The System Operability Design Process

Going from guessing to knowledge based decisions!

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Tacoma Narrows Bridge = Steady state solutions

- Income: Is the expected production realistic?
- Operability: Is the design solution a possible physical solution?
- Operability: Is the design in natural equilibrium with the actual boundary conditions?
- Operability: Expose system to all possible rates, pressures and temperatures over the life of field.
Transient (dynamic) simulation models

Dynamic simulation is the use of a computer program to model the time varying behavior of a system. The system are typically described by ordinary or partial differential equations. The mathematical models incorporate real-world constraints and the equations become nonlinear.
Premises – many uncertainties – typical input from customer

Case example: Satellite tie-back of oil field into existing infra structure

Objective: To design a subsea boosting system within acceptable cost and risk

Fluid Characteristics
OIL BRIM (layer)
GAS CAP

Identify if any Flow Assurance stoppers

Power: 5-7 MW spare power available

Reservoir pressure: 320 bar
Reservoir temperature: 120 °C
Max Shut-in pressure 270 bar
Design water depth: 100 m
Ambient temperature: 25°C
Design sea current velocity: 1 m/s

Objective: To design a subsea boosting system within acceptable cost and risk

Tie-back distance 90 km

SPS

FPSO

Arrival pressure: min16 bar

Early-, Mid- and Late Phase rates assumed within processing capacity
Traditionally Flow Assurance approach in Case

- **Hydrates**
  - Ruled out (Ambient temperature above Hydrate Formation Temperature)

- **Wax**
  - Ruled out (Ambient temperature above Wax Appearance Temperature)

- **Asphaltenes**
  - Ruled out
  - Reservoir Expert input

- **Corrosion rate prediction positive**
  - Expert input: with use of corrosion inhibitors the pipeline can be made of carbon steel

- **Left with unknown parameters:**
  - Pressure, temperatures and rates all along the flowline and subsea process network
  - Pipeline size (Main cost driver)
  - Needed head for pump sizing (Main feasibility parameter)
  - Velocities and rates (needed for evaluations of Erosion, Flow Induced Vibrations, Slugging)
Traditional approach of subsea system design

- Conceptual selection phase
- Design selection phase
  - Design selection phase
    - FEED
    - EPC
  - High Risk
- Operation
  - Risk = As Low As reasonable Practicable (ALARP)
- Flawless delivery

COST vs. RISK diagram
Schematic FlowManager™ Design model

Objective - Maximize oil/gas production

Reduce pressure loss in system to achieve objective

P, T, Q for each well

Subsea Boosting station

Multiphase flow

Well and flow line geometries and sizes of existing infrastructure

Find natural equilibrium for a robust system solution

Reservoir or well information

Individual fluid properties for each well

Inflow performance (IP) equations to simulate inflow from well, alternatively coupling between FlowManager™ and Eclipse

Compressor: compressor chart, power and torque limitations
Cooler: FMC subsea passive cooler or other design
Separator: phase split
Pump: vendor data
Going from guessing to knowledge based decision taking!

Risk = As Low As reasonable Practicable (ALARP)

A System Operability Design Process

Large number of unknown parameters
Reduce number of unknown parameters
Reduce risk in cost
Reduce uncertainty in operation

High Risk

Conceptual selection phase

Reduce Risk
Reduce Risk
Reduce Risk
Reduce number of unknown parameters
Reduce risk in cost
Reduce uncertainty in operation

Operation
Flawless delivery
EPC
FEED
Design selection phase

Going from guessing to knowledge based decision taking!
Next step in the operability design process in our case example

<table>
<thead>
<tr>
<th>Initial simulations</th>
<th>Main costs and drivers</th>
<th>Model set-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsea boosting needed</td>
<td>Pipeline size and installation of pipeline</td>
<td>Qualified assumptions for unknown parameters</td>
</tr>
<tr>
<td>Agreed with company on new design rates for the screening</td>
<td>Constraints on receiving facilities</td>
<td></td>
</tr>
</tbody>
</table>
Simulation model set-up
Case 1: MPP Station

Arriving pressure > 16bar

Single multiphase export flowline 90km

Infield flowlines

MPP

PROD
WELLS

PROD
Case 1: MPP Station

Required pressure out of SPS to meet topside
FPSO (16 bar)

10” single export flowline

12” single export flowline

14” single export flowline

Upstream SPS conditions

- Feasible solution
- Low complexity
- Low CAPEX (Capital Expend.)
- Mature technical solution

- Not feasible for gas break-through
- Large ID on export flowline

Risk in operability – low cost
Case 1
Low cost
Risk in operability
Reduced uncertainty
Operability Simulations
High Risk
Conceptual selection phase
Operation
Case 2: G/L Separation & Liquid Boosting

- **WELLS**
  - PROD

- **Gas/Liquid Separator**

- **Liquid Pump**

- **35 km Umbilical**

- **Liquid flowline 90 km**

- **Gas flowline – free flow 90 km**

- **GWA Platform**

- **OKHA FPSO**

- **Power & Controls**

- **Subsea Processing Station** (incl. UTA and distribution)

- **2x10” Flexible Flowlines (2.0 km)**

- **2x10” 85 km gas and liquid export lines to OKHA**
Case 2: G/L Separation & Liquid Boosting

- Large operational envelope, can handle gas break through
- Robust to inlet slugging and upset conditions
- Less power consumption (single phase boosting more efficient)
- Field proven technology
- Dual export pipelines
- Bigger station with heavy separator module
- Liquid build up in gas pipeline is expected
- Gas flashing in liquid line

Good operability – high pipeline cost – Mature technology
Cost and implementation

Uncertainty in operability

Case 1
Reduced cost
Low operability

Case 2
Increased certainty
High cost
Good operability

High Risk
Conceptual selection phase

Operation

Cost and implementation
Case 3: Water Injection & Multiphase Boosting

Good operability
High SPS cost and no reduction in pipeline mature technology – increased complexity

For case 3, the start up phase, no water, is governing for the pipesizing of the production system.
Message: With few premises a conceptual selection can be done with high certainty!

Conclusion:
Go on with case 1 and try to increase the robustness in operability.
Flow Assurance issues

- Hydrates-Ruled out
  - Ambient temp above hydrate formation temp
- Wax-Ruled out
  - Ambient temp above WAT
- Asphaltenes-Ruled out (see next slide)
- Velocities (erosion)- Not likely
  - Can be solved by choke at Okha FPSO
- Emulsion viscosity resulting in increased pressure drop - should be checked
- Corrosion rate prediction show that with use of corrosion inhibitors the pipeline can be made of carbon steel
Flow Assurance issues, cont. Slugging

- Flow regime upstream SPS will be dominated by hydrodynamic slug flow (can be solved by inlet design)
- Flow regime downstream SPS, 12” single pipeline; inlet, outlet, raiser base and an intermediate point i.e. 50 km from inlet, ref. Flow regime table.
  - The dominating flow regime will be hydrodynamic slug flow (characterized by high frequent slugs with small liquid volumes)
  - At the outlet (riser), slug flow is only present in Late Phase, for the previous phases the flow regime will be churn flow (churn flow is not slug flow and has smaller continuous volumes of liquid). Any slugging in riser can be solved by gaslift at raiser base
  - Terrain slugging is unlikely as topography of sea bottom is relatively flat

| Flow regime downstream SPS, with 12” single pipeline |
|-----------------|-----------------|-----------------|-----------------|-----------------|
|                | Inlet | 50km | RB   | Outlet |
| Start up       | Slug  | Slug | Slug | Churn |
| Early          | Slug  | Slug | Slug | Churn |
| Mid            | Slug  | Slug | Slug | Churn |
| Late           | Slug  | Slug | Slug | Slug |

In order to evaluate slugging in more detail, a more comprehensive study is required involving dynamic simulation were also terrain induced slugging is addressed.
Flow pattern map-horizonal flow

All points from the flow regime table (previous slide) for the horizontal flow line is plotted in the flow pattern map. The flow pattern map verifies the slug indicator from the simulations, the flow regime is slug flow.
The points from the flow regime table (previous slide) for the riser is plotted in the flow pattern map. The flow pattern map verifies the slug indicator from the simulations, in the case of the riser; in early and mid phase the flow regime in the riser is churn flow (i.e. No slugging), while for late phase there is a transition to slug flow.
Asphaltenes

- The solubility of asphaltenes will increase due to the release of gas from the oil as the pressure decreases from reservoir, through the well and production system for a production of a reservoir oil brim. The solubility of asphaltenes will be at its lowest at the reservoir conditions when the oil rim is in equilibrium with the gas cap.
- This means that the asphaltenes cannot precipitate after in the well or at the wellhead in the actual system
- The only way the asphaltenes can precipitate after the reservoir is if gas or condensate from other fields are mixed in with the oil and thereof changes the fluid properties
- Reference is state of the art understanding through investigation, analysis and online expertise
A System Operability Design Process taking total system from wells to receiving facilities into consideration from the very beginning!

- **FEED**: Conceptual selection phase
  - Design selection phase
  - High Risk
  - Engineering Simulator Steady State: Flow Assurance & Operability
  - Engineering Simulator Dynamic: Ensure operability of design selection for system, process, flow assurance, module and controls design
  - Risk = As Low As reasonable Practicable (ALARP)

- **EPC**: Flawless delivery
  - Engineering Simulator: Troubleshooting, monitoring and training

- **Operation**: EPC
  - Engineering Simulator Dynamic: Operational Philosophy, Final Design, Monitoring Philosophy

Risk reduction:
- Reduce Risk
- Reduce Risk
- Reduce Risk

Cost:
- COST
Observations

• Have obtained a very good design process in several studies and projects

• Requires very high expertise

• Requires synergy between different fields of knowledge
  – Online experience of field
  – System understanding
  – Model expertise
  – Process equipment

• Requires iterative process to obtain "right model" and "optimal results"
  – Require a model that is easy to rebuild for different cases

• High flexibility in model is necessary, but this gives high user barrier