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Public Trial Lecture

Challenges in design, operation and control of subsea separation processes

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Outline

- **Introduction**
- **Challenges**
  - Design challenges
  - Power system
- **Conventional subsea separation**
  - Examples: Troll pilot, Tordis SSBI
  - Process control
  - Simulation study in OLGA
- **Subsea gas separation systems**
  - Examples: Pazflor (Angola), Åsgard (Norway)
- **Compact subsea separation systems**
  - Examples: Perdido (Mexico), Marlim (Brazil)
  - Process control (Marlim)
- **Summary**

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Introduction

Where subsea separation used until now:

- High water-cut and limited water handling capacity on topside
- Low reservoir pressure

Advantages:

- Increased production
  - Decreasing static head on oil wells
  - Added water treatment capacity
- Improved recovery of reservoir
- Decreased produced water emission to environment
- Performing functions at seabed instead of topside (limited space)

Future vision:

- Moving all processes to subsea

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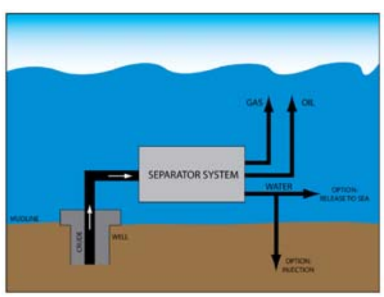
Subsea processing

At least one of these tasks:

- Water separation and injection
- Oil and gas boosting (multiphase pump)
- Gas separation
- Gas compression



Gustafson et al. (2000)

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Challenges in subsea separation

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Challenges in separator design

- Maximum oil/water interface area (long separators)
- Reduction of inlet fluid momentum (laminar flow → good separation)
- Oil in injected water less than 1000 ppm
- High pressure (160-180 bars)
- Huge throughput (water: 6000 m^3/day, oil: 4000 m^3/day)
- Well-stream flow rate variations (slugs)
- Future process modification is not possible

Horn et al. (2003)

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Challenges in separator design

- Low maintenance
- Failure tolerance against sand, clogging, erosion (30 years)
- Reduction of emulsions (Inlet assembly, Chem. demulsifier)
- Sand removal system
  - Usually disposed with the water into an injection well
- Hydrate strategy (Troll Pilot: 60 C, Insulation)
- Supply of chemicals (Methanol, Scale inhibitor, Demulsifier)

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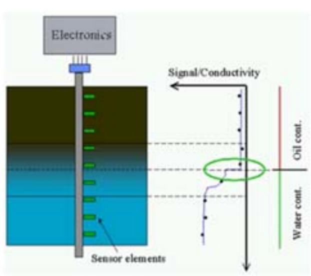
Challenges in level detection system design

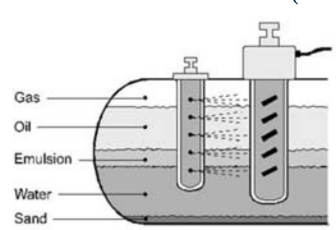
To identify the boundary between the water phase and the oil phase.

- Effective (sensitive) methods
  - Inductive
  - Nucleonic (can identify emulsion layer and oil/gas boundary)
- Redundancy
- No moving parts for durability and low maintenance
- Easily retrievable by a ROV (Remotely Operated Vehicle)
- Long term durability in presence of chemicals

Horn et al. (2003)



Inductive level detection system



Nucleonic level detection system

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Sand Handling Challenge

Sand may cause
- Degradation of pumps due to wear
- Clogging of separation equipment
- Erosion of pipelines

Where the sands should be routed?!
- Re-injected with the water (Tordis field: 500 kg/d)
  - Includes bypass of sand around the water injection pump
- Recombined with oil and transported to surface (Pazflor field, Angola)
- Stored / disposed in another way

Vu et al. (2009)

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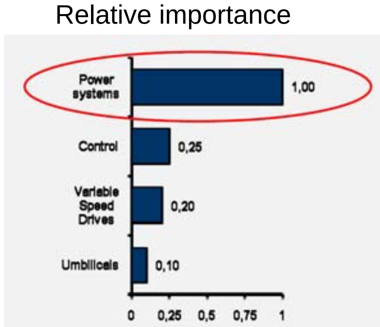
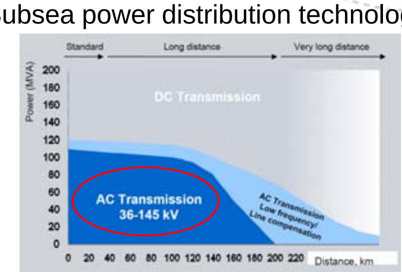
Subsea Power Distribution

- 10-30 MW (Pumps & Compressors)
- 72 kV power lines and connectors
- 50-100 km Step-out

Relative importance



Subsea power distribution technologies



AC is the key focus area today, while DC by most are put off for the next 3-5 years

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Source: SIEMENS

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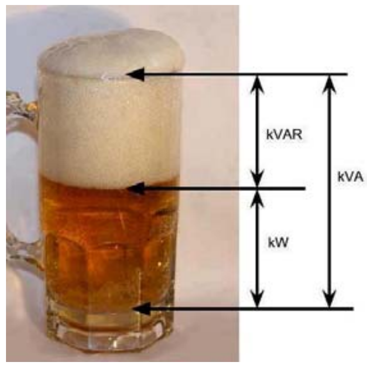
Reactive Power Loss

- Reactive power loss is due to capacitance of cables
- CD current does not induce reactive power (CD transmission)
- It requires AC-to-DC and DC-to-AC convertors



$$I = C\frac{dV}{dt}$$

Impedance:

$$Z_c = \frac{1}{j\omega C}$$

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Subsea Power Distribution

Main Components in Power Grid (Siemens Subsea)

Transformer

Switchgear

Variable speed drives

Drives for Multiphase Boosting Pumps, Compressors and Water Injection Pumps

- Subsea Step Down Transformer
- 3000 m (10.000 feet)
- 30 years design life

Source: SIEMENS

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Conventional subsea separation

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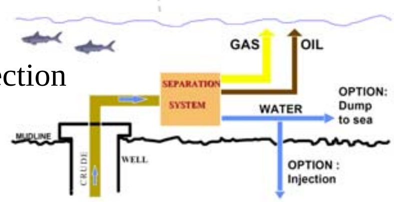
Troll Pilot: World’s first subsea separation



Main tasks: water separation and injection

Troll Pilot (Norway)
ABB, Norsk Hydro (2001)
Size: 17×17×8 m
Weight: 350 tons
Water depth: 300 m
Design pressure: 150 bars
Pump: Framo 35-180 bars

Gustafson et al. (2000), Horn et al. (2002), Horn et al. (2003)

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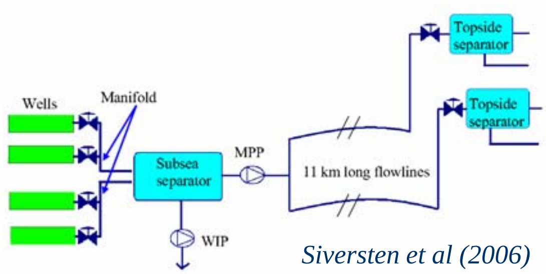
Tordis SSBI
(Subsea Separation Boosting & Injection)



Siversten et al (2006)

Main elements:
Foundation Structure and Manifold
Separator Module
Sand Removal System
Water Injection Pump (WIP)
Multiphase Pump (MPP)

Tordis Field (Norway)
FMC (2007)
Weight: 1000 tons
Water depth: 200 m
Design pressure: 345 bars
Pump: Framo 2.3 MW

FMC Technologies website, Gjerdseth et al. (2007)

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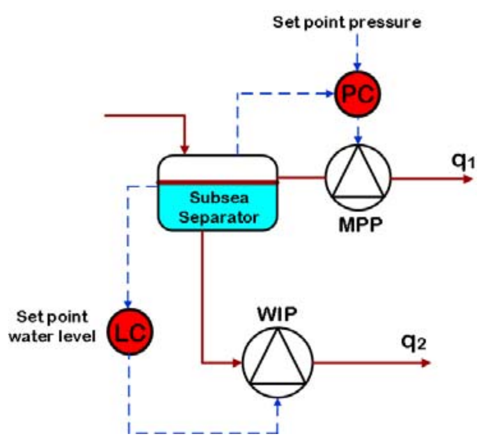
Process Control: Tordis SSBI



Siversten et al. (2006), Faanes et al. (2007)

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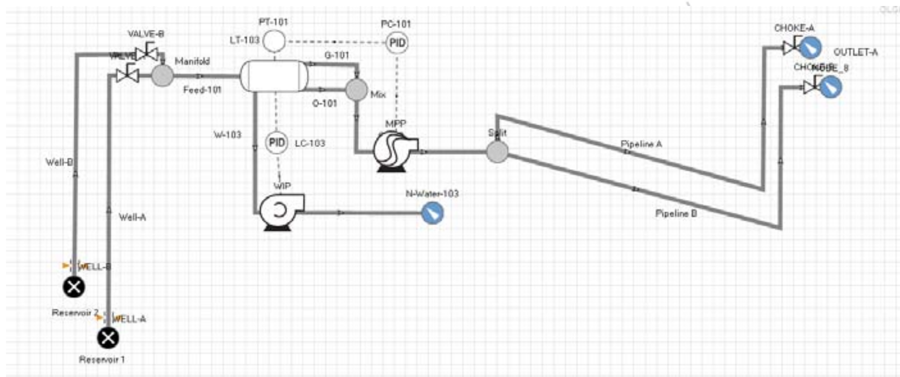
Process Control: OLGA Simulations



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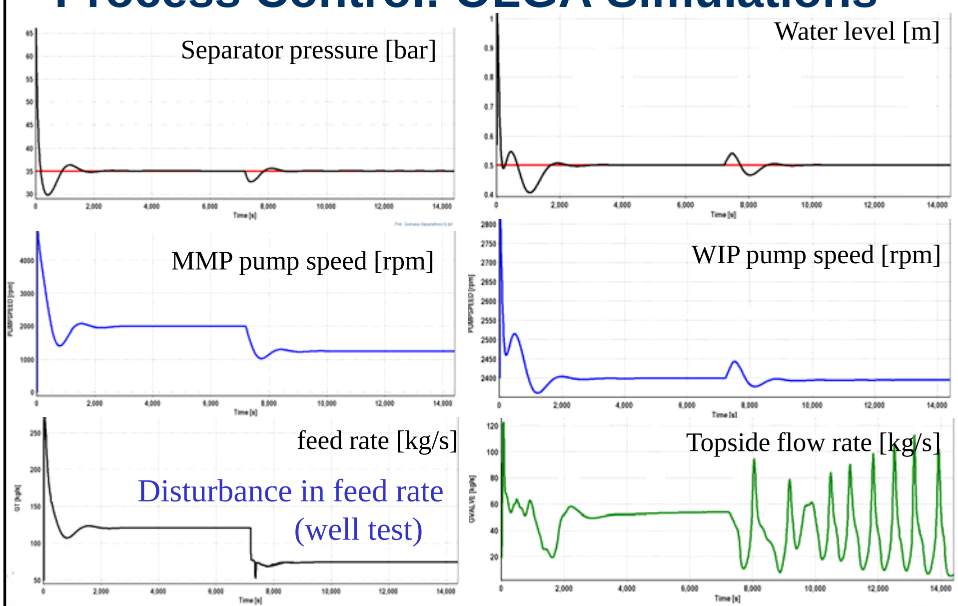
Process Control: OLGA Simulations



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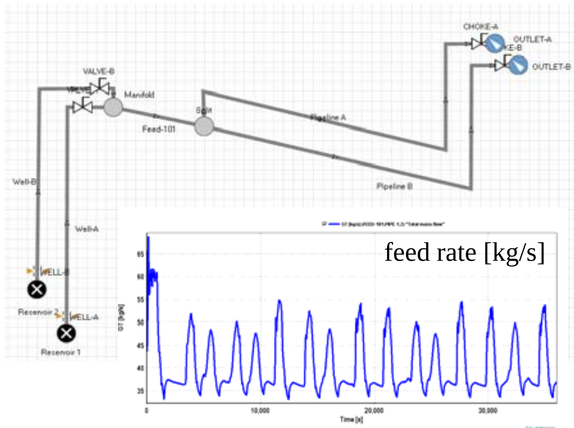
Process Control: OLGA Simulations

Same case without subsea processing



Results: Subsea separation increases the production rate, and reduces the slugging problem, but can not eliminate it completely

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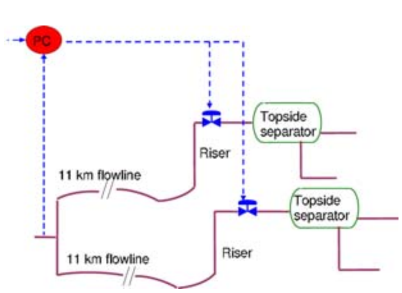
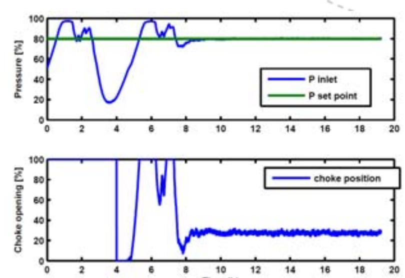
Process Control: Slugging

A simple PI controller using the topside valve and controlling the pressure upstream the flow-line is effective to prevent slugging.



Godhavn et al. (2005)



Siversten et al. (2006)

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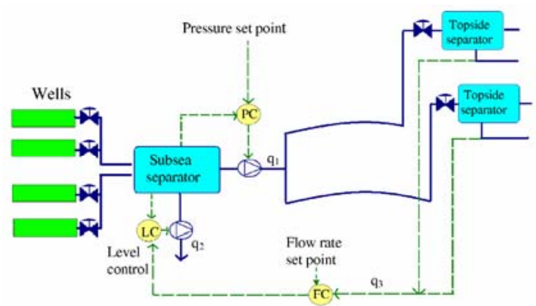
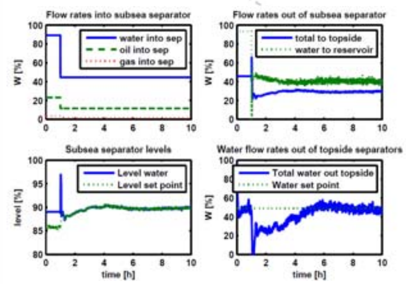
Process Control: Cascade control

Amount of water that topside can handle is limited





Siversten et al. (2006)

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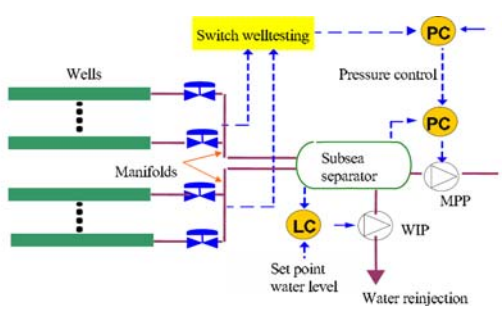
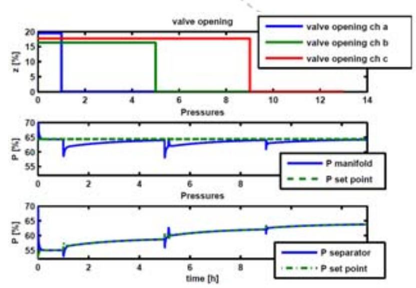
Process Control: Well head pressure

During the well test, the manifold pressure is kept constant





Siversten et al. (2006)

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Subsea gas-liquid separation

Boosting Power

- Rules of thumb:
  - Typical multiphase vertical gradient: 0.3 psi/foot
  - Typical multiphase pipeline frictional loss: 50 psi/mile
  - Maximum boosting by a multiphase pump: 700 psi (50 bars)

Example: A reservoir in 6000' of water depth located 15 miles from the potential host.

6000*0.3 = 1800 psi

15*50 = 750 psi

potential pump duty = 2350 psi (160 bar)

Vu et al. (2009)

→ Subsea gas/liquid separation is required
(Higher hydraulic efficiency of single phase pumps)

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Subsea gas-liquid separation

Where is it used: reservoirs with high GOR and gas fields

- Is it done by vertical separators
  - Height 9 m
  - Diameter 3.5 m

- No Slugging
- Easier gas-lift

Pazflor field (Angola)
Total & FMC (2011)
Size: 21×21×19 m
Weight: 900 tons
Water depth: 800 m
Design pressure: 345 bars
Pumps: Hybrid to 18% GVF

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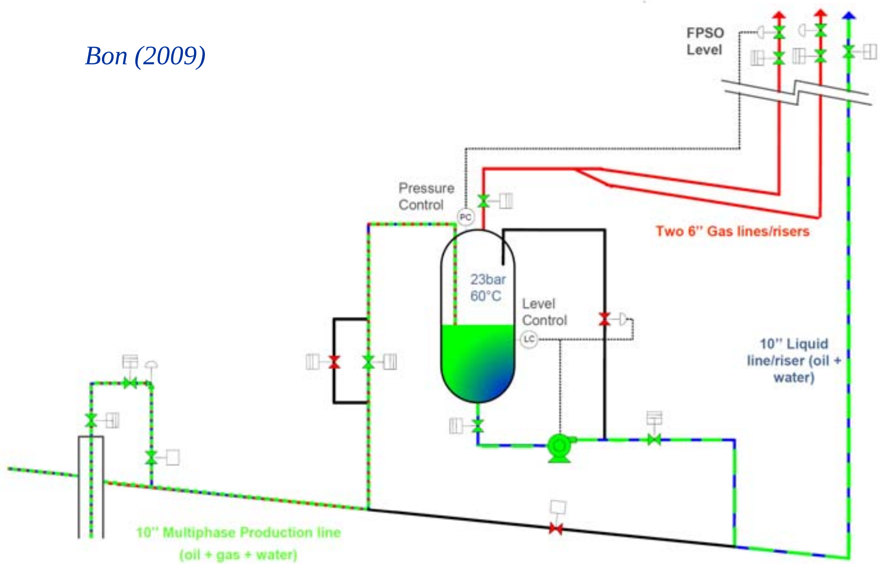
Subsea gas-liquid separation: Pazflor

Bon (2009)



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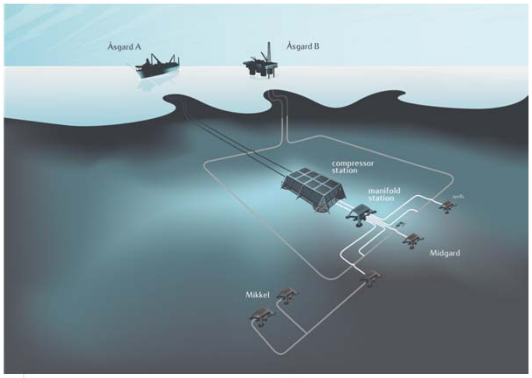
Subsea gas-liquid separation: Åsgard



Gas-condensate separation
Gas compression

Åsgard (Norway)
Aker Solutions (2015)
Size: 44×74×24 m
Weight: 4800 tons
Water depth: 250-325 m
Tie back: 50 km
Power: 2×11.5 MW
Flow rate: 21 mill Sm3/d
Diff. pressure: 50 bar

Hodne (2012)

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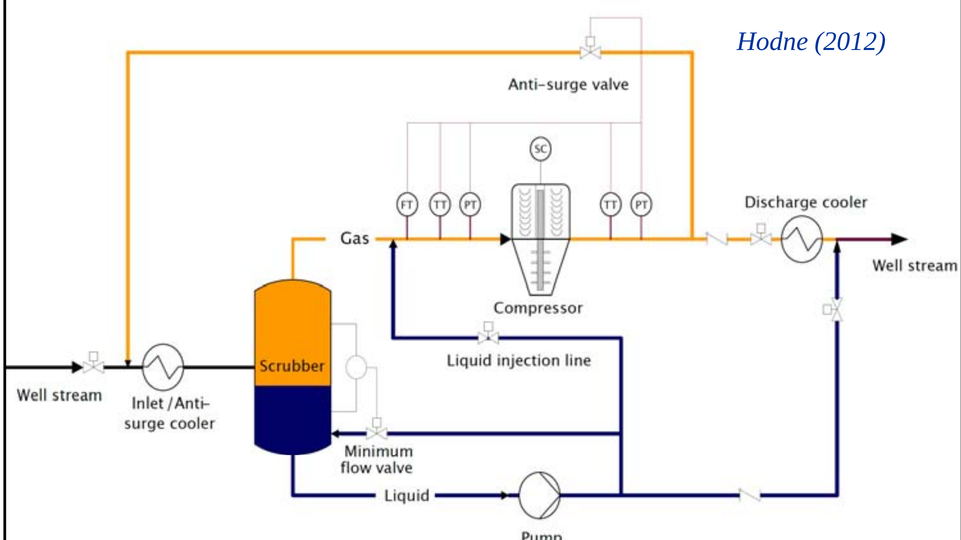
Subsea gas-liquid separation: Åsgard

Hodne (2012)



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Compact subsea separation systems

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Compact subsea separators

For heavy oil or deep water applications:

- Inlet separation technology applying high G-force
  - Continuous Deflective Separation (CDS) Technology
- Separation in pipe segments instead of in large vessels
- Use of electrostatic coalescence technique

Vu et al. (2009)

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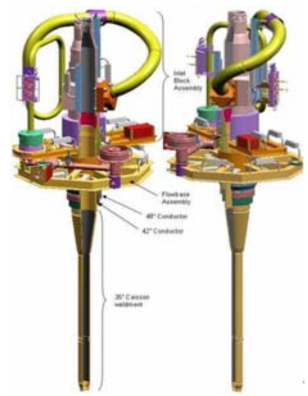
Compact sep. 1: Hydrocyclone

Continuous Deflective Separation (CDS) Technology

FMC Tech.



Caisson

Perdido Field (Gulf of Mexico)
Shell (2008)
Water depth: 2500 m
Step-out: 0 miles
Design pressure: 310 bars
Pumps: 1.2 Mw, 152 bars

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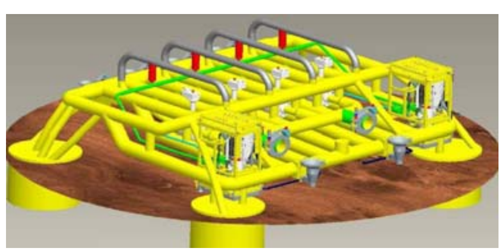
Compact sep. 2: Multipipe slug-catcher

Used for subsea bulk gas/liquid separation

1. Distributes the gas/liquid two-phase flow into several parallel pipe sections with small diameter.
2. Increases the total cross sectional flow area in the separator to reduce the fluid velocity.
3. Reduces settling distance for the liquid droplets.

FMC Technologies website



Vu et al. (2009)

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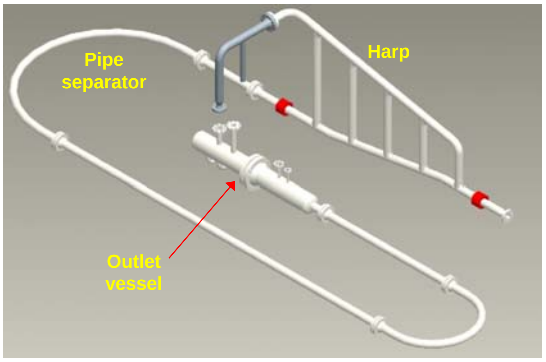
Compact sep. 3: Pipe separator

Used for subsea bulk water separation

Patented by Norsk Hydro (Statoil)

Utilizes effect of small diameter and short residence time



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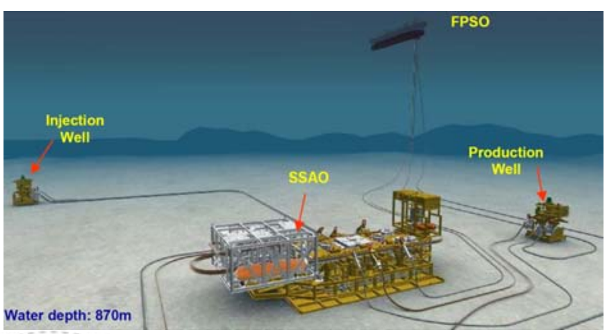
Compact sep. 3: Pipe separator

Marlim Field (Brazil)
FMC & Petrobras (2011)
Water depth: 870 m
Size: 29×10.8×8.4 m
Weight: 392 ton

Orlowski et al. (2012)



SSAO: separação submarina água-óleo

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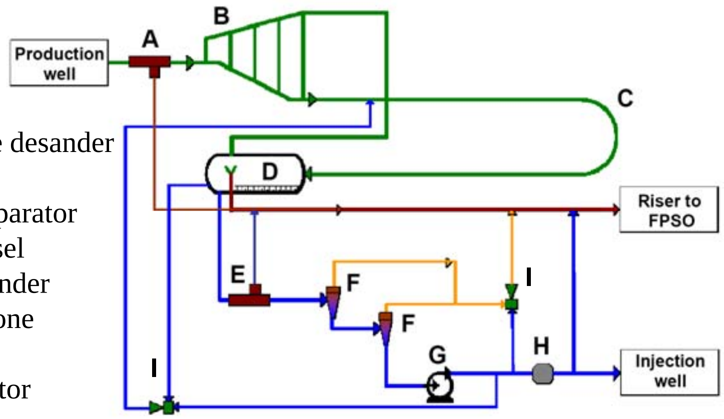
Marlim subsea separation (Brasil)

A – Multiphase desander
B – Harp
C – Tubular separator
D – Outlet vessel
E – Water desander
F – Hydrocyclone
G – Pump
H – OIW monitor
I – Ejector



Orlowski et al. (2012)

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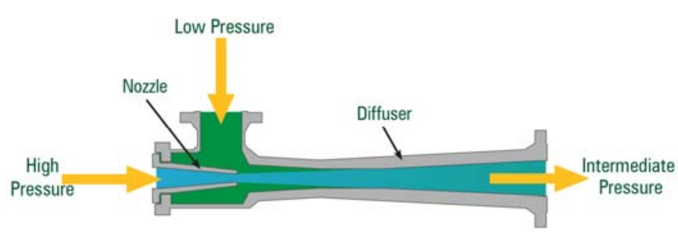
Ejector

An Ejector is a simple device which uses the energy within a high pressure fluid to entrain and compress a low pressure fluid to an intermediate pressure.



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Modularization

10 modules considered for Marlim subsea project (Brasil)

1. By-pass module
2. Multiphase sand remover module (desnader module)
3. Pipe separator module
4. Water sand remover system (desander module)
5. Hydrocyclone module
6. Pump module
7. Water injection choke module
8. Recirculation module
9. Flushing module
10. Electro-hydraulic module for multiplex control (EHCM)

Orlowski et al. (2012)

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Process Control: Marlim SSAO

Challenges:

- Strong interactions between different process components
- Stiff system dynamics due to small hold-ups and low GOR
- Pressure drops of inlet cyclonic equipment need to be balanced
- Constraints on valve opening/closing speed
- Instrumentation is limited compared to top-side

Sensors:

- Differential pressure transmitters
- Pressure and temperature transmitters
- Flow transmitters
- Density profiler
- Sand detector
- Oil in water monitor

Pereira et al. (2012)

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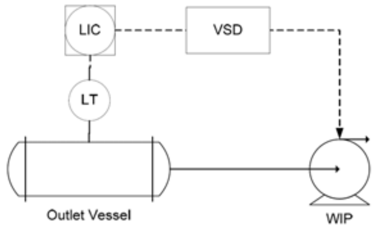
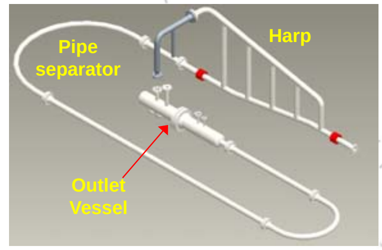
Process Control: Marlim SSAO

Level controller





- Quick response is required (3 sec)
- To avoid constant speed changes a dead band is used
- Filtration of input can be used

Pereira et al. (2012)

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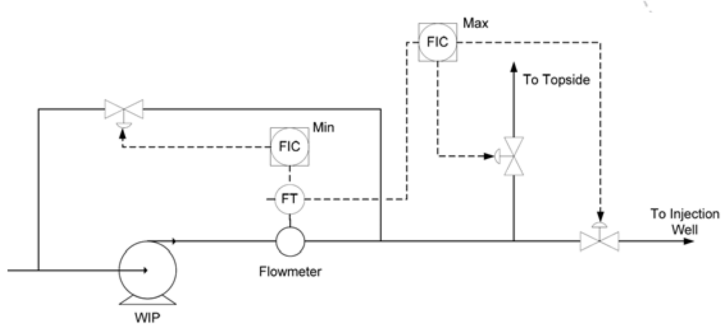
Process Control: Marlim SSAO

Two pump flow rate controllers (Min/Max flow)



- To keep the operating point inside the pump envelope
- Min opens when flow is less than minimum
- Max closes when flow is more than maximum

Pereira et al. (2012)

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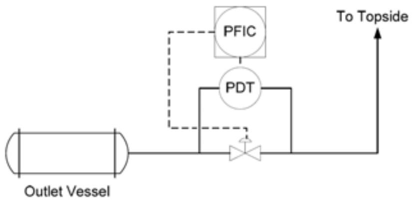
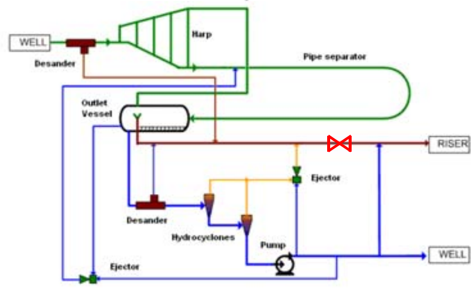
Process Control: Marlim SSAO

Multiphase choke valve-DP controller





- To maintain stable backpressure for the rejects from desnader and hydrocyclone
- Asymmetrical dead band is applied to reduce choke movements

Pereira et al. (2012)

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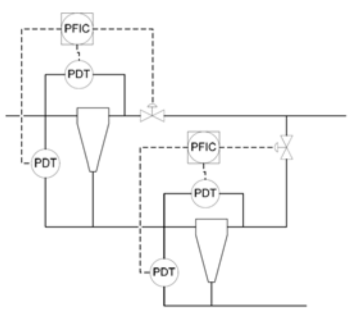
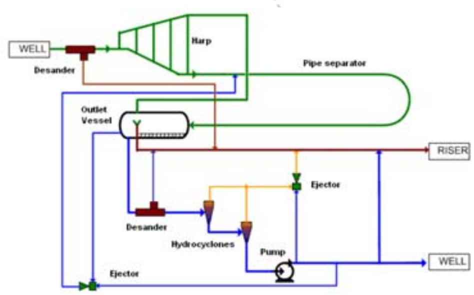
Process Control: Marlim SSAO

Two hydrocyclone controllers





- To keep the reject rate between 2-6%

Pereira et al. (2012)

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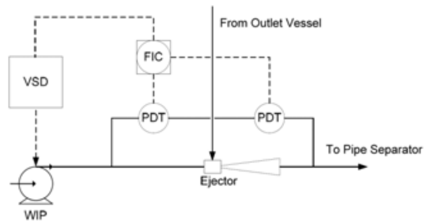
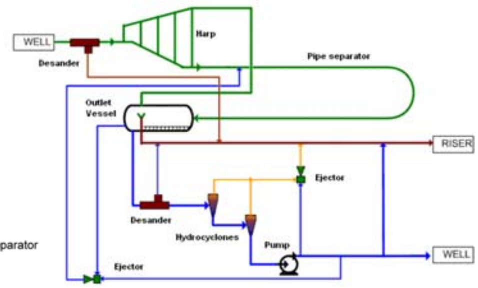
Process Control: Marlim SSAO

Flushing controller





- Is active only when pipe separator flushing sequence is executed
- Adjusts pump speed to achieve required flow velocity

Pereira et al. (2012)

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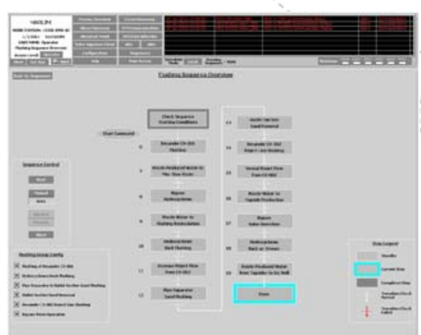
Operation: Automated sequences

- Start up of water injection pump
- Flushing sequence
- Planned shutdowns
- Injecting chemicals

Pereira et al. (2012)



Screenshot of flushing sequence

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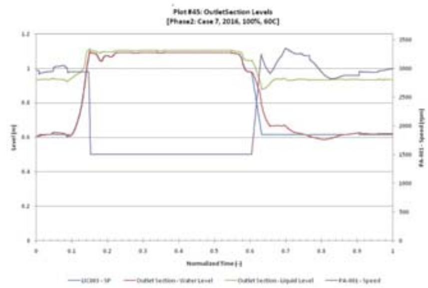
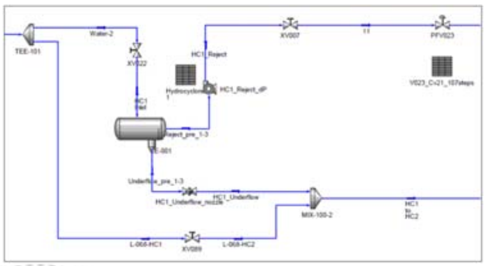
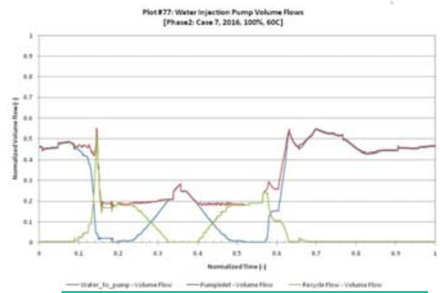
Dynamic Analysis

- Verification of control philosophy
- Pre-tuning PID controllers (SIMC)
- Verification and development of automated sequences

Pereira et al. (2012)







Hydrocyclone model in Unisim or HYSYS

Simulation of flushing sequence

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Summary

Main challenges in design

- Sand removal
- Flow assurance e.g. Hydrates (MEG injection, depressurizing)
- Secure foundation & Leveling of subsea separators
- Durability & Low maintenance
- Modularization
- Power distribution
- Compactness for deep-water applications
- Laboratory test (Technology Qualification Program)

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Summary

Main challenges in process control

- Simpler (compared to topside control systems)
- Strong interactions between control loops
- Redundancy
- Safety & Emergency Shutdown (ESD)
- Fast dynamics of compact separators
- Data transfer to topside
  - Comes-on-power (slow, suitable for old bulky systems)
  - Fiber optic communication (fast, high rate, long distance)
- Modeling and dynamic simulations
- Controller tuning
- Wear and tear of control valves (constraint on speed of valves)
- Slugging flow and well-test

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Strong interaction + constraint handling + economic operation ➔ MPC

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Thank you!

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