Catcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear rate</td>
</tr>
<tr>
<td>Temp=</td>
</tr>
<tr>
<td>μ=</td>
</tr>
<tr>
<td>ID=</td>
</tr>
<tr>
<td>ρ=</td>
</tr>
<tr>
<td>QLT=</td>
</tr>
<tr>
<td>u=</td>
</tr>
<tr>
<td>Velocity</td>
</tr>
<tr>
<td>Re=</td>
</tr>
<tr>
<td>Re&lt;2300 Laminar</td>
</tr>
<tr>
<td>Re&gt;4000 Turbulent</td>
</tr>
</tbody>
</table>

| Laminar |
| t= | 1.0 N/m² |
| s= | 0.045805 S⁻¹ |
| Laminar |
| s= | 34.84989 S⁻¹ |

**note:** use the lab data with shear rate =10 S⁻¹

**non-Newtonian Behaviour at Low temperature**

![Steady State Dynamic Viscosity Profiles For Ravn Oil](chart)

- Dynamic Viscosity mPa.s [cP]
- Temperature °C

Steady State Dynamic Viscosity Profiles For Ravn Oil

- 1 s⁻¹
- 10 s⁻¹
- 100 s⁻¹
**Fluid modelling**

**Effect of pressure & light end component on WAT**

**Note**: The dynamic changes in the fluid composition (e.g. Gas Oil Ratio) in the pipeline and the effect on WAT has been considered in thermo-hydraulic simulation. However the model has not taken into account the composition change due to wax drop-out (conservative).
Ravn system schematic

Fluid Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>API°</td>
<td>38.2</td>
</tr>
<tr>
<td>Viscosity at 60°F (cP)</td>
<td>24.1</td>
</tr>
<tr>
<td>WAT (°C)</td>
<td>27.5</td>
</tr>
<tr>
<td>N-Paraffin Content (wt%)</td>
<td>2.625</td>
</tr>
<tr>
<td>Pour Point (°C)</td>
<td>-51</td>
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Ambient Conditions

-10°C, 54 m/s, 5°C, 0.34 m/s
Risk of wax deposition (in-field line, early life)
Wax deposition thickness (in-field, early life)
**Total wax deposition (without inhibitor)**

Total growth rate of wax (in-field pipeline) is $<0.4 \text{ m}^3/\text{d}$ without inhibitor

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<th>Gas Lift</th>
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<tr>
<td></td>
<td>Oil [m$^3$/d]</td>
<td>Gas [m$^3$/d]</td>
</tr>
<tr>
<td>1</td>
<td>310</td>
<td>29448</td>
</tr>
<tr>
<td>2</td>
<td>620</td>
<td>58896</td>
</tr>
<tr>
<td>3</td>
<td>620</td>
<td>58896</td>
</tr>
<tr>
<td>4</td>
<td>369</td>
<td>39979</td>
</tr>
</tbody>
</table>

**Wintershall Ravn Field**

**Wax Deposition Simulation**

In-field Line - No Inhibitor

Volume of Wax Deposition
Total wax deposition (with inhibitor)

Total growth rate of wax (in-field pipeline) is <0.3 m³/d with inhibitor

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Wintershall Ravn Field
Wax Deposition Simulation
In-field Line - With Inhibitor
Volume of Wax Deposition
Summary of the results (in-field line)

- WAT is lower at higher pressure for the live fluid
- The effect of pressure is more pronounced for the fluids with a higher GOR (i.e. Gas Oil Ratio)
- As soon as the fluid reaches ambient temperature, no wax deposition would occur (No heat flux to drive the wax deposition – cold slurry flow).
- The first location for wax to deposit depends on the flow rates, GOR, phase fractions, etc.
- After 30 days of operation <4mm and <13mm of (max) wax thickness can be expected at seabed and topside conditions respectively without inhibitor.
- The recommended frequency of pigging operation is every month (based on maximum 4mm of wax deposition in the system) without inhibitor and every 45 days with inhibitor injection (40% efficiency).
Risk of wax deposition (Export Line)
Wax deposition thickness (Export line)
Pressure drop vs. max wax thickness (Export Line)
Self insulation on wax deposition

(Export Line)

Results are for the topsides (i.e. the highest deposition thickness and rates)
Summary of the results (Export line)

- Higher flow rate leads to longer section of the export line subject to wax deposition risk.
- Self-insulation effect was observed (Lower rate of deposition by time).
- The maximum wax thicknesses identified for the 4 cases are comparable, however the total wax deposited is more at higher flow rates.
- After 22 days and 31 days of operation <4mm of (max) wax thickness can be expected at seabed condition without and with inhibitor (40% efficiency), respectively.
- Pigging of 4” >100 km export line is challenging and is currently under further evaluation.
- Alternative wax mitigation strategy like wax dispersant, gas condensates has been considered.
Other Flow Assurance challenges

• Slugging in the in-field line at the early life and during the start-up and turn-down operations has been observed. The following mitigation methods has been considered:
  o Increased back pressure (for start-up and turn-down operations)
  o Gas lift injection (if required)
Questions?

Special thanks to:

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[nordsøfonden logo]