High Pressure High Temperature Multiphase Subsea Cooling - A Cost Reducer for Greenfields, an Enabler for Brownfields

Mattias Gillis Winge Rudh
FMC Technologies
Subsea Coolers

Surrounding sea acts as heat sink

**Cooling Spool (Passive)**
- Mature Technology, first installation 1995 East Spar Development
- Typical U-value 400-700 W/m²K

**Manifold Cooler (Passive)**
- New technology, first installed 2014, Åsgard
- Typical U-value 600-900 W/m²K

**Active Cooler**
- Emerging Technology
- Typical U-value 900-1500 W/m²K
Cooler Equipment

Passive Cooler
- No moving parts
- Robust
- Pipe

Active Cooler
- Active transport of sea water (pumping)
- Control System
- Shell & Tube

Cooling Loop
Manifold Cooler
Qualification Specimen from the Åsgard Cooler TQP
Cooler Operation

Passive Cooler

An external flow of sea water is generated by the hot pipes.

From S. Grafsrønningen, PhD Dissertation 2012
Msi Kenny Cooling Spool

Active Cooler

An external flow of cooling fluid (sea water) is generated by a pump.
Subsea Cooler Applications

Enabling lower temperature rated equipment

Gas / Liquid Separation

Subsea Gas Compression

Multiphase Production

HPHT

HT

Choke

XT

Cooler

Subsea Flow Line

T

Gas

Liquid

Compressor
Subsea Gas Dehydration

- 2 Stage separation with in-between cooling to maximize liquid removal
- Gas dehydration (topside glycol regeneration).
- Cooling only on gas stream - > more efficient cooling design.
- Subsea gas export quality
Temperature Effect on Subsea Equipment Design

Corrosion Rate

Uninhibited Well Stream Carbons Steel Corrosion Rate vs Temperature

- High Corrosion Rate
- Low Corrosion Rate

Conditions:
- $P=40$ bar, $P_{CO2}=2.7$ bar, $ID=800$mm, $Q_G=6843$ Am$^3$/h, $Q_L=130$ m$^3$/h

Cathodic Protection

Current Capacity Effect of Temperature


Material De-Rating

- High temperature
- Low temperature

Hydrate Formation

Typical Hydrate Equilibrium Curve

«Equilibrium between hydrate formation and dissociation»

$4CH_4 + 23H_2O \leftrightarrow 4CH_4\cdot23H_2O$

Kinetics of Hydrate Formation

Some Literature Data
Lv, X. F et al Oil and Gas Science and Technology 2015

High Pressure Flow Loop
Induction Time $0.5 – 3 \text{ hrs}$


High pressure reactor
Induction Time $1 – 50 \text{ h}$

Induction Time in a real system?

Difficult to say
Predictive model fair,
Experimental testing required,
however for a real subsea system
the time scale is probably >>
residence time in any subsea cooler!
Wax

- Wax forms when a phase change occurs in long chained hydrocarbons.
- Complex mechanism dependent on composition
- Small «contaminants» can have significant impact on the WAT
- Predictive models generally poor, laboratory tests required.
- High cooling rate leads to lower wax yield strength.
Green Field - Case Study #1 – Hot Transport

Development of a Gas Condensate HPHT well
- Generic Gas Condensate Composition
- P=700 bar, T=200°C
- 1000m water depth
- 5km subsea tie back to host

Reducing the temperature upstream the choke enables lower temperature rated choke.

Insulated flowline
Green Field - Case Study #2 – Cold Transport

What is most cost effective, continuous MEG injection or insulation?

- MEG injection upstream cooler
- No insulation, cold transport

**HPHT Well**
- \( T = 200°C \) (392°F)
- \( P = 700 \text{ bar} \) (10152 psi)

**XT**
- \( T = 31°C \) (86°F)
- \( P = 700 \text{ bar} \) (10152 psi)

Subsea Flowline
- 5km

Riser
- 1000m

**MEG**

**Choke**

**Cooler**

**HIPPS**

**Case #2 – Cold Transport**

**Cold Transport**

**MEG vs Insulation cost**

- Insulation
- MEG
Green Field - Case Study #3 – G/L Sep

- MEG injection upstream cooler
- Separating liquid and gas at ambient conditions
- Cold transport of liquid and gas
- Dedicated liquid and gas transport pipe
- No further condensation will occur in the gas line
Comparison – Temperate Effects

The corrosion rate is dependent on the temperature, the CO₂ content, wall shear stress and whether the system is saturated by FeCO₃ and/or the presence of corrosion inhibitors.

The effect of adding MEG in Case II and III are incorporated in the corrosion rate calculation.

Case I gives the highest corrosion rate.

By using a higher design temperature the strength of the material needs to be de-rated = thicker pipe walls required for Case I.

CP design for Case I would require approximately 3 times as large anode mass as for Case II and III compared to Case I.
Cooler Opportunities

Case Comparison
When the temperature decrease, the gas volume is reduced and some components condensate. This leads to less frictional pressure drop or a possible increased production while maintaining the same pressure drop.

- **Case I - Hot**
  - \( \Delta P, ID = \text{Const} \)

- **Case II - Cold**
  - \( \Delta P, ID = \text{Const} \)

- **Case III – Cold G/L Sep**
  - \( \Delta P, ID = \text{Const} \)

![Graph](image-url)
Summary

- Subsea Cooling enables the use of low(er) temperature rated downstream equipment.
- Subsea Cooling enhance G/L separation.
- Subsea Cooling enables subsea compression.
- Subsea Cooling enhance gas dehydration.
- A low(er) design temperature is favorable for the hardware design.

Favorable for:
- Hydrate and Wax inhibition

Favorable for:
- Corrosion, Mechanical strength, thermal stress, CP system, marine growth, scaling and production.