Presentation for:

National Subsea Research Initiative

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Document title:
Subsea storage
Flow assurance – issues and challenges

Document reference:
P-TT160401-000-B
### Revision status

<table>
<thead>
<tr>
<th>Revision</th>
<th>Date</th>
<th>Description</th>
<th>Prepared by</th>
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<td>B</td>
<td>21 Apr 16</td>
<td>Issued for presentation</td>
<td>steve.howell</td>
<td>fiona.shearer</td>
<td>steve.howell</td>
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<tr>
<td>A</td>
<td>20 Apr 16</td>
<td>Draft - issued for information</td>
<td>steve.howell</td>
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Acknowledgements

Gareth Smith, Jamie Burnett and Neil Raby – Flowsure.
Abercus

Abercus is an independent, privately-owned consultancy specialising in advanced engineering simulation within the energy sector – computational fluid dynamics (CFD), finite element analysis (FEA), the development of bespoke software tools and teaching/training.
Agenda

- Why subsea storage?
- What needs to be stored?
- Conventional thinking for subsea storage
- Flow assurance issues
- Challenge conventional thinking.
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• Why subsea storage?
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Why subsea storage?

• In order to make small pools more economically viable it’s necessary to challenge conventional thinking and approaches

• Subsea storage could improve the economics for small pools –
  – remove requirement for pipeline or an FSU, leading to lower CAPEX

• Subsea storage could improve the independence of small pools –
  – they’re no longer dependent upon a host facility, and therefore won’t become stranded if the host is decommissioned

• Other high-cost items could be removed –
  – there are emerging possibilities for local subsea power generation, so storing chemicals locally on the sea bed for direct injection could allow umbilicals to be minimised or even removed.
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- Why subsea storage?
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What needs to be stored?

- Reservoir
- Processing
- Offload

- Crude
- (Partially) stabilised crude
- Injection chemicals
- Gas
- Produced water

- Gas
- Produced water
What needs to be stored?

- Crude oil? Multiphase?
  - Could we get benefit from storing crude over a longer period and allowing stratification/separation?
  - Risk of a slug received at the storage unit? Implications for storage volume
- Export grade or partially stabilised oil?
- Injection chemicals? – MEG or methanol, corrosion inhibitors
- Gas? Liquefied gas?
- Assume that there has already been some degree of processing – focus on partially stabilised oil.
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- Why subsea storage?
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Conventional thinking for subsea storage

• There are several precedents, including the Brent field, for example, which shows that this is not a new concept.

From Shell UK: http://www.shell.co.uk/sustainability/decommissioning/brent-field-decommissioning/brent-field-process.html
Conventional thinking for subsea storage

- There are several precedents, including the Brent field, for example, which shows that this is not a new concept
  - On Brent D, part of the driver for the tanks was that they were used as flotation tanks during the installation of the platform
  - Brent was one of the first fields operating within the UKCS (1976), so the subsea storage tanks (and the Brent Spar that was decommissioned in the 1990s) were used to allow early production, before the installation of the Brent and FLAGS pipelines (in 1978 and 1982 respectively)
  - The Brent flare – excess gas was flared before FLAGS installation
  - There have been lessons learned, and particularly with regard to current decommissioning of the tanks.
Conventional thinking for subsea storage

- Conventional thinking to date seems to be to install a rigid tank on the sea bed.
- The word rigid is important (and we have purposely used the word *tank*) – although it’s related to structural engineering, it has significant implications for flow assurance:
  - This demonstrates why a holistic, multi-discipline engineering approach is required
  - Collaboration and innovation
- We’re here today to think about how to challenge conventional thinking.
Conventional thinking for subsea storage

• On the Brent field, the subsea storage tanks were concrete
  – Difficulties when decommissioning
• Steel tanks have been used for other, more recent precedents, including the Siri Platform, in the Danish sector of the North Sea.
Conventional thinking for subsea storage

- How much fluid must be stored?
  - Volume of stored fluid changes
  - For export oil, there’ll be a reasonably steady continuous supply rate but offloading is periodic
  - For a small pool producing, say, 5,000 bbl/day, offloading every 7-10 days, a volume of at least 100,000 bbl is required to allow production to continue during periods of bad weather

- The tank needs to be capable of holding a variable amount of stored fluid.
Conventional thinking for subsea storage

• What pressure is the fluid to be stored?
  – If this is close to ambient pressure, the differential pressure across the tank walls, and the associated structural loading, is minimised
  – Can operational procedures always ensure that the internal pressure is close to that outside?
  – During shut down, installation, or any unplanned events, the tank may not contain any stored fluids and may be at low pressure.
Conventional thinking for subsea storage

• The external pressure \( p \) is proportional to the depth of water
  \[ p = \rho g h \]
  
  – External pressure at the surface is 1 bar
  – In the UKCS, the external pressure at the sea bed may be around 10 bar
  – In deep water, the external pressure at the sea bed may be +100 bar

• It is difficult, or maybe even impossible, to design cost effective subsea storage tanks to withstand this pressure differential

• A sealed rigid tank is inherently not a robust design.
Conventional thinking for subsea storage

• The common approach to minimise the pressure differential across the tank and reduce the structural design requirement is to introduce ballast water into the tank.

• The produced oil floats above the layer of ballast water.

• **FLOW ASSURANCE ALERT** – as soon as water is introduced into the same tank as the stored oil there are associated flow assurance issues:
  – Emulsion layer in the region between the water and oil
  – Biocides injected into the water to prevent marine growth in the lower part of the tank
  – Inhibitor to prevent corrosion at the base of the tank.
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Flow assurance issues

- Thermal considerations
  - Viscosity behaviour of the stored oil
  - Wax appearance
- Prolonged residence time
  - Separation/stratification of stored oil
- Contact with water
  - Emulsion layer
  - Biocides
  - Corrosion
  - Hydrates
- Decommissioning.
Flow assurance issues – viscous behaviour

- The viscosity of oil is highly dependent upon its temperature.

![Graph showing the relationship between viscosity and temperature.](image)
Flow assurance issues – viscous behaviour

- The viscosity of oil is highly dependent upon its temperature.
- Heat loss is around 300kW for maintaining 100,000 bbl at 20°C, or 700kW for maintaining 100,000 bbl at 40°C.
Flow assurance issues – wax appearance

- Wax precipitation is not strongly affected by the pressure – it’s the temperature which has the dominant effect

Typically 40°C
Flow assurance issues – wax appearance

• Wax precipitation is not strongly affected by the pressure – it’s the temperature which has the dominant effect
• Wax precipitation does not necessarily lead to deposition – needs a nucleation site, but wax precipitated throughout the bulk of the stored fluid will form a slurry and will increase viscosity
• Cold storage to intentionally allow a cold slurry to form without deposition – is this a useful strategy?
Flow assurance issues – wax appearance

- Or should the temperature of the tank be maintained above the wax appearance temperature (typically 40°)?
  - Insulate?
  - Heat?
  - Add inhibitor to lower the wax appearance temperature?

- Wax precipitation is reversible but the melting temperature is higher than the wax appearance temperature.
Flow assurance issues – residence time

- Over a prolonged time the stored oil may become stratified
- Is this to be allowed?
  - Dissolved volatiles may separate and evaporate to form a vapour pocket, especially in the event of a depressurisation of the tank
  - Any produced water within the stored oil may drop out and settle at low level
- Should the stored oil be agitated?
Flow assurance issues – emulsion layer

- Why is this bad?
- Will it really be sustained? Without agitation?
  - Long residence time within the tank so would an emulsion layer settle out without sustained agitation?
  - Especially for light crude at an elevated temperature
  - What about heavy crude at 4°C?
Flow assurance issues – biocides

- Will marine life within the ballast water layer be an issue?
- At the wax appearance temperature of 40°C, marine life may thrive
  - \( \text{H}_2\text{S} \) concerns
- At higher temperatures, the environment may be too warm for marine life to be sustained.
Flow assurance issues – corrosion

• If the subsea storage tanks are steel, could there be corrosion issues?
  – Water + steel = corrosion potential, especially at elevated temperatures and in the presence of marine growth

• Coatings for steel tanks?

• Could plastic tanks be used? Aromatics within the stored oil may cause problems with plastics – integrity issues?
Flow assurance issues – hydrates

- Volatile hydrocarbon vapours may evaporate and form a gas pocket, especially in the event of a depressurisation of the tank.
- Water is present too so is there a hydrate risk?
Flow assurance issues – decommissioning

• Brent D lessons learned, particularly with respect to decommissioning
• Abercus has been involved in CFD studies relating to the removal of attic oil from the subsea storage facilities
  – No one is certain of what is within the tanks
  – Accumulation of sand/solids over a 40 year operational life
  – How can such colossal concrete tanks be cleaned and removed?
• Small pools may only produce for 6-8 years, so decommissioning is not some far-off event as it was for Brent in the 1970s.
Flow assurance issues – operations

• What is done with the displaced/produced water?
  – Re-inject into the reservoir? Requires an injection well
  – Clean on board the offloading vessel and dump overboard?
  – Bring back to shore?

• What is done with volatiles?
  – Collect hydrocarbon vapours and flare?
  – Compress and re-inject into the reservoir? Requires an injection well
  – Compress and store for sale?
Flow assurance issues – riser

• The riser to surface will become cold – it’s a long dead-leg!
  – Low temperature, viscous oil - large head to overcome
  – Wax blockage
  – Hydrate risk
• Drain the riser using a flow loop (via the riser annulus?) to flush out oil and inhibit the dead-leg?
• Trace-heat the riser?
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Challenge conventional thinking

• Is it possible to minimise or even eliminate the contact between the stored oil and the ballast water?

• Floating roofs are used onshore
  – Confine the liquids to reduce hydrocarbon evaporative losses

• Could a similar floating floor concept successfully separate the export oil from ballast water?
  – Seals around the perimeter of the floating floor?
  – Water drop-out over a prolonged storage period?
  – At least the formation of a flammable atmosphere is not a primary risk subsea, since hydrocarbon vapours cannot mix with oxygen

• Or could a flexible membrane be incorporated into the tank?
Challenge conventional thinking

• How to maintain the temperature of the tank?
  – Insulation? Oil will arrive at an elevated temperature, but will this be sufficient to maintain the temperature over a prolonged period?
  – Circulate oil through a heat exchanger? Source of heat for the exchange? (Could this be a use for excess gas? Or a WSHP? Or other novel heating methods?)
  – Heat incoming ballast water?

• Where should the stored fluids enter and leave the tank?
  – Fixed locations? Could this work with a floating floor?
  – Variable location, depending upon the fill level?
Challenge conventional thinking

• Kongsberg have challenged conventional thinking with respect to subsea storage
• Adam will explain more next!