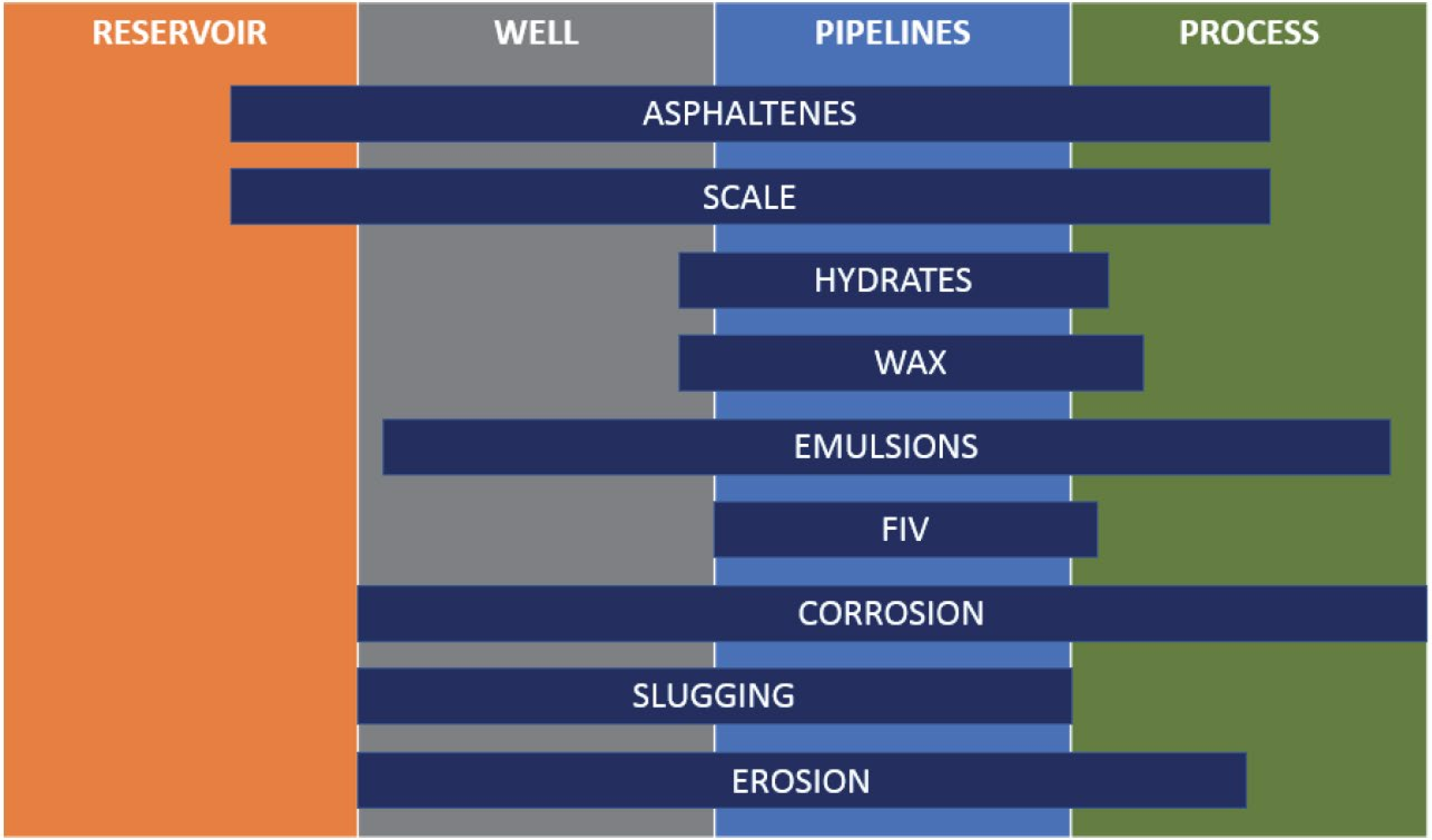
Flow assurance considerations in hydrocarbon field development and planning

Prof. Milan Stanko (NTNU)

Issues

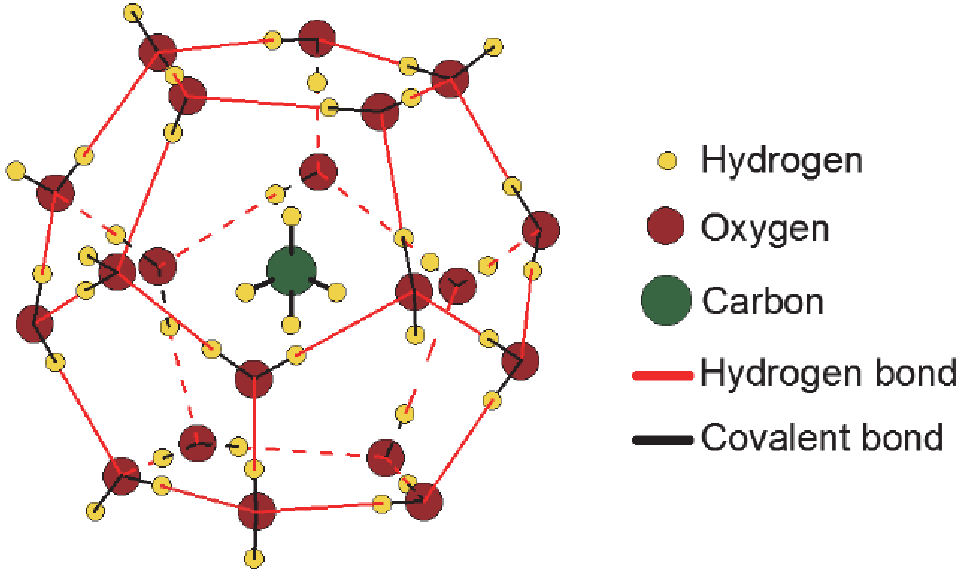


Naphtenates

Foam

- microorganism growth

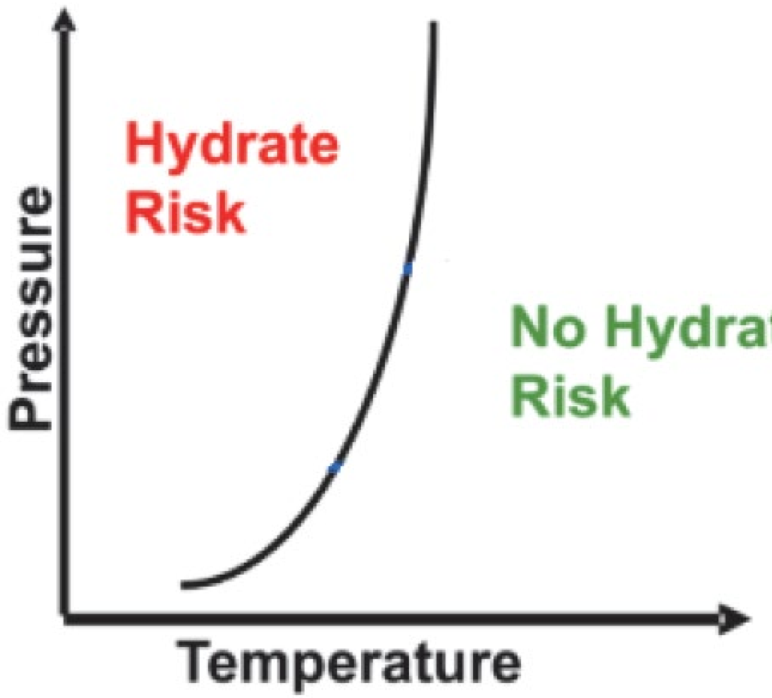
Hydrates



https://www.youtube.com/watch?v=Oz4NLXfdqpA

Hydrates - conditions

- Free water (in liquid phase)
- Small hydrocarbon molecules
- Particular range of pressure and temperature.



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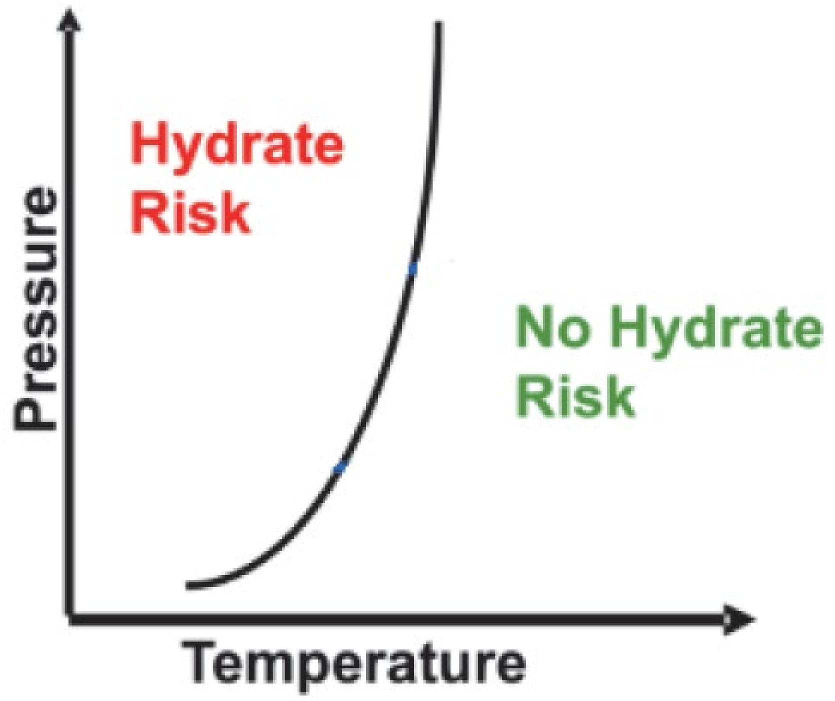
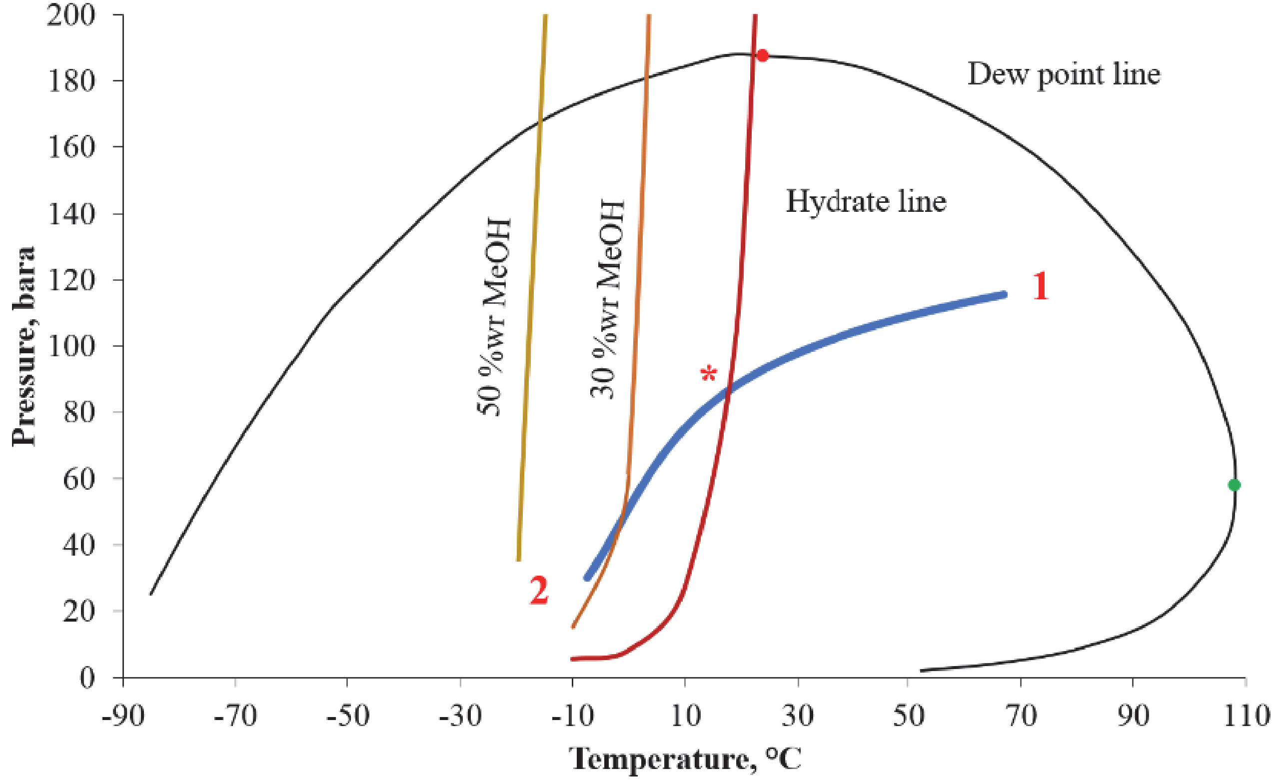
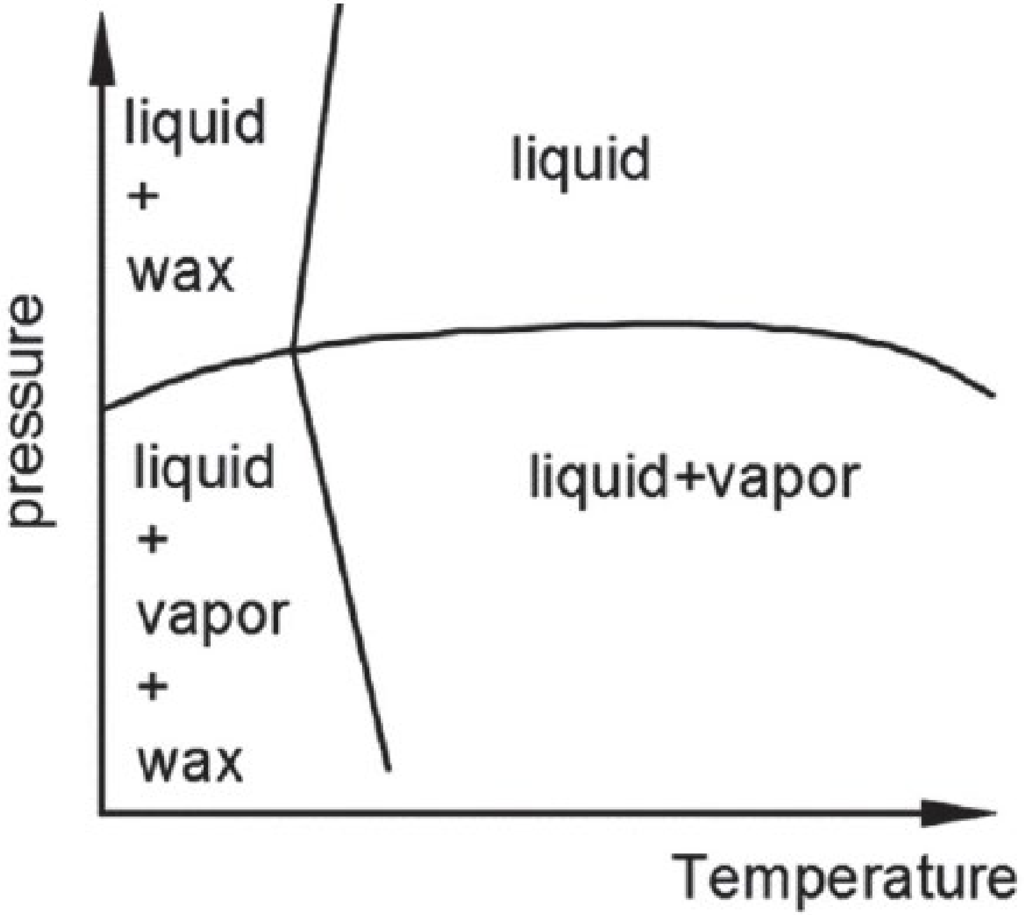




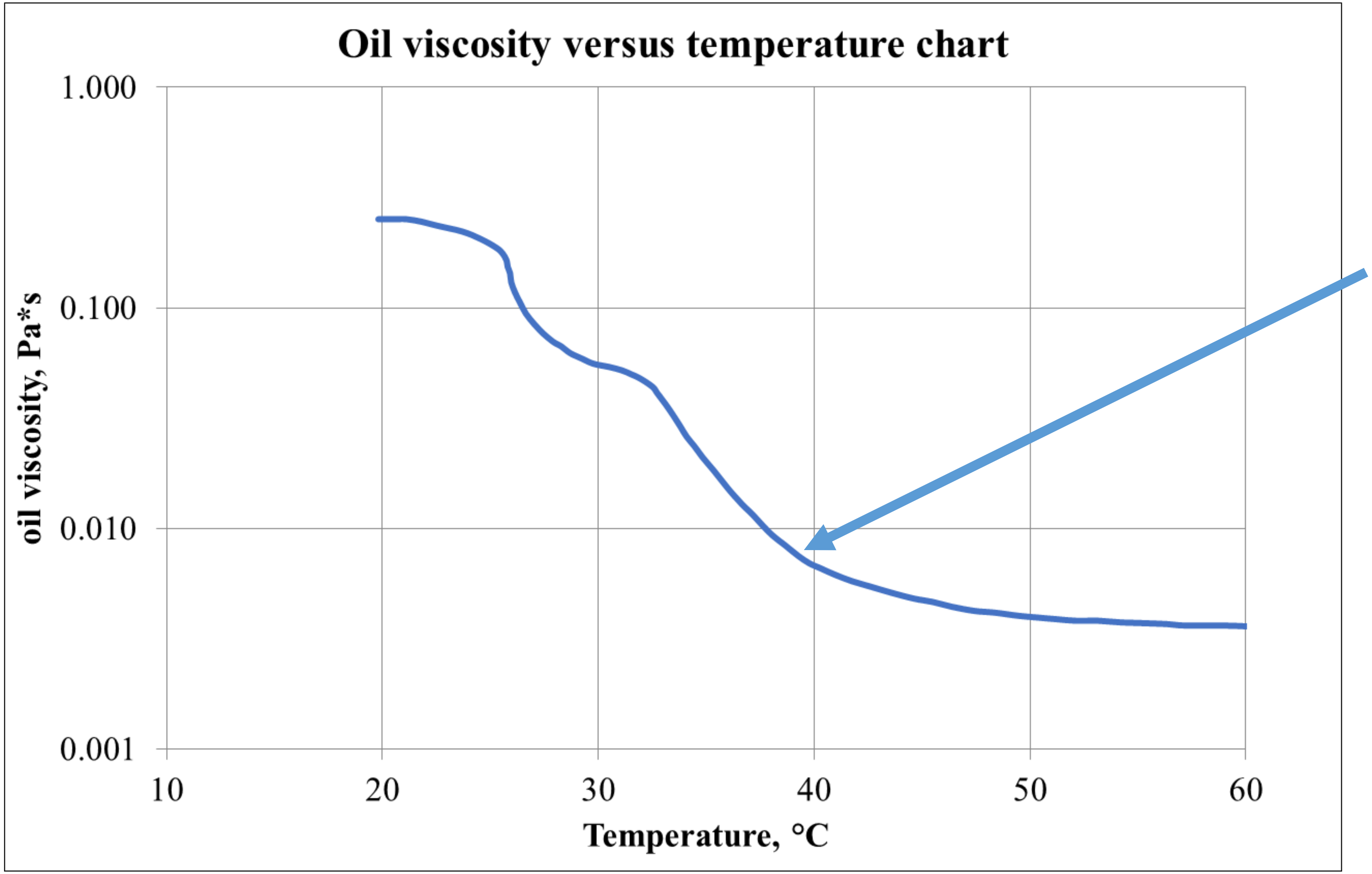
Wax

TAKEN FROM EQUINOR

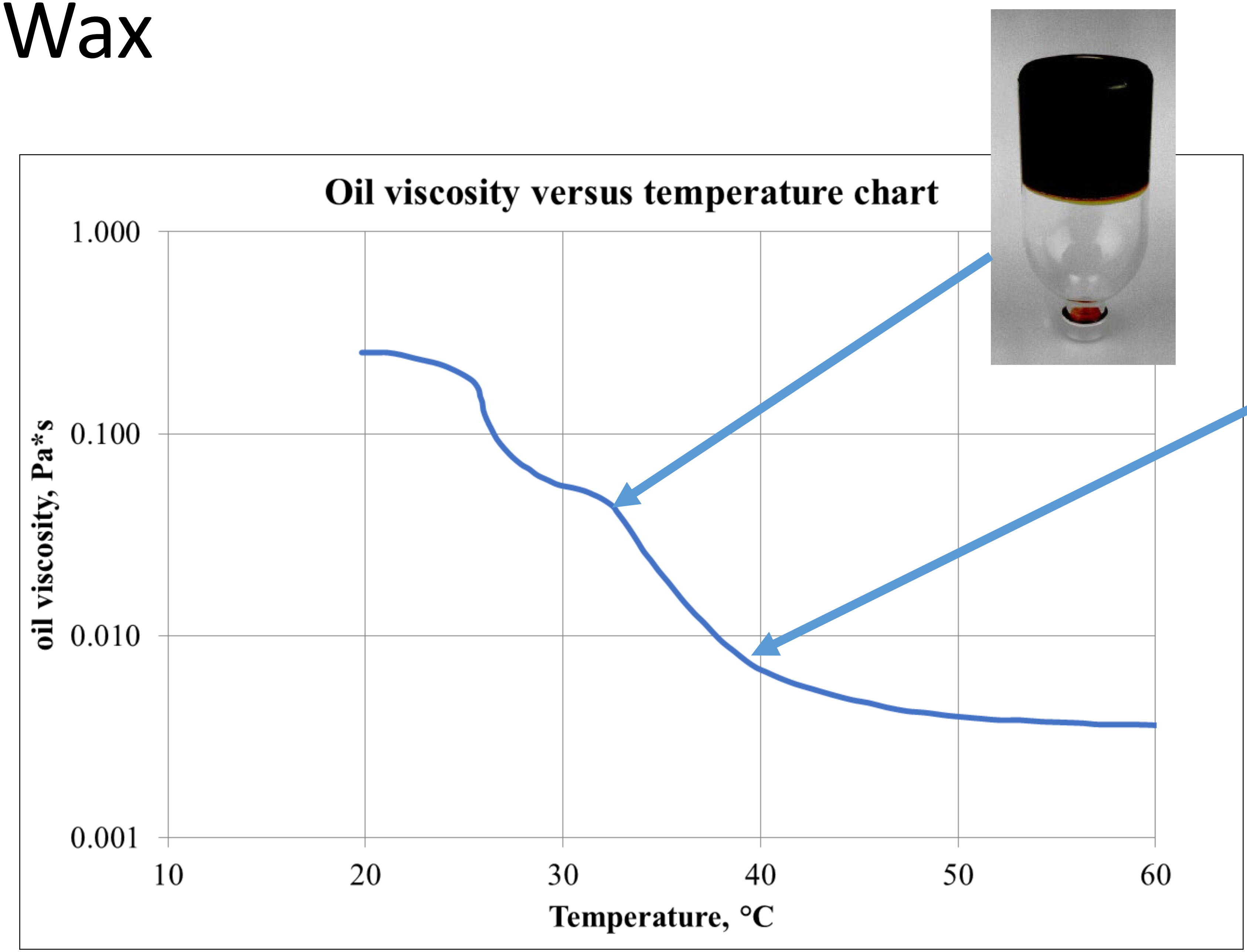


Paraffins (C18 - C36)

Wax


Oil viscosity versus temperature chart
1.000
0.100
0.010
0.001
oil viscosity, Pa*s
10
20
30
40
50
60
Temperature, °C

Wax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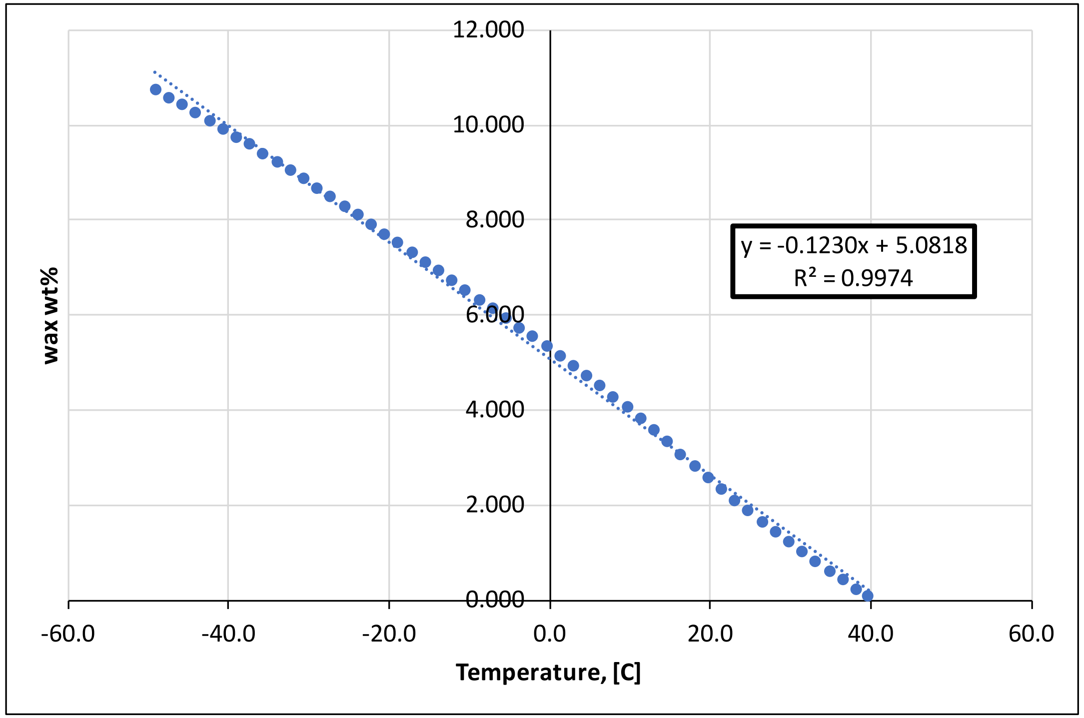
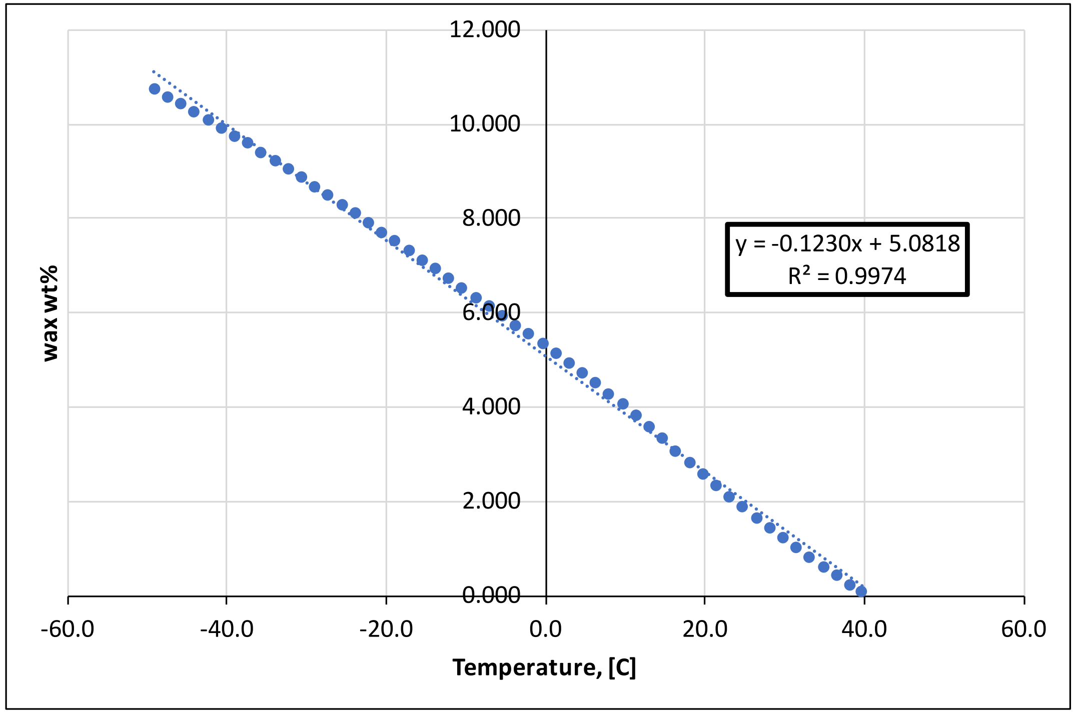
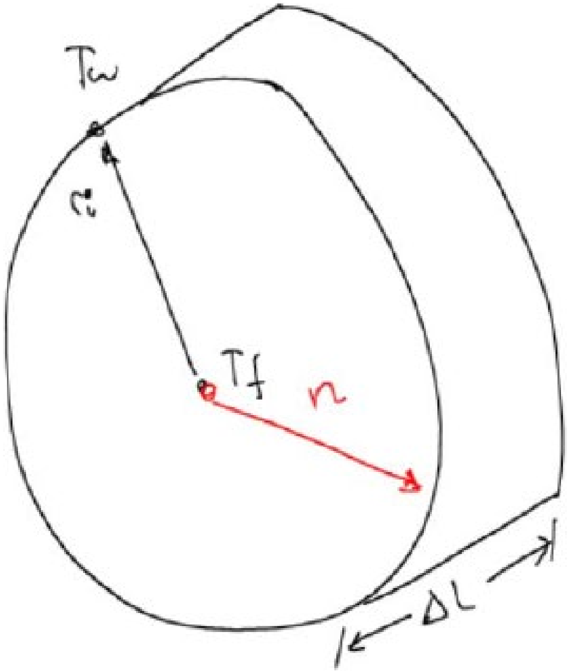
Wax



12.000
10.000
8.000
6.000
4.000
2.000
0.000
wax wt%
y = -0.1230x + 5.0818
R² = 0.9974
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
Temperature, [C]

Wax





r_i : internal pipe diameter

T_f : fluid temperature

T_w : wall Temperature

n : mass flux of wax from fluid to wall [kg/s.m²]

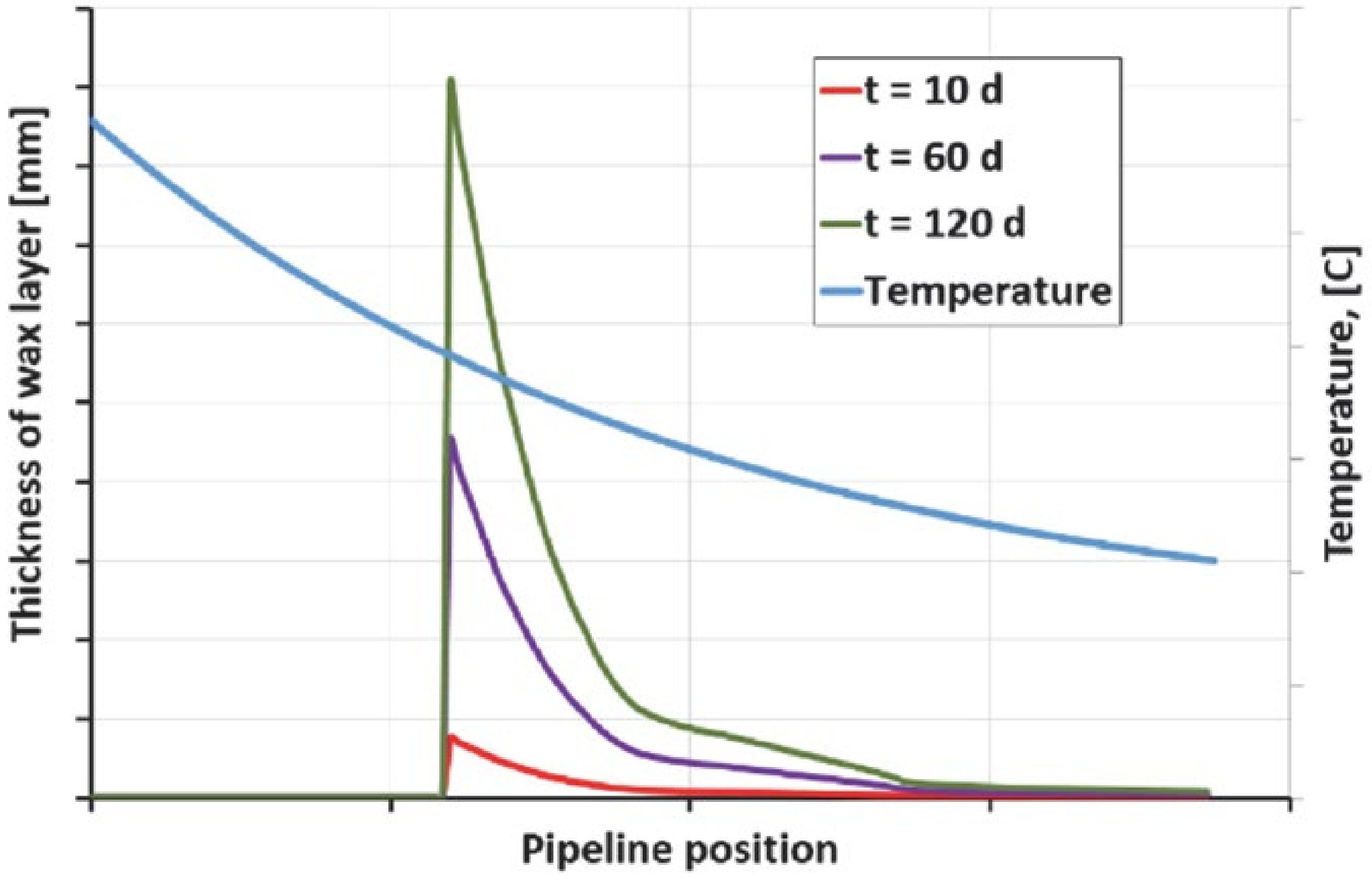
$dA = 2\pi r_i \, dL$

total mass flow of wax (m_w) deposited in a section

$m_w = n \cdot dA$

$$n = \rho_{wax} \cdot \frac{B}{\mu_o} \cdot \frac{dC}{dT} \cdot \frac{dT}{dr}$$

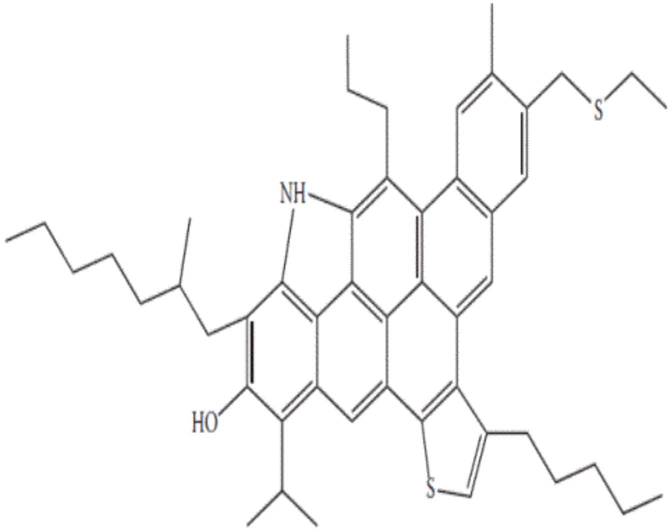
Wax

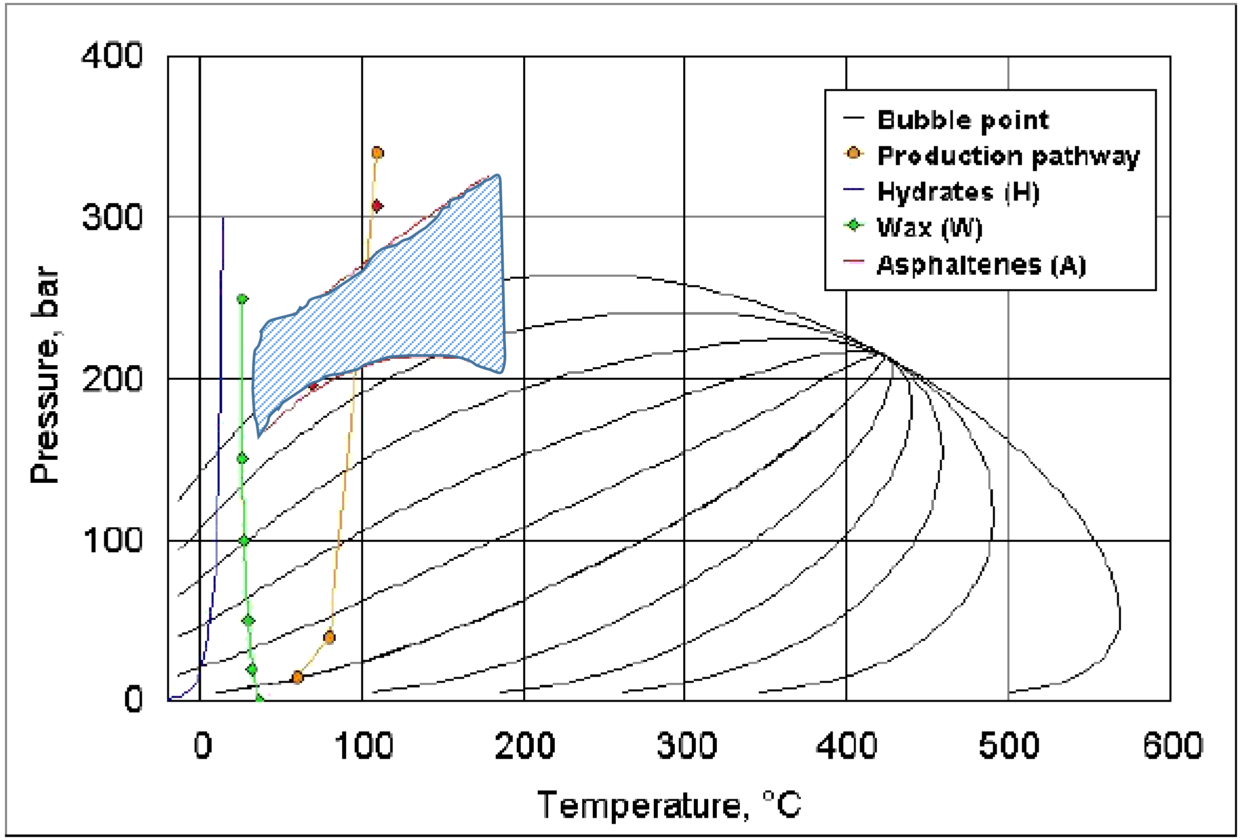


t = 10 d
t = 60 d
t = 120 d
Temperature
Thickness of wax layer [mm]
Temperature, [C]
Pipeline position

Asphaltenes

TAKEN FROM EQUINOR (KALLEVIK)





Scale

Ion	Formasjonsvann [mg/l]
Na	14 800
K	520
Mg	13
Ca	378
Ba	410
Sr	228
Fe	58
Cl	23 600
SO4	0

+

Ion	Seawater [mg/l]
Na	10 680
K	396
Mg	1 279
Ca	409
Ba	8
Sr	0
Fe	0
Cl	19 220
SO4	2 689

$$Ba^{2+} + SO_4^{2-} = BaSO_4(s)$$

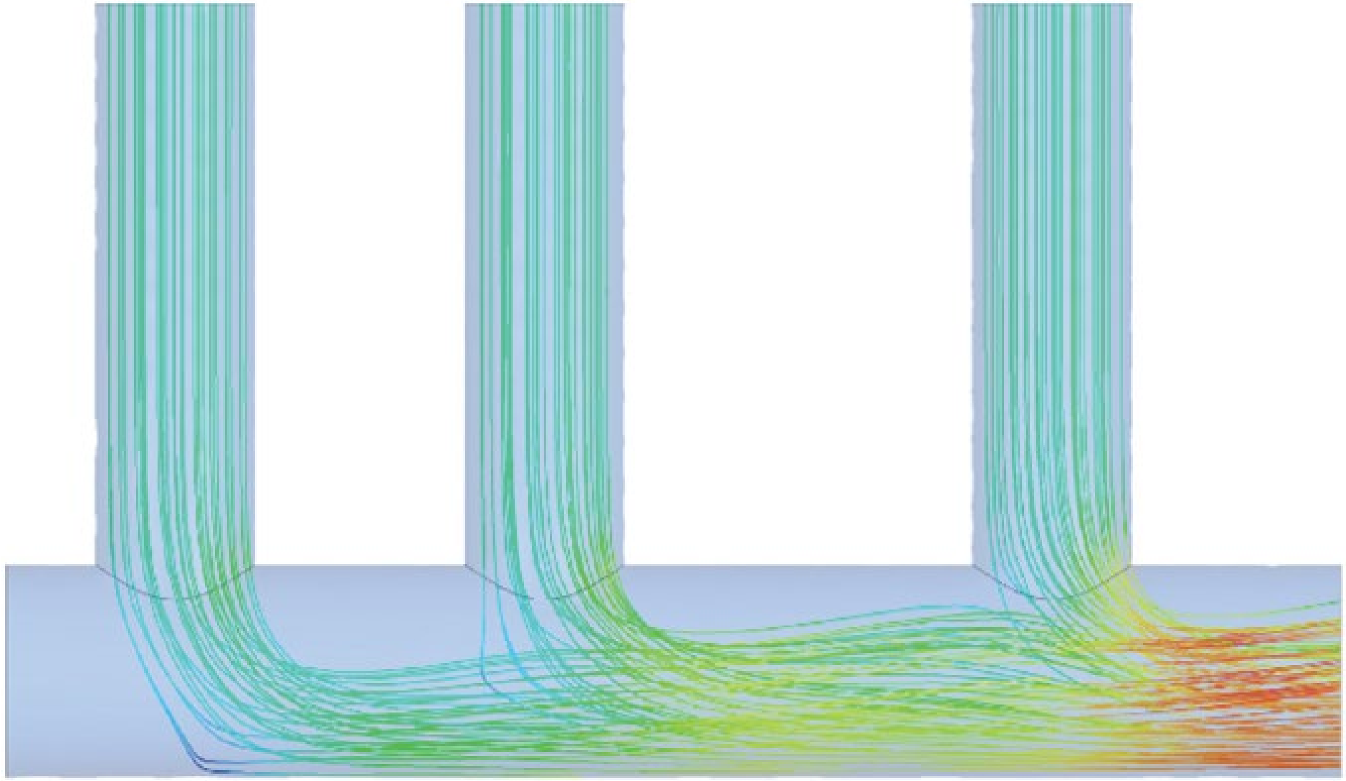
$$Ca^{2+} + CO_3^{2-} = CaCO_3(s)$$

p↓
T↑ →

$BaSO_4$ $CaCO_3$ NaCl

TAKEN FROM EQUINOR (SANDENGEN)

Erosion



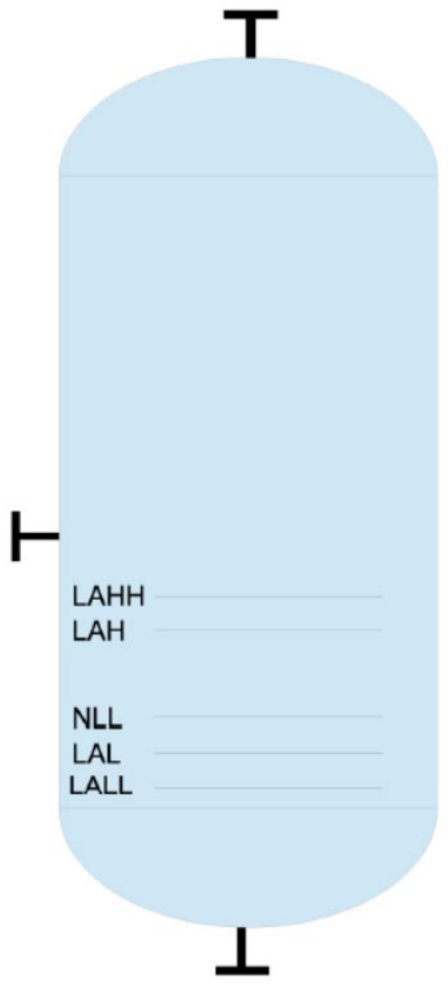
Slugging

https://www.youtube.com/watch?v=j59QLHsTs_c

Slugging – slugcatcher handling

https://www.youtube.com/watch?v=LKLW5284adI

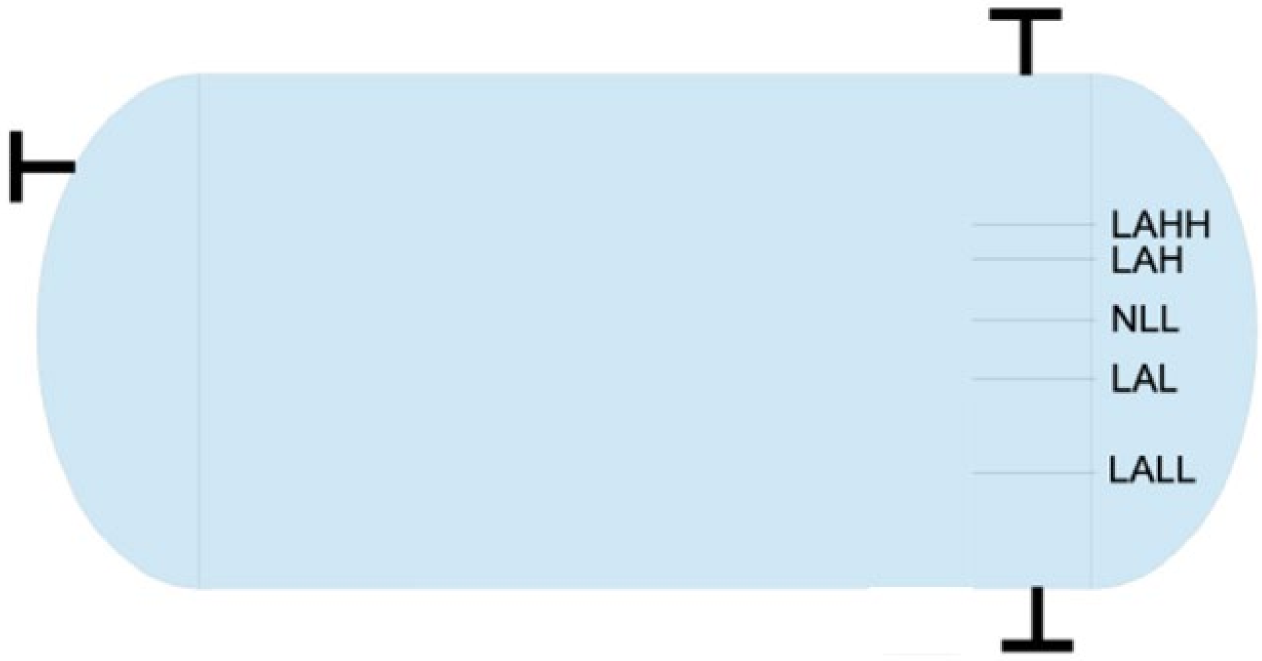
Slugging – impact on separator operation



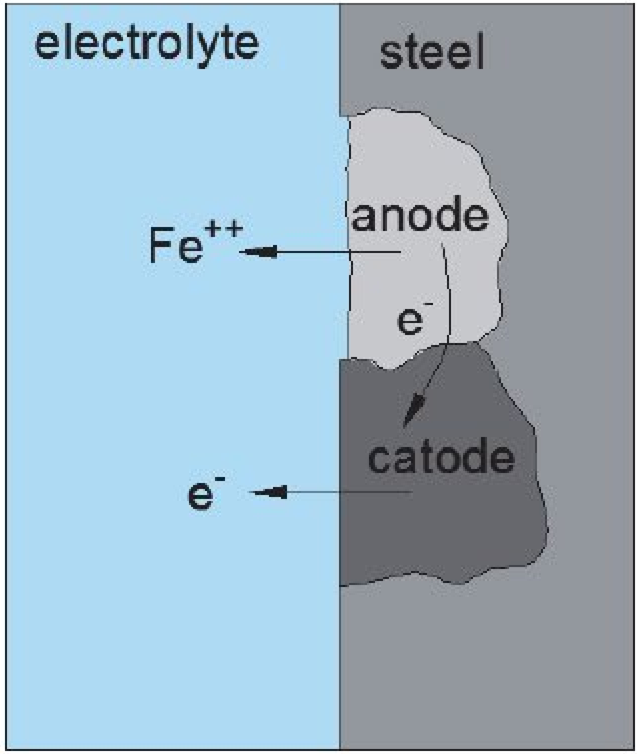
LAL: Level alarm low
LAH: Level alarm high
LALL: Level alarm low low
LAHH: Level alarm high high

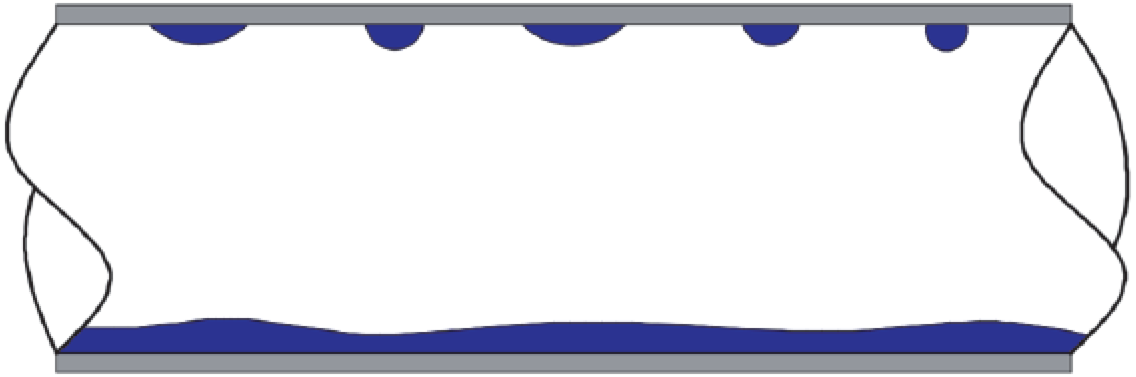
https://pubs.spe.org/en/ogf/ogf-article-detail/?art=1028

Slugging – impact on separator operation



Corrosion

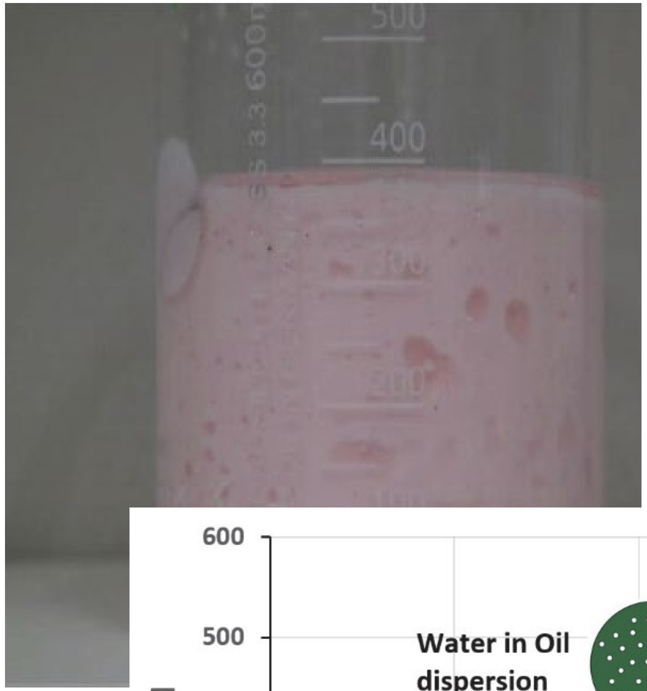


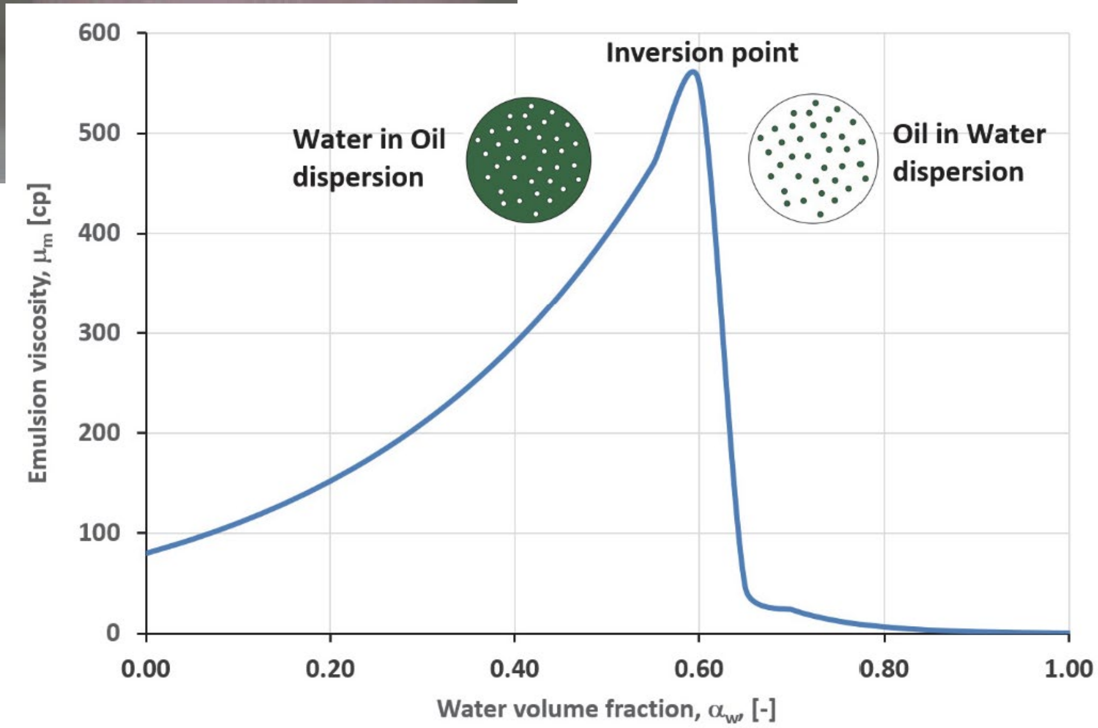


Oil-water emulsions

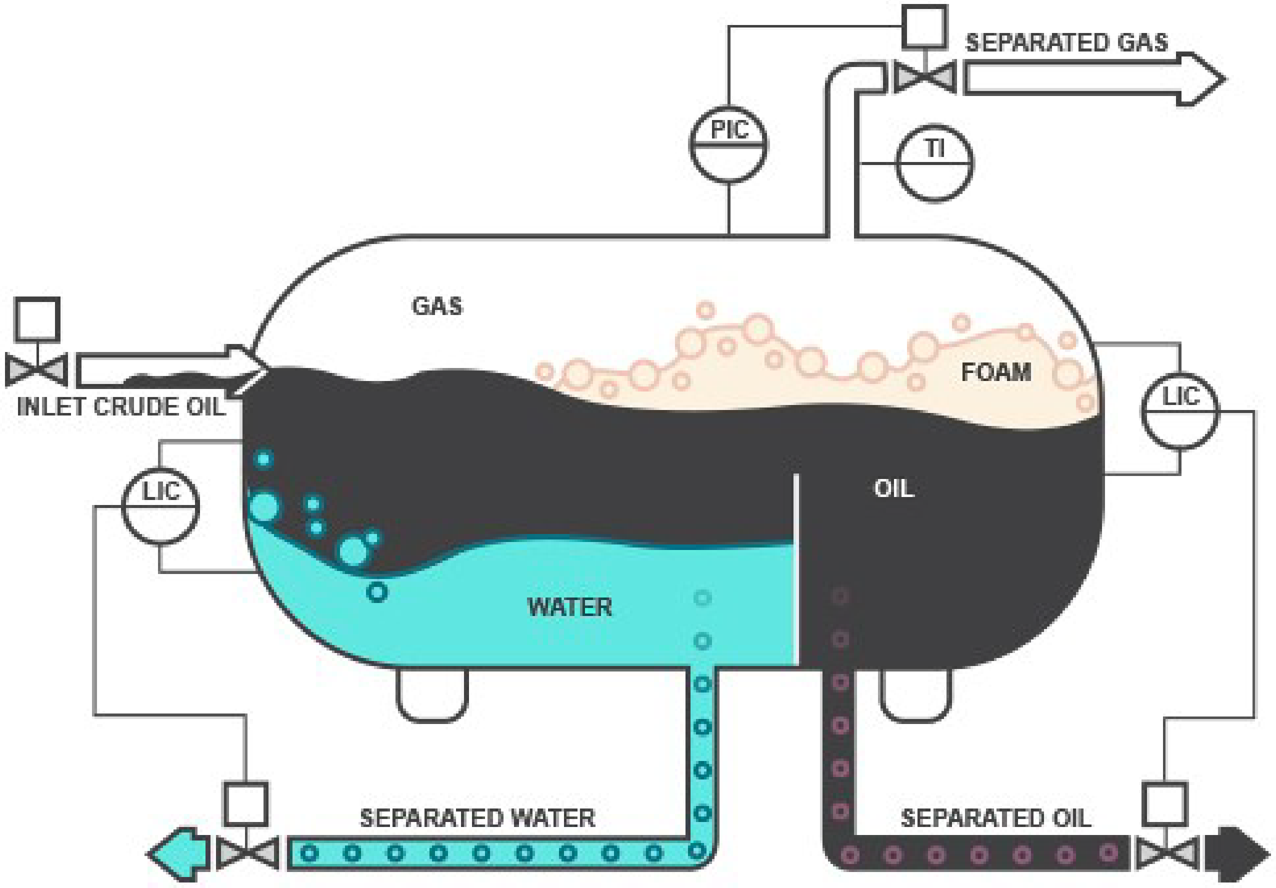
Oil-water emulsions

Oil-water emulsions

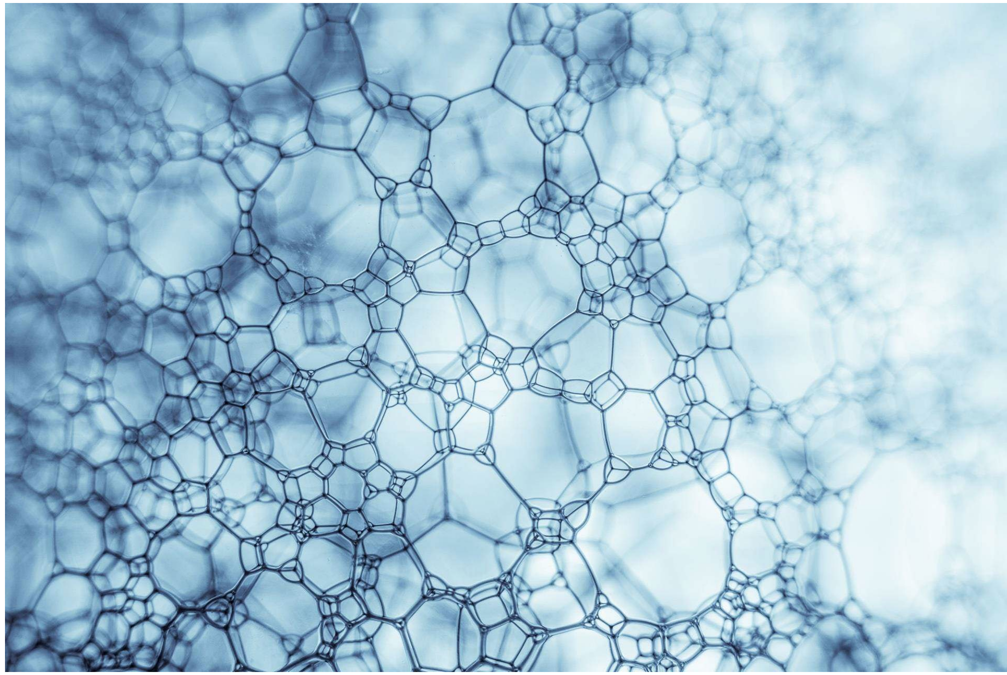




Foam



https://www.arab-oil-naturalgas.com/foam-in-oil-gas-separators/



https://www.crodaoilandgas.com/en-gb/discovery-zone/functions/foamers

Flow assurance issue	Causes	Potential Consequences	Prevention/solution	Tools available for analysis
Hydrates	• Small gas HC molecules • Free water • Begin to form at a given p and T (low T, high P) given by thermodynamic equilibrium of the hydrate phase.	• Blockage of flowlines and pipelines	Reduce the hydrate formation region: •Continuous or on-demand injection of chemical inhibitor (MEG or MEOH) Stay out of hydrate formation region: •Improve thermal insulation •Electric heating Others: •Cold flow* •Water removal and gas dehydration*	To determine Hydrate formation conditions: •Laboratory tests •Empirical correlations •Thermodynamic simulators (e.g. Hysys, PVTsim, Unisim) To determine p and T along the pipe: •Multiphase simulator (Olga, LedaFlow). •Computational fluid dynamics (CFD)
Wax	• Composition of the crude oil • Begins to form at given p and T due to changes in solubility • Cold wall	In wells, flowlines and pipelines: •Increase pressure drop (pipe roughness) •Reduces heat transfer •Reduction of cross section area •Pipe blockage •Changes fluid rheology •Gelling (problem for startup)	• Pigging • Thermal insulation • Electric heating • Chemical inhibitors • Chemical dissolvers • Pipe coating • Cold flow*	• Laboratory tests • Transient multiphase simulators (e.g. Olga, LedaFlow) • Computational fluid dynamics (CFD)
Slugging	• Dynamics of multiphase flow of liquid and gas • Reduction of rate • Liquid accumulation on low points	• Fluctuating liquid and gas input to processing facilities In flowlines and pipelines: • Vibration • Added pressure drop • Fatigue	• Change separator size • Pipeline dimensioning • Maintain flow above minimum flow rate • Gas lift in riser base • Choking topside • Pipeline re-routing • Subsea separation*	• Transient multiphase simulator (OLGA, LEDA) • Structural analysis (usually with FEA, e.g. Ansys) • Laboratory experiments
Scaling	• Changes in solubility (e.g. changes in P and T conditions, changes in pH, mixture of incompatible water, CO_2 injection).. • Irregularities on surface	In wells, pipelines and flowlines: •Reduction of cross section area •Pipe blockage •Malfunctioning of valves and equipment	• Continuous injection of chemical inhibitors • Dilution by adding more water • Chemical dissolvers • Mechanical removal • Coating	• Laboratory tests • Simulation tools

Flow assurance issue	Causes	Potential Consequences	Prevention/solution	Tools available for analysis
Erosion	• Sand production • High flow velocities • Liquid droplets in the gas • Gas droplets in the liquid	In wells, pipelines and flowlines: •Structural damage •Vibration •Leaks •Corrosion	• Change geometry • Replacement and maintenance of components • Reduce flow rate (reduce formation drawdown) • Sand separation* • Coatings	• Standards (DNV-RP-0501) • Computational fluid dynamics • Laboratory testing
Corrosion	• Water • O_2 • CO_2 • H_2S	• Leaks • Integrity	• Chemical inhibitor • Coatings • Material selection • Surface passivation	• Laboratory testing
Emulsions	• Emulsification agents in the crude • Mixing, shear when flowing through valves, chokes, etc	• Added pressure drop • Increased separation time	• Injection of demulsifiers • Heating	• Laboratory tests • Multiphase models
Asphaltenes	• Crude with asphaltenes • Pressure reduction • Addup of light hydrocarbon components	• Blockage of formation, well, flowline and pipeline • Loss of equipment functionality • Emulsification and foamification	• Mechanical removal • Chemical injection	• Laboratory tests • Some simulation tools

Measures and consequences

- **Chemical injection**
- System design, e.g.
  - pipe and component insulation
  - heat tracing
  - dead legs
  - pipeline routing
- Well intervention needs
- Water injection strategy
- Define procedures when shutting down and starting up
- Ensure proper distribution of chemicals

Example of chemical injection program

Tabell 5-2. Foreløpig oversikt over kjemikalietyper

Type kjemikalie	Konsentrasjon (ppm vol.)	Tilsettes i	Frekvens
Avleiringshemmer A	50	Produsert vann	Kontinuerlig
Avleiringshemmer B	20-50	Sjøvann	Kontinuerlig
Korrosjonshemmer	50	Produsert vann	Kontinuerlig
Emulsjonsbryter	50	Total væske 1)	Kontinuerlig ved behov
Skumdemper	5	Total væske	Periodisk
Flokkulant	10	Produsert vann	Kontinuerlig
Vokshemmer	150	Total væske 1)	Periodisk
Biocid	80	Total væske 1)	Kontinuerlig
Oksygenfjerner	5	Sjøvann	Kontinuerlig
H2S fjerner	150	Produsert vann	Kontinuerlig ved behov
MEG	Batch	Brønnstrøm	Ved behov

1) Olje og produsert vann.

From Ivar Aasen PDO, Del 2

Release and disposal of chemicals

Tabell 7-1 Klassifisering av kjemikalier i henhold til OSPAR

(svart)	Svart kategori: Stoffer som er lite nedbrytbare og samtidig viser høyt potensial for bioakkumulering og/eller er svært akutt giftige. I utgangspunktet er det ikke er lov å slippe ut kjemikalier i svart kategori. Tillatelse til bruk og utslipp til spesifikke kjemikalier gis dersom det er nødvendig av sikkerhetsmessige og tekniske grunner.
(rød)	Rød kategori: Stoffer som brytes sakte ned i det marine miljøet, og viser potensiale for bioakkumulering og/eller er akutt giftige. Kjemikalier i rød kategori kan være miljøfarlige og skal derfor prioriteres for utskifting med mindre miljøfarlige alternativer. Tillatelse til bruk og utslipp gis kun av sikkerhetsmessige og tekniske hensyn.
(gul)	Gul kategori: Kjemikalier i gul kategori omfatter stoffer som ut ifra iboende egenskaper ikke defineres i svart eller rød kategori og som ikke er oppført på PLONOR-listen (se under). Ren gul kategori er uorganiske kjemikalier med lav giftighet eller kjemikalier som brytes ned >60% innen 28 dager. Gul-Y1 er 20-60% nedbrutt og forventes å brytes ned fullstendig over tid. Gul-Y2 er moderat nedbrytbare til ikke giftige og ikke-nedbrytbare komponenter. Y2 skal forsøkes substituert på lik linje med røde kjemikalier.
(grønn)	Grønn kategori: Stoffer som er oppført på OSPAR-konvensjonens PLONOR-liste (Substances used and discharged offshore which are considered to Pose Little Or No Risk to the Environment). Disse kjemikaliene vurderes å ha ingen eller svært liten negativ miljøeffekt. Kjemikalier i grønn kategori omfatter også vann som inngår i kjemikaliene.

From Ivar Aasen PDO, Del 2

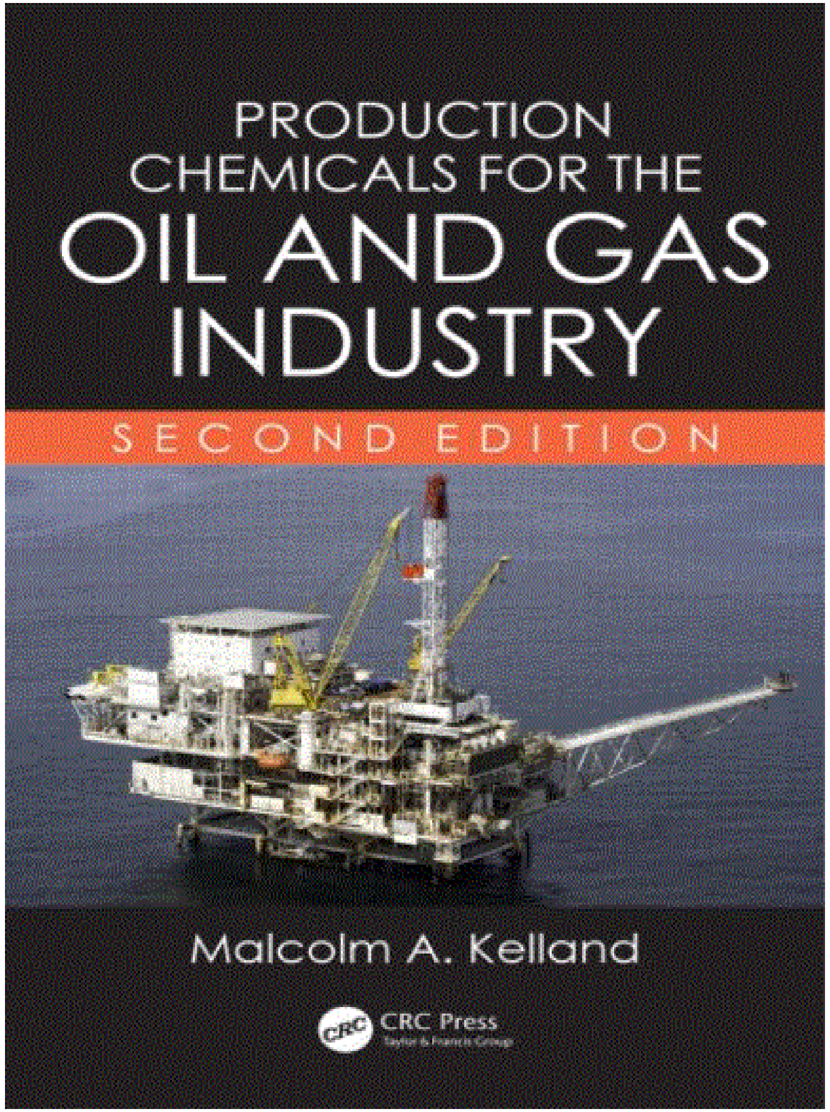
Release and disposal of chemicals

Tabell 7-4 Miljømessige egenskaper til produksjonskjemikalier som vil følge produsert vann fra Johan Castberg-feltet

Type kjemikal	Vannfase/oljefase	Klassifisering
Avleiringshemmer	Vannløselig. Følger produsert vann.	Det er antatt at gult kjemikalie (i klassen Y2) kan velges. Kjemikaliet er moderat bionedbrytbart til ikke bionedbrytbart Det er ikke giftig og vil ikke bioakkumuleres i næringskjeden.
Emulsjonsbryter	Oljeløselig. Følger hovedsakelig oljefasen (95%). 5% følger produsert vann.	Alle disse kjemikaliene er klassifisert som røde, pga det ikke er bionedbrytbart. De er ikke giftige og vil ikke bioakkumulers i næringskjeden.
Vokshemmer	Oljeløselig. Følger oljefasen.	
Skumdemper	Oljeløselig. Følger i all hovedsak oljefasen, lave konsentrasjoner i produsert vann.	
Flokkulant	Vannløselig, men binder seg til oljedråper. Følger hovedsakelig oljefasen (80%). 20% er antatt å følge produsert vann.	
Biocid/Glutaraldehyd	Vannløselig. Følger injeksjonsvannet eller produsert vann.	Kjemikalie er klassifisert som gult pga giftighet. Det er ikke nedbrytbart og vil ikke bioakkumuleres i næringskjeden.

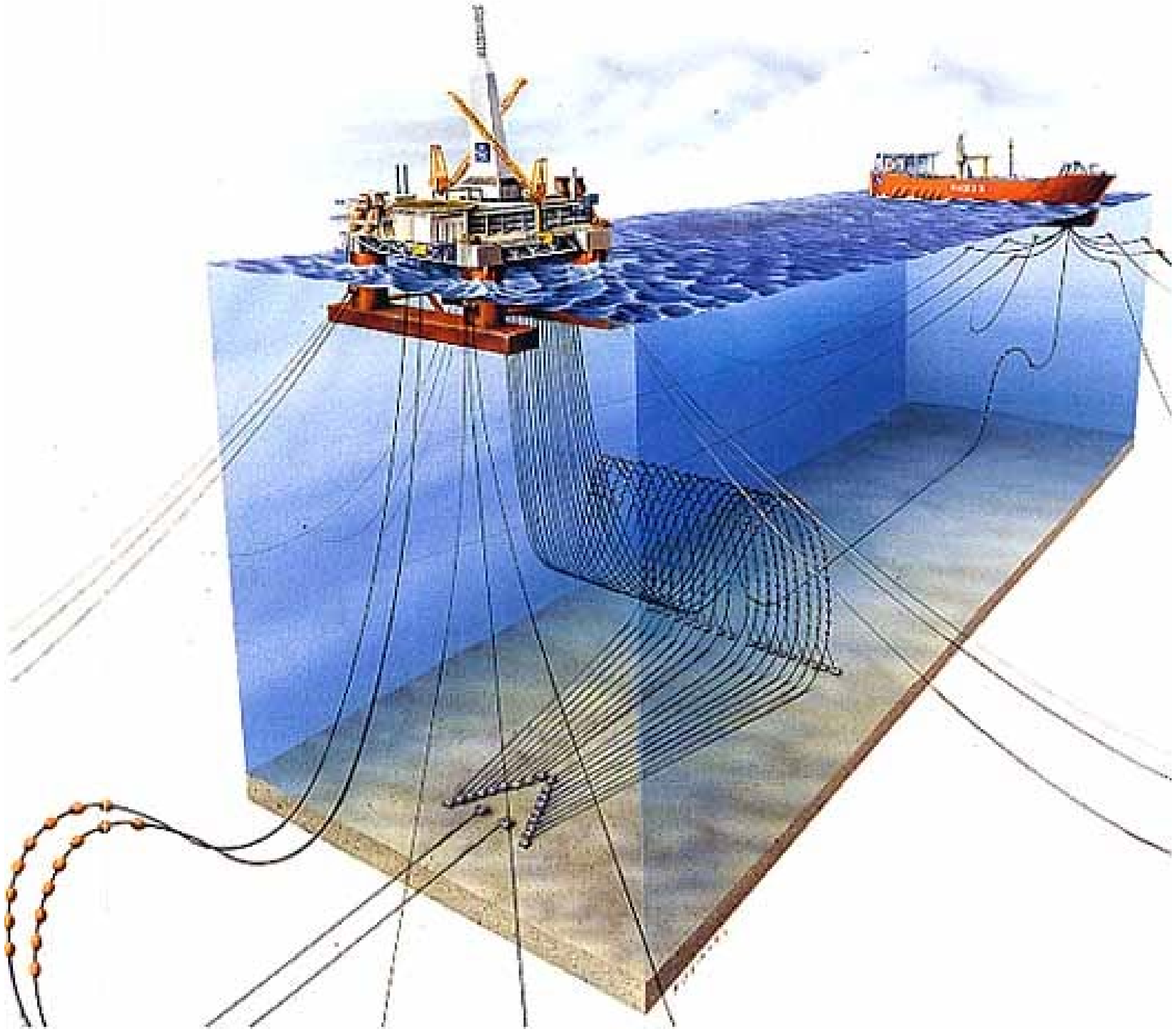
From Johan Castberg PDO, Del 2

More about production chemicals



Injection of production chemicals subsea

Injection of production chemicals



Umbilicals, injection of production chemicals

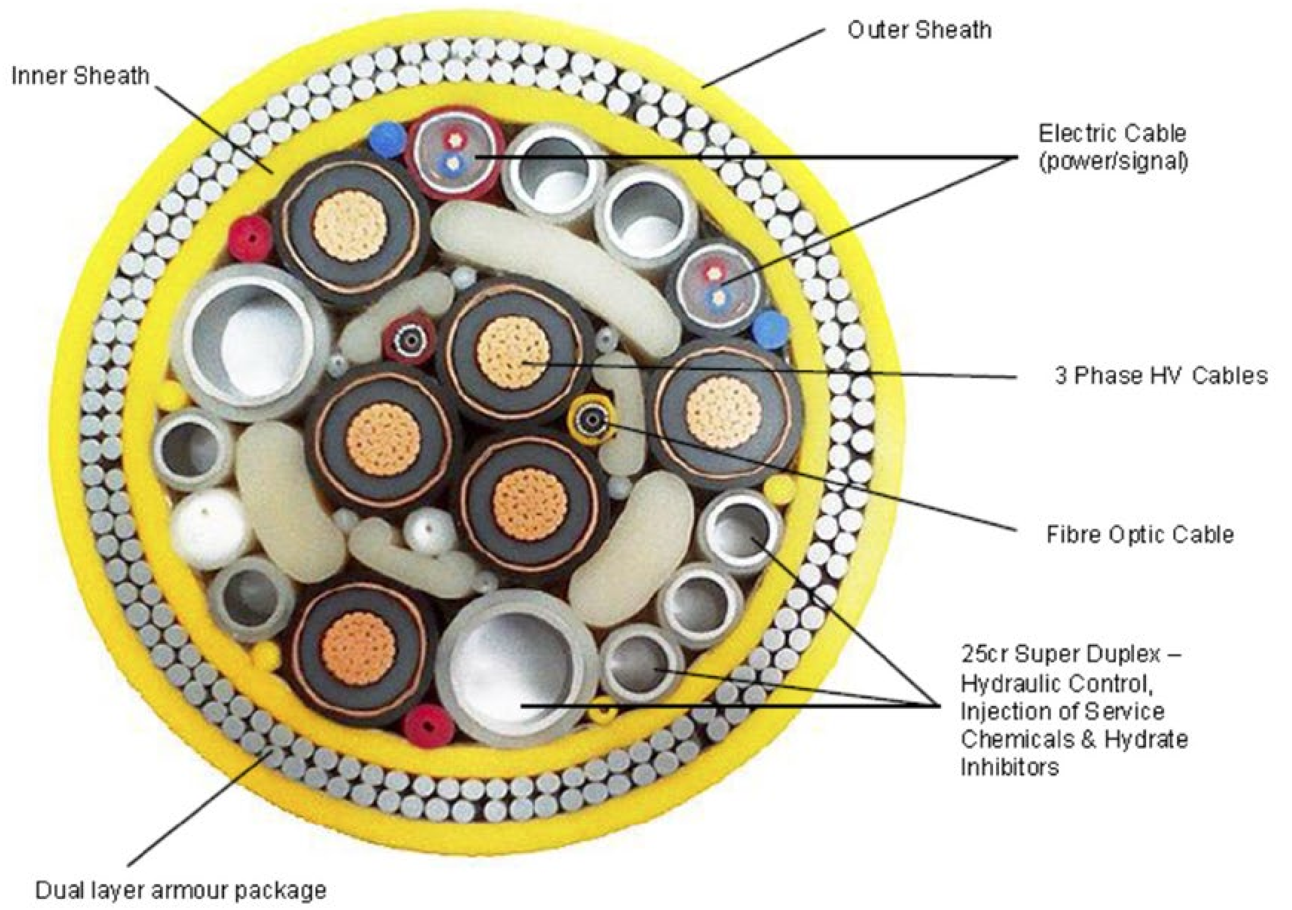
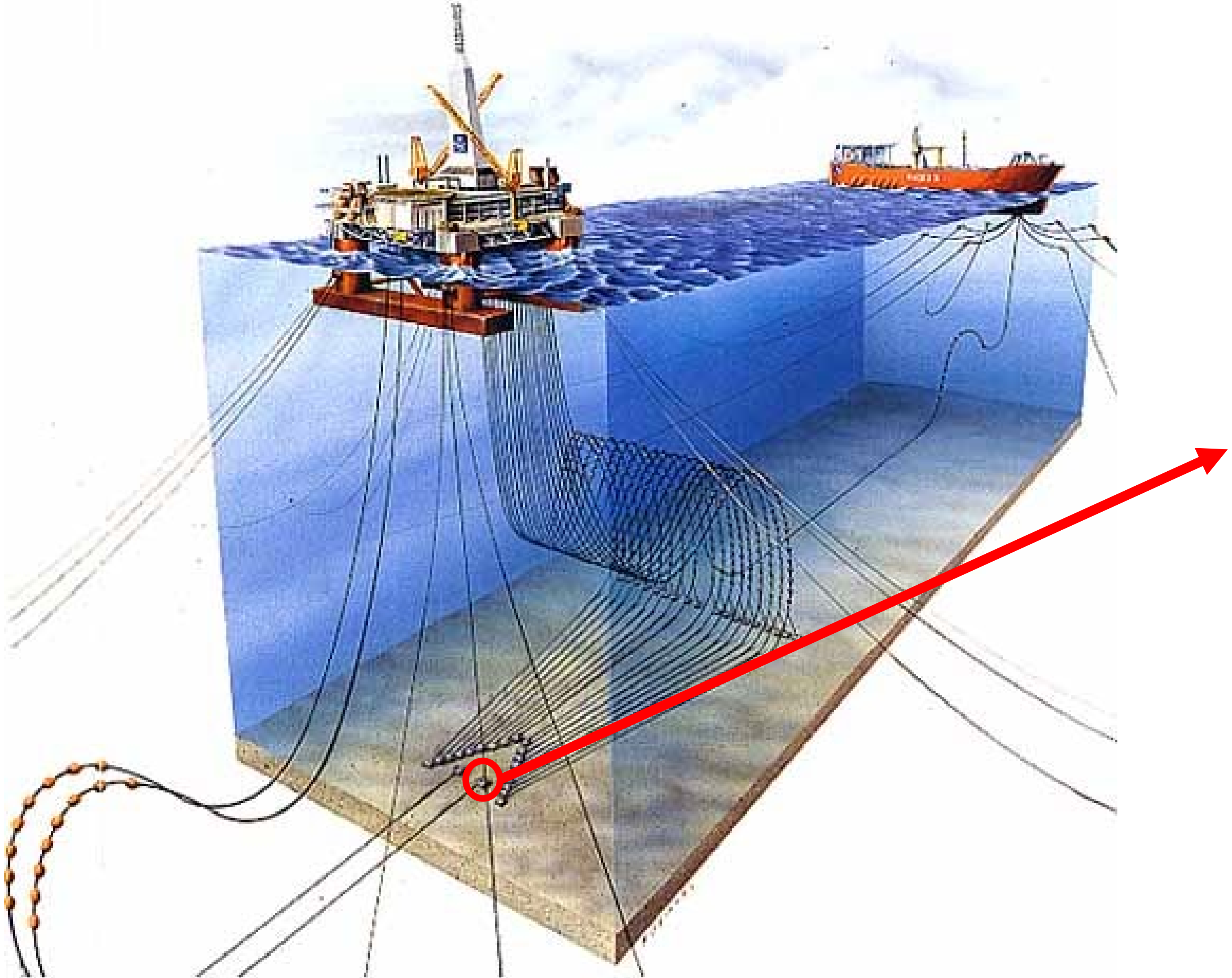
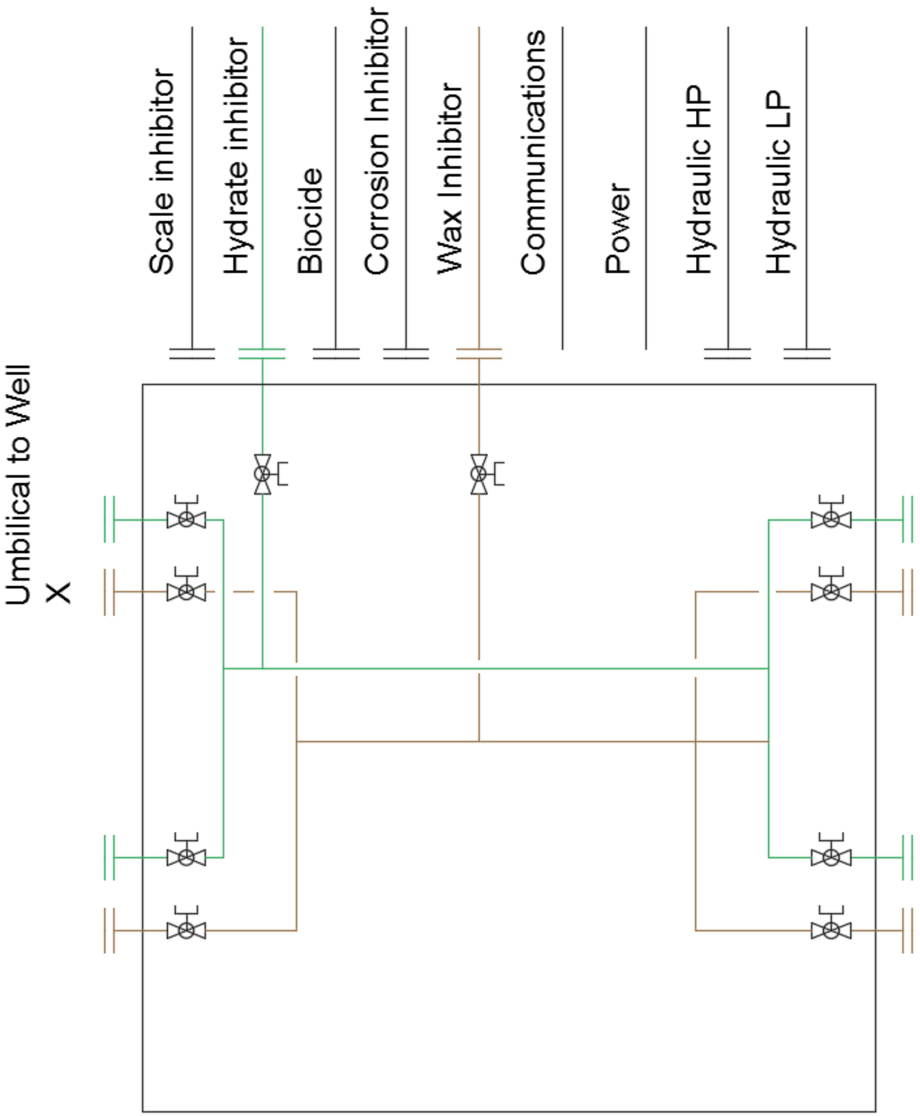


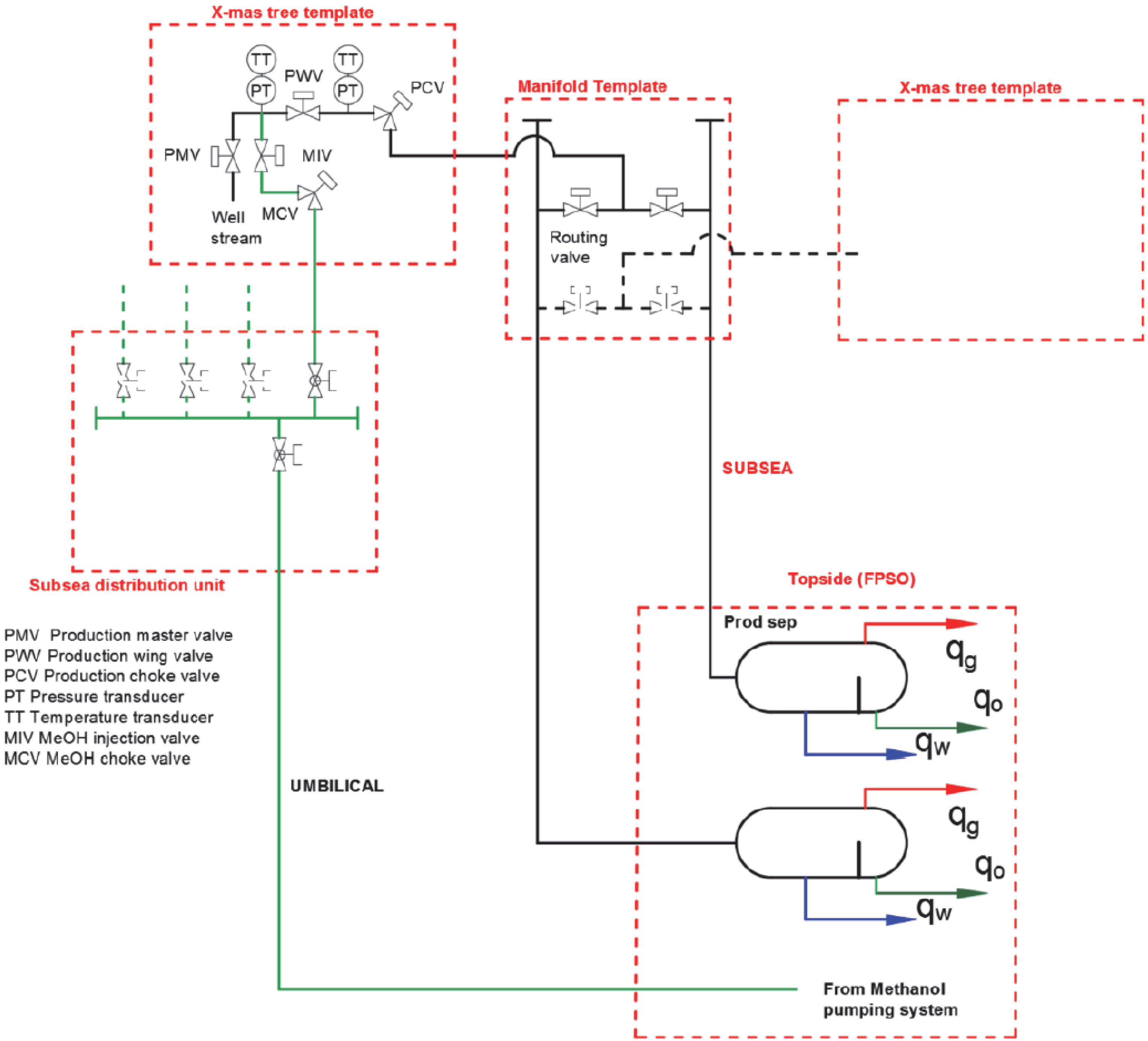
Figure 3 – Umbilical Cross Section Example

Umbilicals, injection of production chemicals

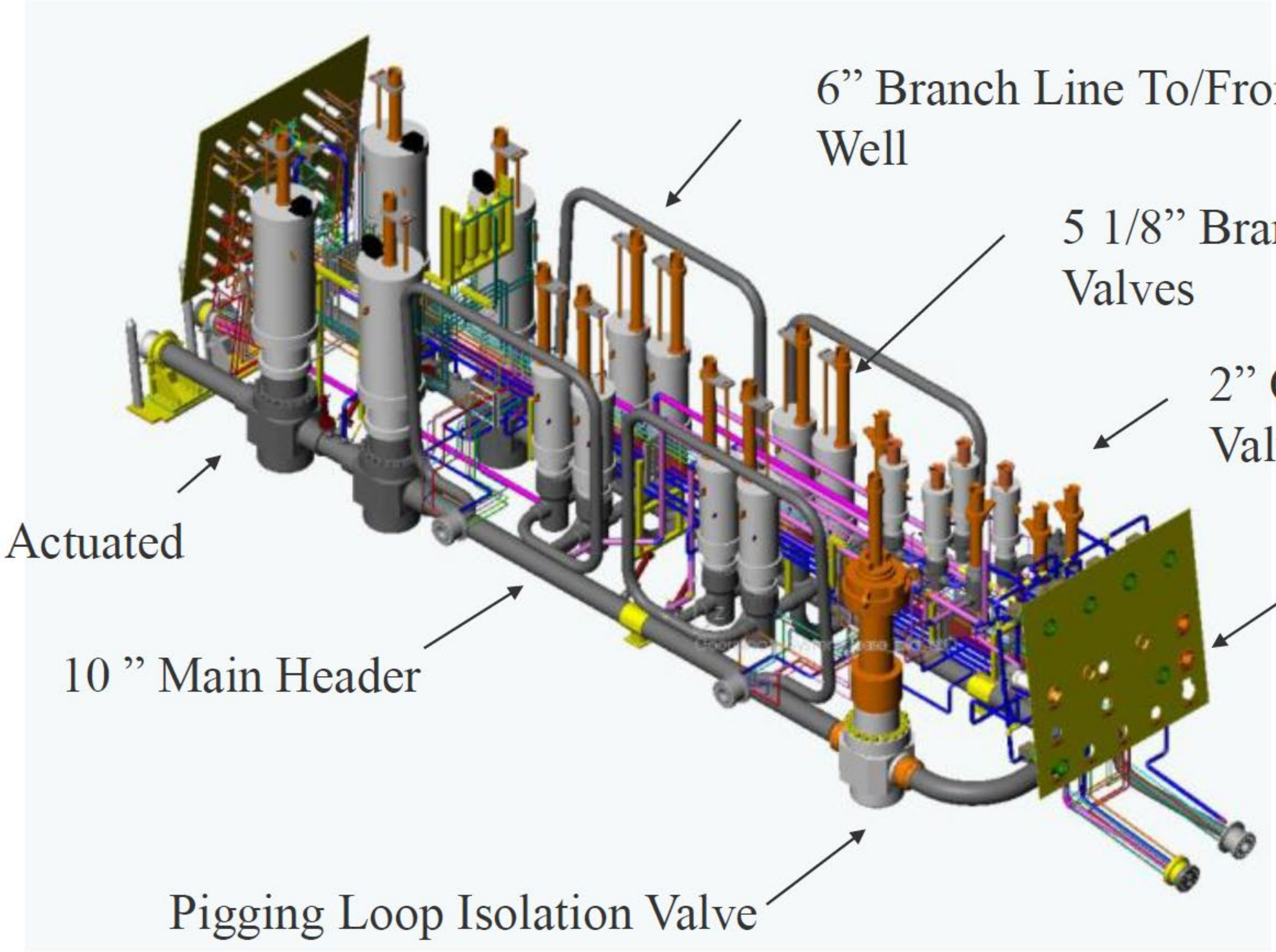


Release and disposal of chemicals

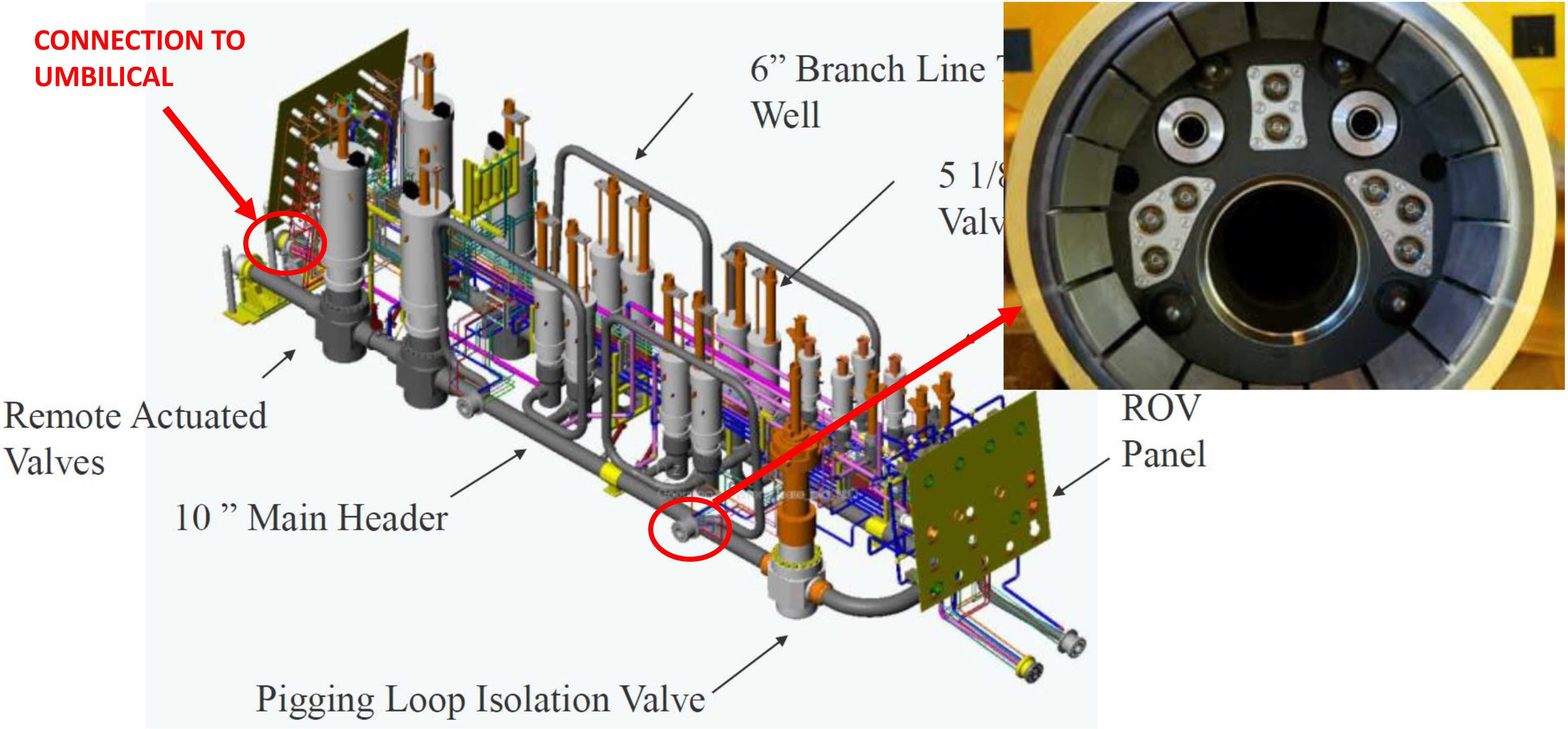


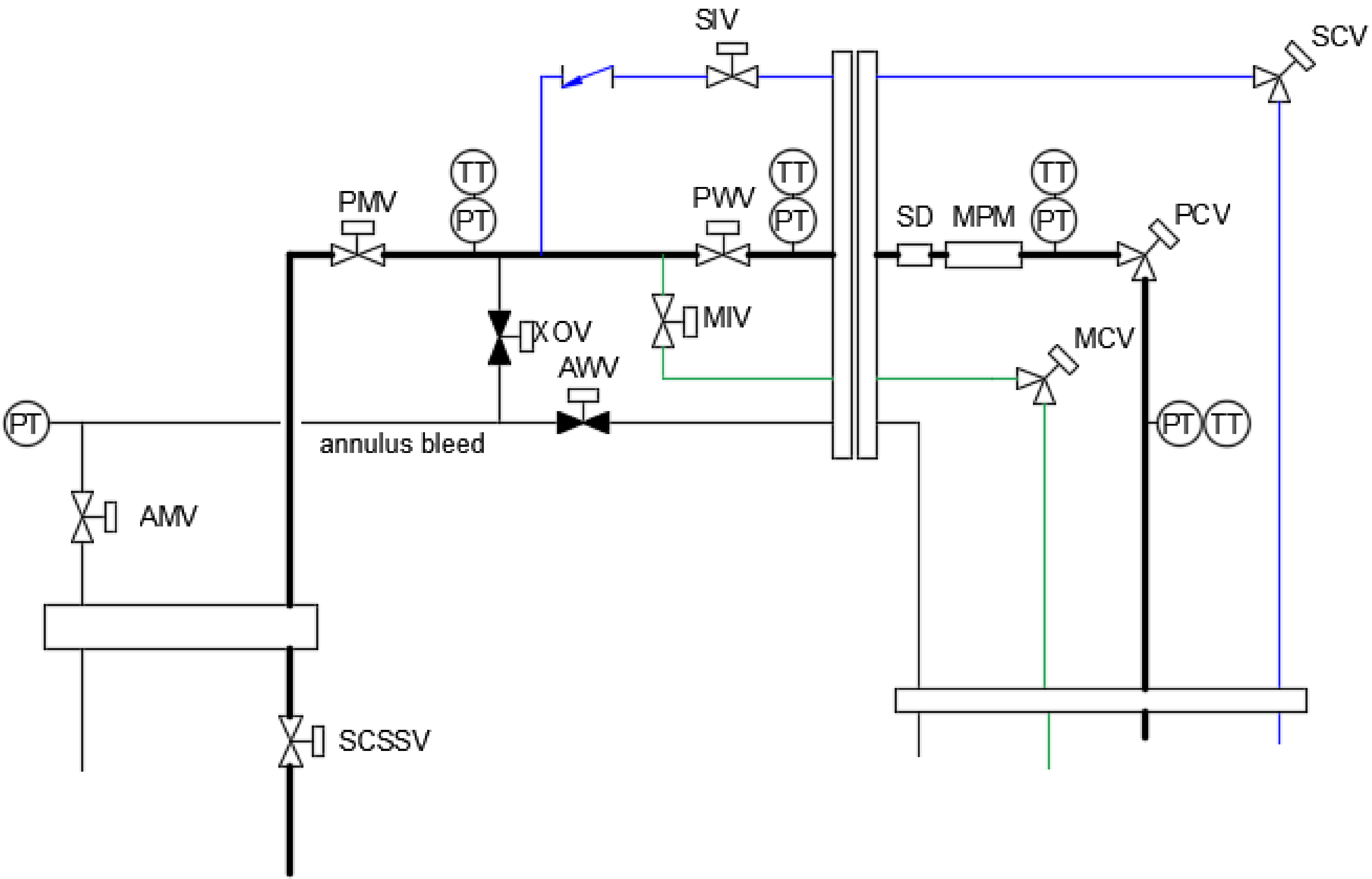

X-mas tree template
TT
PT
PWV
TT
PT
PCV
PMV
MIV
Well
stream
MCV
Manifold Template
Routing
valve
X-mas tree template
Subsea distribution unit
SUBSEA
Topside (FPSO)
Prod sep
q_g
q_o
q_w
q_g
q_o
q_w
PMV Production master valve
PWV Production wing valve
PCV Production choke valve
PT Pressure transducer
TT Temperature transducer
MIV MeOH injection valve
MCV MeOH choke valve
UMBILICAL
From Methanol
pumping system

Injection of production chemicals – template wells



Injection of production chemicals – template wells

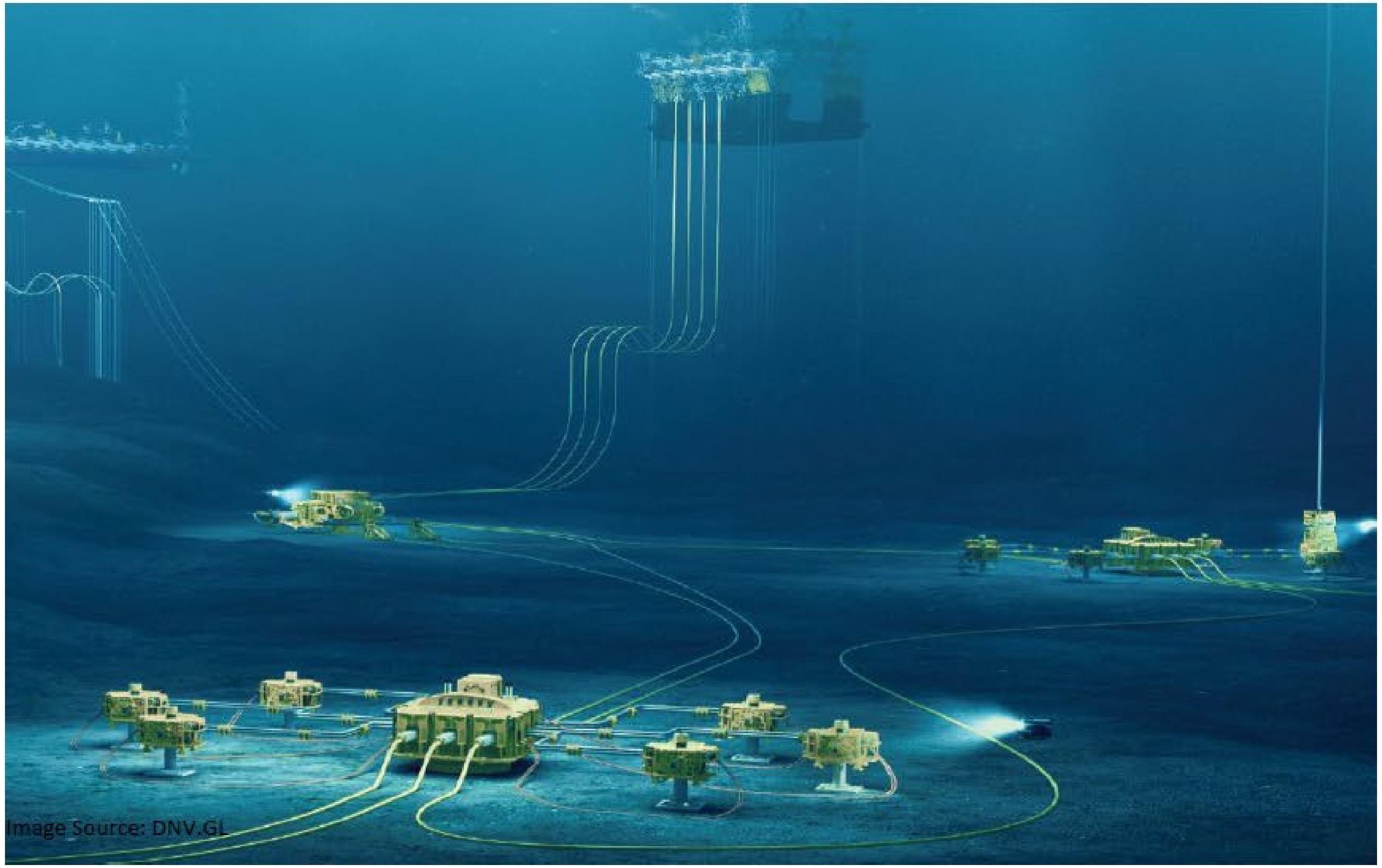


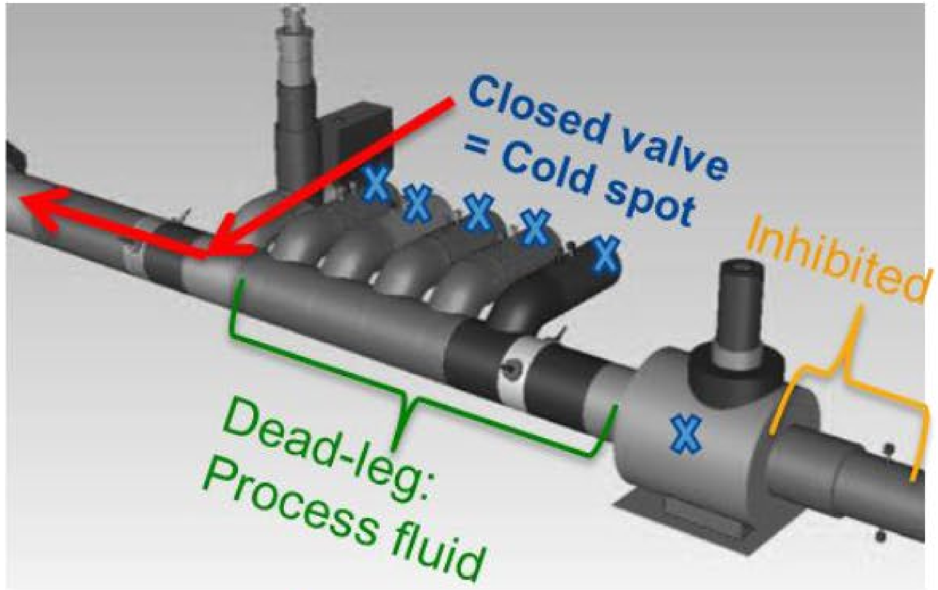

SIV
SCV
PMV
TT
PT
PWV
TT
PT
SD
MPM
TT
PT
PCV
XOV
MIV
MCV
AWV
PT
annulus bleed
PT
TT
AMV
SCSSV

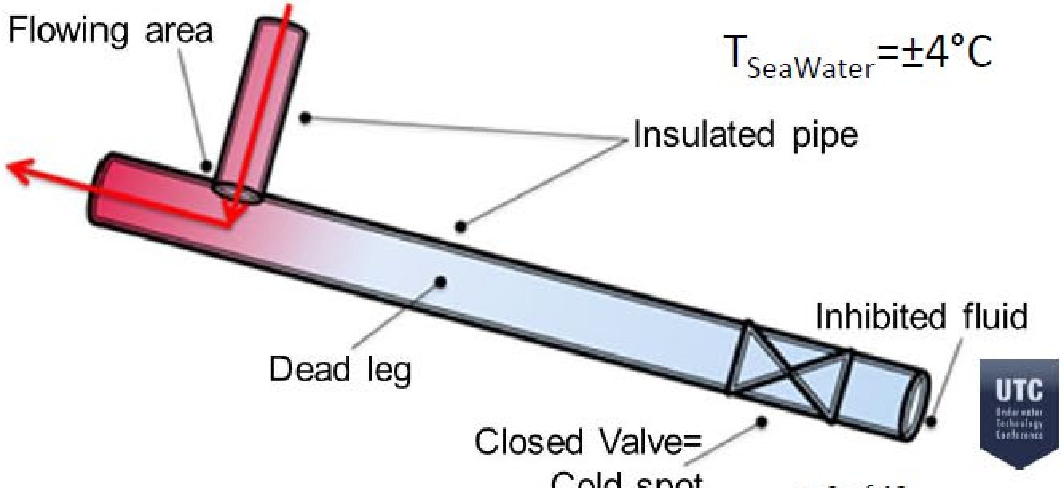
Injection of production chemicals in well

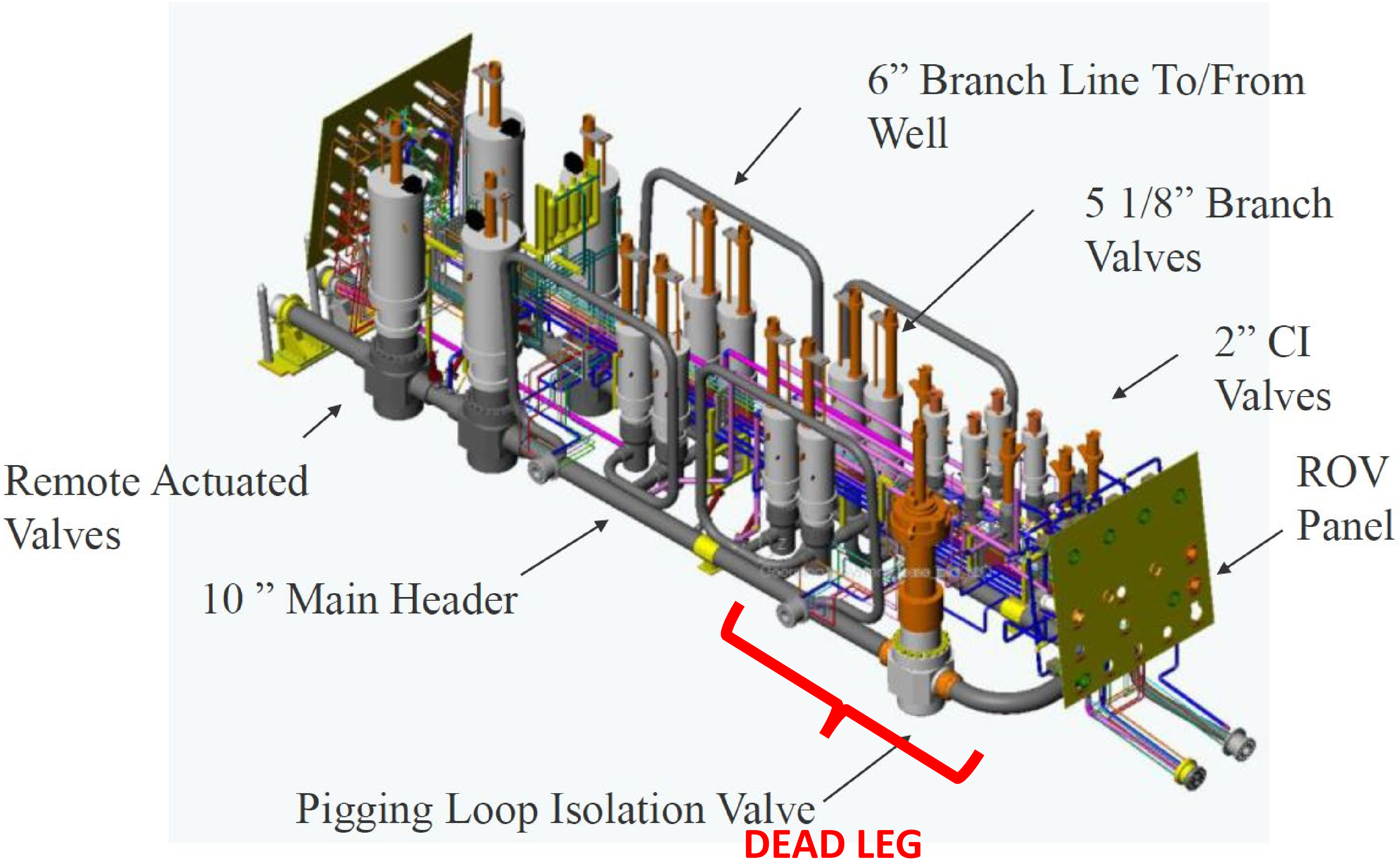
Subsea manifold and dead-leg geometry

- Dead-legs are inherently present

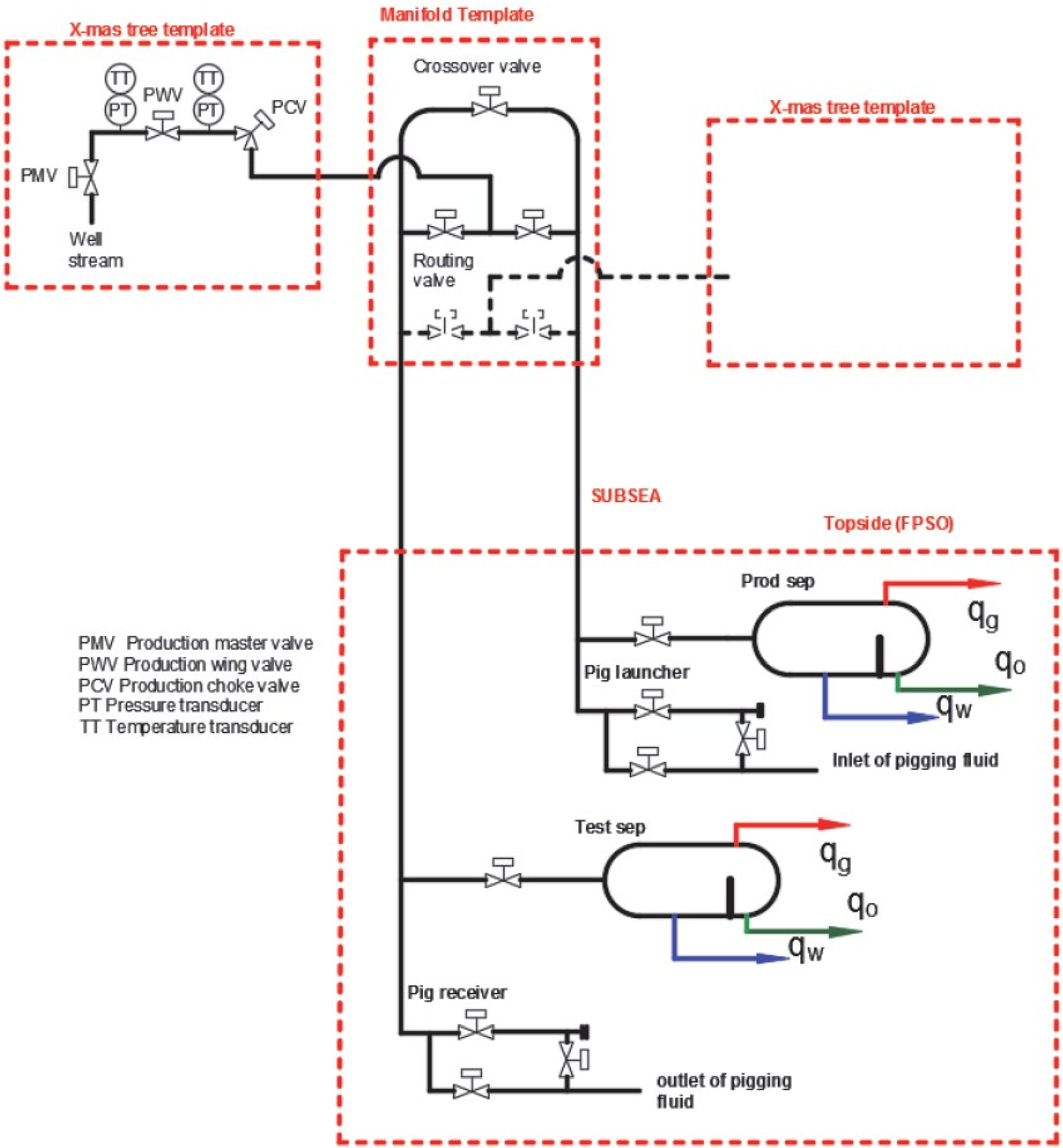






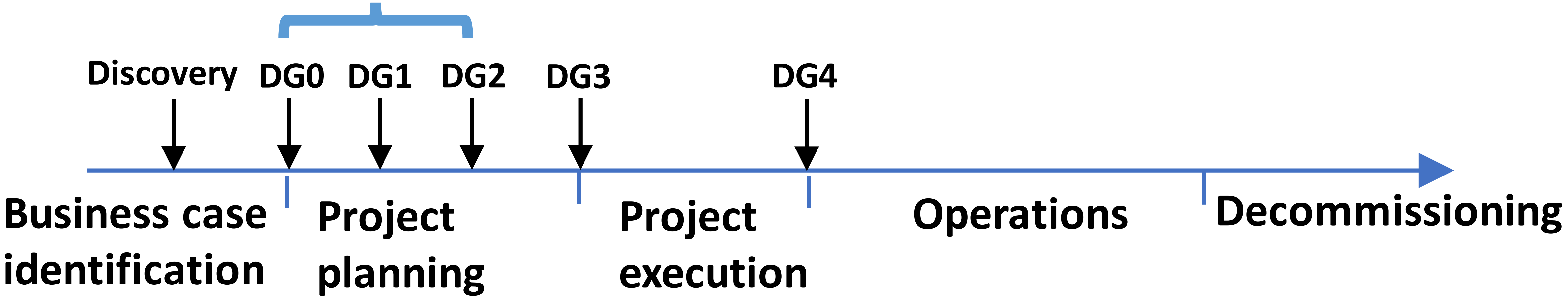

6" Branch Line To/From Well
5 1/8" Branch Valves
2" CI Valves
ROV Panel
Remote Actuated Valves
10 " Main Header
Pigging Loop Isolation Valve
DEAD LEG

Pigging loop



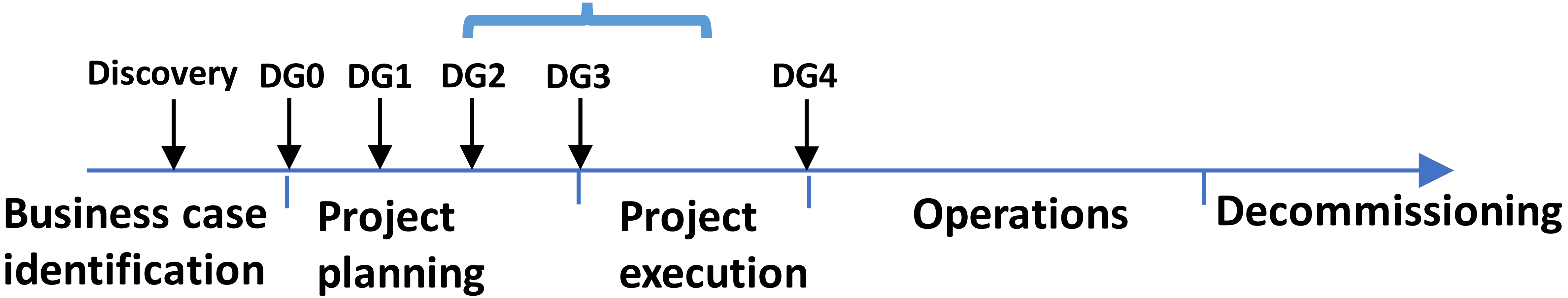
Flow assurance evaluation during field planning

- Detect potential showstoppers and communicate technical constraints and repercussions to field planner
- Laboratory tests



Flow assurance evaluation during field planning

Refine the flow assurance strategy
-More laboratory tests
-Management plan
-prediction of p and T
-Study of startup and shutdown
-System design and verification
-FIV



Tools for analysis

- Laboratory tests of fluids (oil, gas, water)
- Steady state flow simulators (Hysys, Gap, Pipesim, Olga, Leda, FlowManager)
- Transient flow simulators (Olga, LedaFlow, FlowManager, Hysys)
- Thermodynamic or PVT simulators (PVTsim, Hysys)
- Standards (DNV, API)
- CFD simulation for 3D flow analysis of pressure and temperature (Comsol, Ansys)
- Finite element analysis for structural analysis and heat transfer in solids (Abacus, Ansys)