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Welcome!

The program will begin soon.

You will not hear audio until we begin.

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Intelligent Hydrate Management (IHM)

Confining Hydrate Blockages to History

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Intelligent Hydrate Management (IHM)

What are the aims/objectives?

- Avoid hydrate formation altogether
- Alternatively, accept some hydrate formation while avoiding hydrate blockage
- Minimise inhibitor usage
- Reduce/eliminate the effect on the environment
- Thermal calculation
- Possibility of transporting as slurries
- Monitors hydrate dissociation
- Developing an integrated monitoring systems
- Developing IIoT (Industrial Internet of Things)

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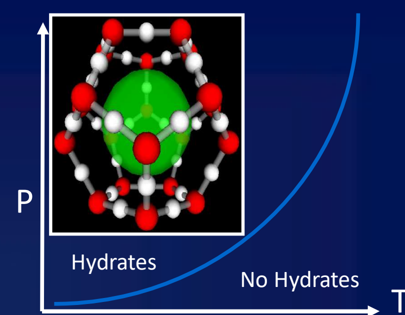
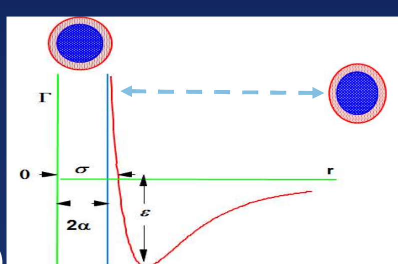
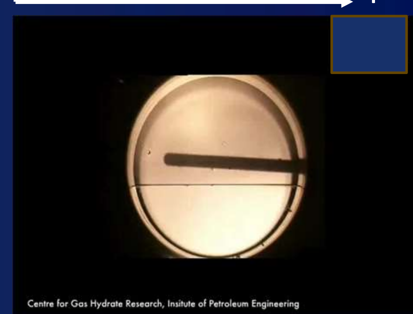
Conditions for Hydrate Formation

- The necessary conditions:
  - Presence of water or ice
  - Suitably sized gas/liquid molecules (such as C_1, C_2, C_3, C_4, CO_2, N_2, H_2S, etc.)
  - Suitable temperature and pressure conditions
- The temperature and pressure conditions are a function of **hydrocarbon and aqueous compositions**.



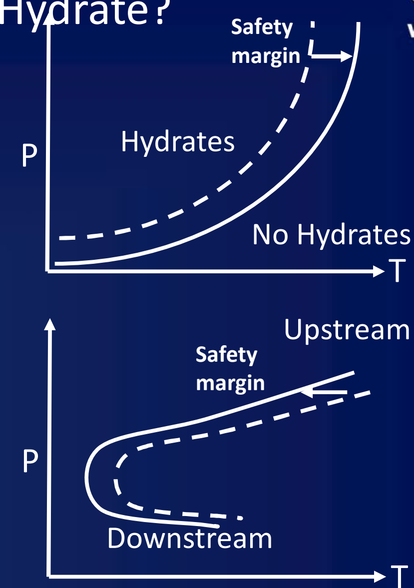


Kihara potential for attraction between molecules



How to Evaluate Risk of Hydrate?

- Determine **hydrate phase boundary**
  - Hydrocarbon composition does not change significantly
  - However, aqueous phase composition may change
- Determine **pipeline conditions**, using
  - Modelling,
  - Pressure and temperature gauges
  - Or the worst condition
- **Adding a safety margin** by
  - Shifting the Hydrate Curve to the right,
  - Or by shifting the pipeline condition to left
- **Superimpose the two figures**



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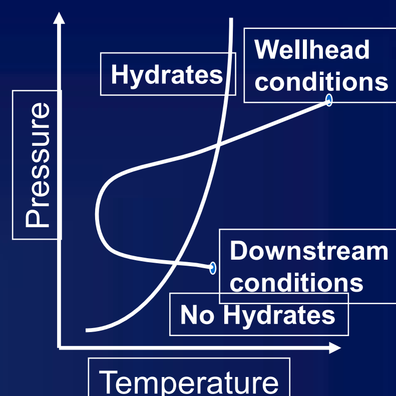
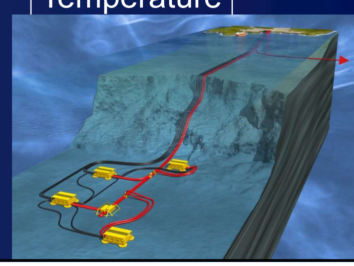
Avoiding Hydrate Problems

- Water removal (De-Hydration)
- Controlling the system temperature
  - Insulation
  - Heating
- Reducing the system pressure
  - Not normally used, removal of hydrate blockage
- Injection of thermodynamic inhibitors
  - Methanol, ethanol, glycols, etc.
- Using Low Dosage Hydrate Inhibitors
  - Kinetic hydrate inhibitors (KHI)
  - Anti-Agglomerants (AA)
- Cold Flow
- Various combinations of the above





What Changes Can We Expect?

- Minimum **ambient/pipeline temperature** changes on a **daily and/or seasonal** basis
- **Reservoir pressure reduction**, changes in **pipeline pressure, and/or residence time**
- **Water cut changes**, which could affect inhibitor concentration
- **Formation water,** can be produced, the effect of the rate
- Changes in **inhibitor partitioning** in various phases
- Inhibitor injection **pump malfunction**
- **Human error**
- **Off-spec** inhibitor
- etc.

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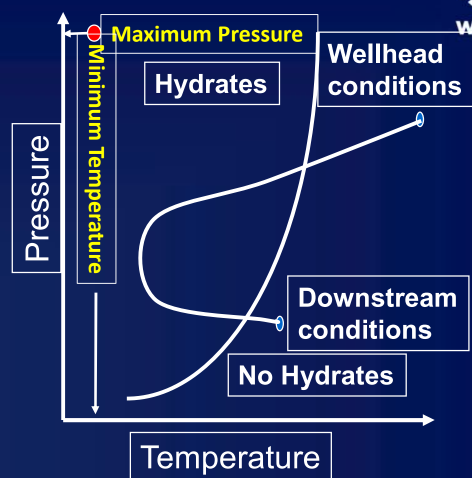
Industrial Practice

- In general, there are **no changes** in inhibitor injector rate
- Design of inhibitor is also based:
  - **Minimum** temperature and maximum **pressure**
  - Maximum **residence time**
- Sometimes **an extra 10-30** wt% for potential bad mixing
- Normally **too much** inhibitor
- Still hydrate **blockage happens**



- Too much inhibitor could result in **other problems**, like **salt deposition/plug**

More Realistic

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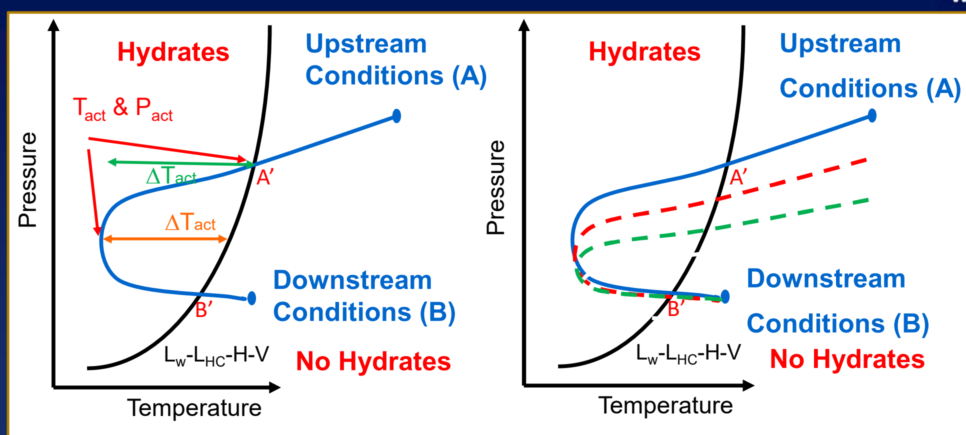

The actual Residence Time (RT) is the time required for travelling from Point-A' to Point-B', under actual subcooling.

The actual P (perhaps T and RT) changes with the age of reservoir.

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Intelligent Hydrate Management (IHM)

Confining hydrate blockages to history

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- **What is it?**
  - **Minimize/eliminate** the chemicals while reducing the **risk of hydrate blockage**
  - Reducing **carbon footprint** and a step toward **zero-emission**
- **How is it possible?**
  - Monitoring the **hydrate safety margin**
  - Detect **early signs of hydrate formation**, providing early warning against hydrate blockage

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How to Determine Hydrate Safety Margin?

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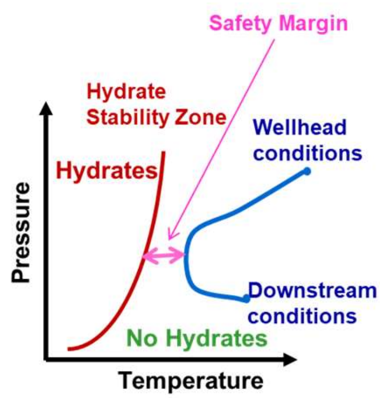
- Hydrate Safety Margin can be determined by comparing "Pipeline Condition" to "Hydrate Stability Zone"
- How to Determine Hydrate Stability Zone?
  - Composition of hydrocarbon phase
  - Hydrate inhibitor in the aqueous phase
    - <u>Salt</u>
    - <u>Chemical hydrate inhibitors</u>
  - Pressure and temperature profile and/or the worst operation conditions
    - Computer simulation and/or P & T sensors



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Intelligent Hydrate Management (IHM)

Confining hydrate blockages to history

- **Extra safety factors**
  - **Transportability of hydrate slurry** in the unlikely event of hydrate formation to assess the risk of blockage
  - Effect of **heat transfer** in hydrate formation/melting
  - **Monitoring the pressure and temperature** of the system and providing necessary actions to minimise the risk
  - Developing database and **machine learning** systems
- In the unlikely event of hydrate blockage
  - **Develop/improve remediation techniques** and apply them ASAP, as hydrate blockage gets harder with time

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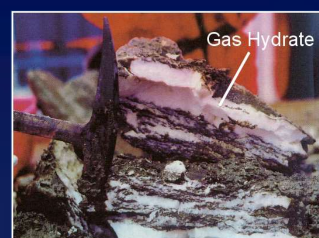
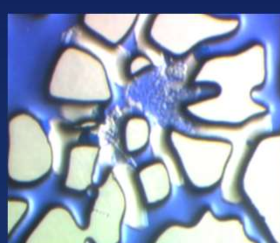
Blockage Removal

- Hydrate blockage in pipelines is initially porous and permeable, unlike in-situ hydrates
- During their formation, some free water has been trapped among hydrate crystals
- Mass transfer (guest, salt, inhibitor) and heat transfer (heat of hydrate) required for further hydrate formation





t=31 hrs, P=54.9 bar, T=3.4 ºC

t=94 hrs, P=53.0 bar, T=3.2 ºC

t=142 hrs, P=52.1 bar, T=3.2 ºC

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Why Intelligent Hydrate Management?

- Minimize/eliminate hydrate inhibitors
  - To protect the **environment** (Chemicals and CO_2)
  - Reduce/eliminate the CAPEX and OPEX
    - Improve the **economy** by reducing/eliminating chemicals
    - Reduce/eliminate the **costs** of produced water treatment
    - Reduce/eliminate the direct/indirect **costs** of blockage
- The outcome?
  - More economical, more **environmentally friendly**, and more reliable operation
  - A move toward **automation and IIoT** (Industrial Internet of Things)

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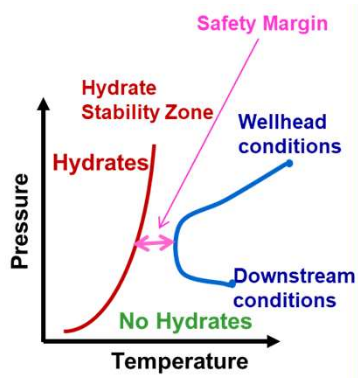
How to Determine Hydrate Safety Margin?

- How to Determine Hydrate Stability Zone?
  - Composition of hydrocarbon phase (does not change in a short period of time)
  - Hydrate inhibitor in the aqueous phase
    - Salt
    - Chemical hydrate inhibitors
    - This can change quickly, sending to a lab (but it could take 12-24 hours)
  - Pressure and temperature profile and/or the worst operation conditions
    - Computer simulation and/or P & T sensors
  - So, there is a need for developing a device that can measure the composition of the aqueous phase quickly



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Monitoring Hydrate Safety Margin

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- How is it possible?
  - We have developed a device that measures the composition of the aqueous phase in **5 seconds**
  - Knowing the hydrocarbon phase, we can determine the hydrate phase boundary
  - Knowing the pipeline P&T condition, we can determine the **hydrate safety margin**
- The device has been deployed across the Globe with excellent results, played a major role in Heriot-Watt University winning the Queen Anniversary Award in 2015 (www.youtube.com/watch?v=70s_Uz_3rYM)
- Some of the case studies:
  - NUGGETS in the North Sea, extending the production for **extra 5 years**, reducing Methanol from 28 wt% to zero, more than £150 million extra production
  - Another company in Central Asia, saving more than **$400 k/year** in chemical costs, with no blockage since this device

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Determining Inhibitor Concentration (Hydrate Safety Margin)

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Produced water sample analyser

C → *V* → *T* → Computer Programme → Salt, KHI, & inhibitor (MEG, MeOH…), concentration

- Measuring electrical conductivity (C) and acoustic velocity (V) in the produced water
- Temperature is also measured to account for its effect
- The measured parameters are fed into a Computer Programme which in turn gives salt, KHI and organic inhibitor concentrations within few seconds (https://youtu.be/qhIM3zqRJRY)

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Potential Implementation of the Device

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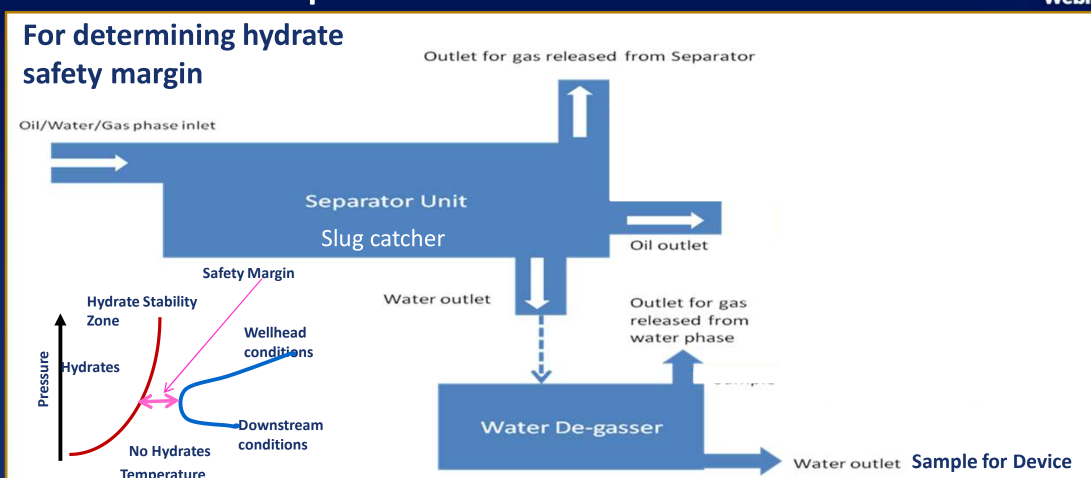

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Detecting Early Signs of Hydrates

- How is it possible?
  - A device has been developed that detects **early signs of hydrate formation** by analyzing the gas phase
  - As the **gas phase is the fastest-moving phase**, the detection is very quick
  - It can also **estimate the location of hydrate** formation
- The device has been field-trialed and was able to detect hydrate formation in a very high gas/liquid (14,000 vol/vol) system
- The results seemed to show that AA was only necessary 10 days in the year. This could have resulted in significant savings and a reduction in chemical usage

Philippe Glénat, Jean-Michel Munoz, Reza Haghi, Bahman Tohidi, Saeid Mazloum and Jinhai Yang, "FIELD TEST RESULTS OF MONITORING HYDRATES FORMATION BY GAS COMPOSITION CHANGES DURING GAS/CONDENSATE PRODUCTION WITH AA-LDHI", *Proceedings of the 8th International Conference on Gas Hydrates (ICGH8-2014), Beijing, China, 28 July - 1 August, 2014*

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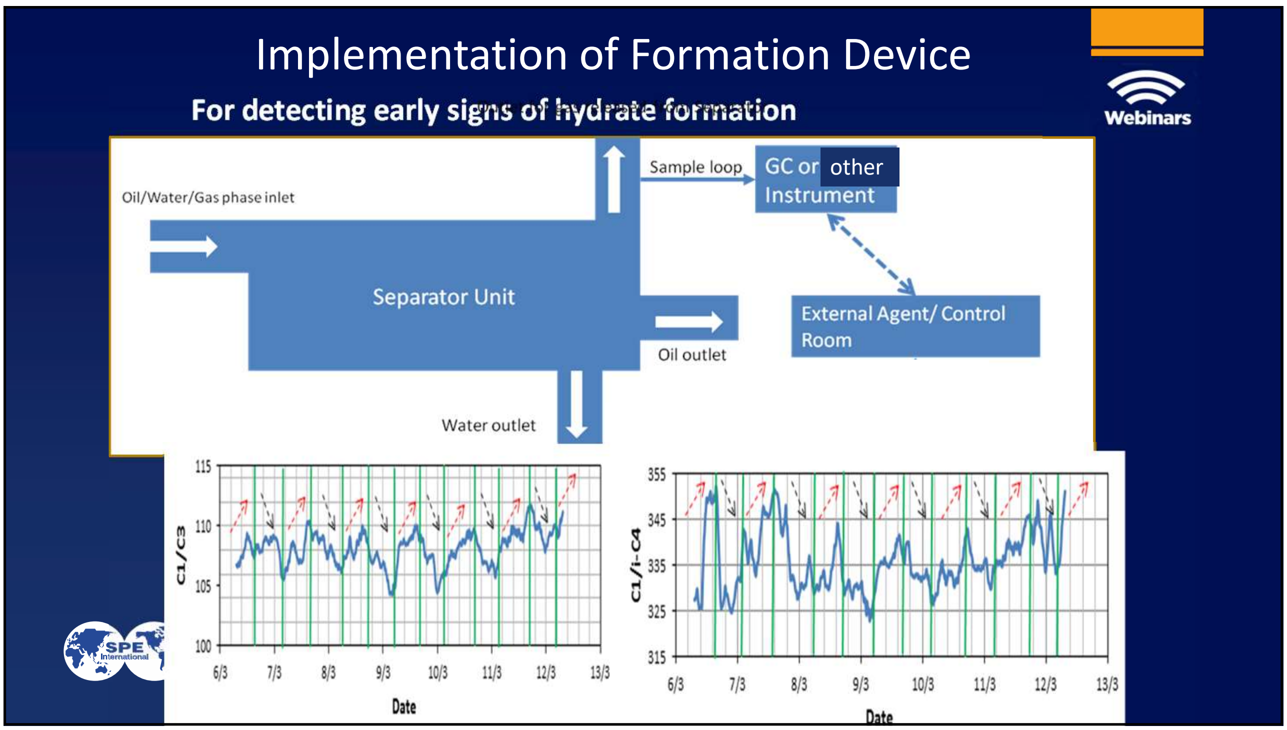
Implementation of Formation Device
For detecting early signs of hydrate formation
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Sample loop
GC or other Instrument
Oil/Water/Gas phase inlet
Separator Unit
External Agent/ Control Room
Oil outlet
Water outlet
C1/C3
115
110
105
100
6/3
7/3
8/3
9/3
10/3
11/3
12/3
13/3
Date
C1/i-C4
355
345
335
325
315
Date

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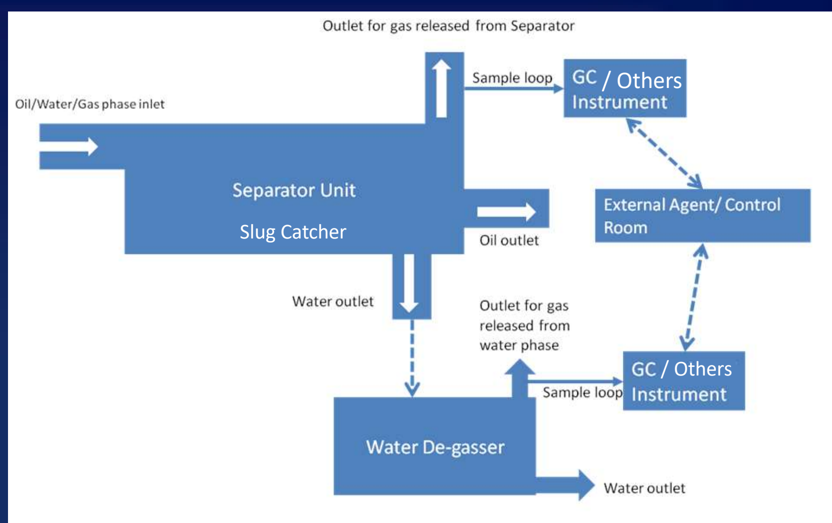
Hydrate Detection Device & Location of Hydrates

Estimating the location of hydrate formation

Knowing the slip velocity (i.e., velocity difference between gas and water phases) is it possible to estimate the location of hydrate formation.



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Integrating the two Devices

- **Combining Safety Margin with Hydrate Formation Detections** will provide a very powerful device to avoid hydrate blockage and minimize chemical injection requirements.
- As the first one detects the **hydrate safety margin**, we can get **as close as we wish to the hydrate phase boundary**.
- If there is an error (or sudden changes in the system), the second one will detect **early signs of hydrate** formation, avoiding hydrate blockage.

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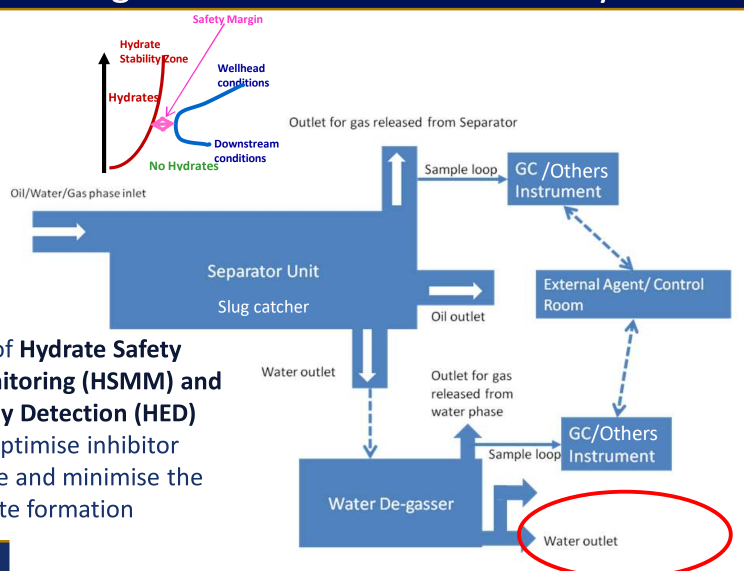
Integration of HSMM and HED Systems



Integration of **Hydrate Safety Margin Monitoring (HSMM) and Hydrate Early Detection (HED)** systems to optimise inhibitor injection rate and minimise the risk of hydrate formation

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Develop/Improve Remediation Techniques

- In the **very unlikely case of hydrate blockage**, we need to have procedures to remove blockage ASAP, as;
  - Initial hydrates are porous but will become harder over time
  - Pressure reduction is likely to be the most efficient technique
  - Another option could be inhibitor injection, in particular when we know the location and rate of hydrate
- **Successful dissociation of hydrates** can be detected by the Device
- The other device can give an estimation of the amount of water that has been converted into hydrate
- Thermal calculations can **estimate the rate of hydrate dissociation**, hence the time required for partial or complete dissociation

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Conclusions

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- It is believed the technology for addressing any **hydrate problem** is available while reducing the **costs**, reducing/eliminating **environmental effects**, and a step toward **Net-Zero**
- The above is possible with
  - **New equipment** (HSM and DEH)
  - Advances in **software**
  - Better understanding of the effect of **heat transfer**
  - **Rheology of hydrate slurries**
- Basically, all major elements of this system have been **tested individually**

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Conclusions

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- The final product will be able to **minimize the inhibitor** injection rate while **increasing the reliability** of hydrate blockage strategies, and **protecting the assets and environment**
- The **reduced inhibitor** injection rate, **avoiding hydrate blockage**, removing the costs associated with remedial actions, depressurization, extra chemicals, delayed production, damage to equipment, flaring, injury, etc.,
- These are major steps toward **Net-Zero emission**

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Acknowledgements

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- I would like to take the opportunity and thank all our sponsors and colleagues
- Also, my thanks to the SPE Webinar Series for their invitations
- Finally for your attention

Q & A

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Trials and Publications

- High concentration of MEG by Statoil (Trondheim, Norway)
- KHI systems by Dolphin Energy (Total) in Qatar[1]
- MeOH + salt systems by Petronas in their FPSO lab (Mauritania)
- MEG + salt systems by NIGC (South Pars Gas Complex (SPGC) Field)[2]
- Methanol + salt, Total, Alwyn, North Sea[3]
- Methanol + salt, Woodgroup (Triton FPSO), and Shell (Shearwater) North Sea[4]
- Salt + Inhibitor, ConocoPhillips, North Sea
- Salt + MEG, Petronas (Turkmenistan), and Cameron (Pilot Plant, University of Manchester)
- KHI systems, Champion Technologies
- Salt + Methanol, NUGGETS, North Sea[5]

1. Lavallie, O., et al., *Successful Field Application of an Inhibitor Concentration Detection System in Optimising the Kinetic Hydrate Inhibitor (KHI) Injection Rates and Reducing the Risks Associated with Hydrate Blockage*, IPTC 13765, International Petroleum Technology Conference held in Doha, Qatar, 7–9 Dec 2009.
2. Bonyad, H., et al., *Field Evaluation of A Hydrate Inhibition Monitoring System*. Presented at the 10th Offshore Mediterranean Conference (OMC), Ravenna, Italy, 23-25 Mar 2011.
3. Macpherson, C., et al., *Successful Deployment of a Novel Hydrate Inhibition Monitoring System in a North Sea Gas Field*. Presented at the 23rd International Oil Field Chemistry Symposium, 18 – 21. Mar 2012, Geilo, Norway.
4. Henderson, S., Smith, A., Mazloum, S., Tohidi, B., “Methanol Partitioning and Optimisation Study Using an Innovative Hydrate Inhibitor Monitoring Technology”, ICGH9, June 2017, Denver, USA
5. Saha, P., Parsa, A. Abolarin, J. “NUGGETS Gas Field - Pushing the Operational Barriers”, SPE 166596, at the SPE Offshore Europe Oil and Gas Conference and Exhibition held in Aberdeen, UK, 3–6 September 2013.

Other Potential Applications

- Monitoring LDHI concentration in produced/disposed water
- Detecting formation water breakthrough
- Determining water production rate by measuring inhibitor concentration in the aqueous phase (assuming inhibitor injection rate is known)
- Monitoring efficiency of processes with monitoring concentrations in the aqueous phase (e.g., MEG regeneration)
- Monitoring quality of chemicals (e.g., fluids introduced into umbilicals)
- **Integration with Multi-Phase Flow Meters (MPFM) could potentially improve the flow measurements in MPFM**
- Could potentially be used for detecting hydrate formation (sudden change in the concentration of salts and/or inhibitors)

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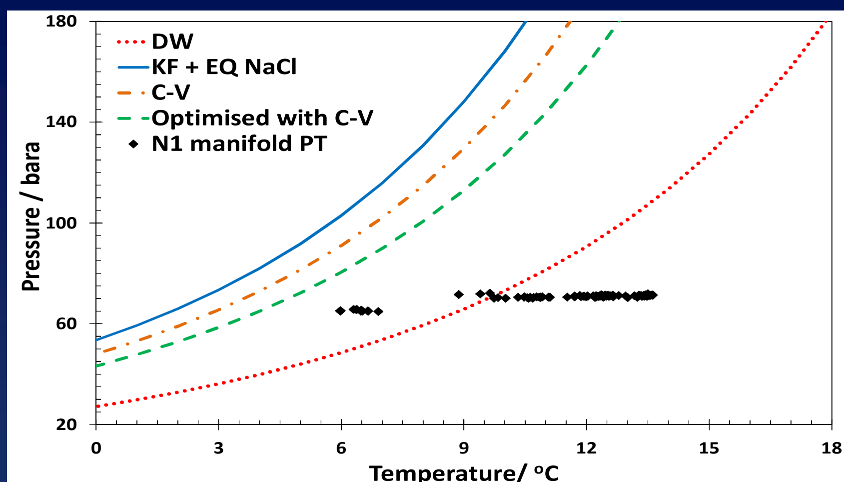
Hydrate Phase Boundary



- Methanol injection was reduced to less than 5 wt% from designed 28 wt%, savings in the order of millions of GBP per year
- See http://hydrafact.com/technology_hydrachek.html for the full paper

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Minimising Methanol Injection

- In 2010 the water production rate reached its maximum
- On the other hand, methanol was causing product contamination
- Methanol injection was reduced to practically zero
  - Methanol is being used only as a carrier fluid for corrosion inhibitor
- The system was operated inside the Hydrate Stability Zone
  - Hydrate Slurry Transport (setting an upper limit of 10%)
  - Salinity increase was used as a measure for monitoring hydrate formation and concentration of hydrates in the slurry

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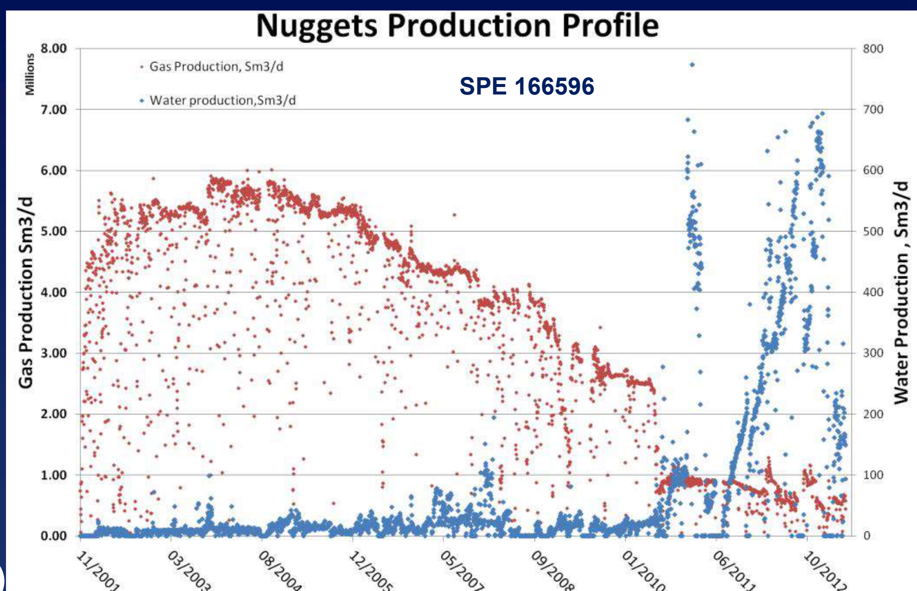
Field Production Profile



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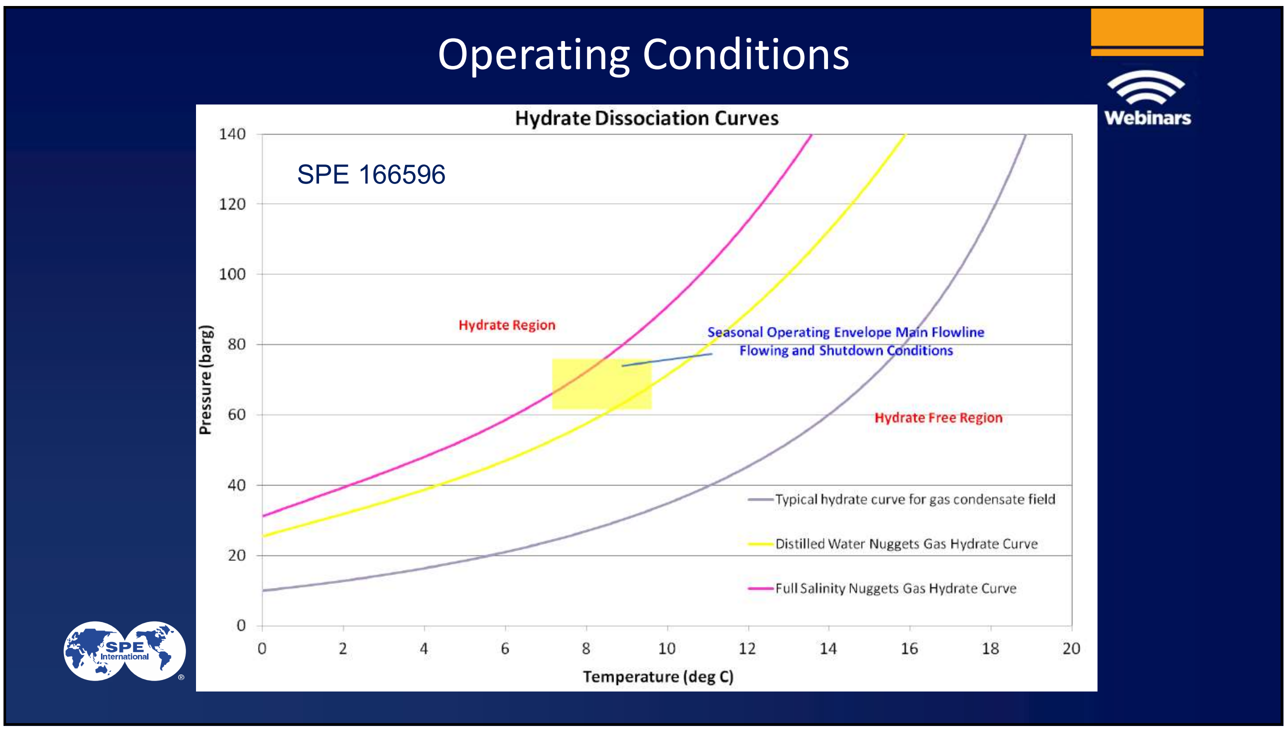

Operating Conditions
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Hydrate Dissociation Curves
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Hydrate Region
Seasonal Operating Envelope Main Flowline
Flowing and Shutdown Conditions
Hydrate Free Region
Typical hydrate curve for gas condensate field
Distilled Water Nuggets Gas Hydrate Curve
Full Salinity Nuggets Gas Hydrate Curve
Pressure (barg)
Temperature (deg C)
0
20
40
60
80
100
120
140
0
2
4
6
8
10
12
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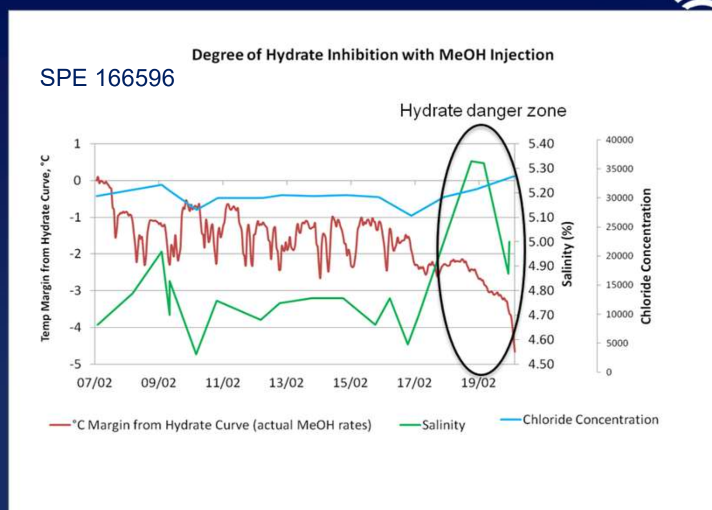
Minimising Methanol Injection

Monitoring change in salinity was used for determining the concentration of hydrates in the slurry, while operating inside the hydrate stability zone



24-48 hours advanced warning prior to blockage

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Summary/Conclusions

- A robust and quick technique based on measuring electrical conductivity and acoustic velocity has been developed for determining concentration of salts and hydrate inhibitors in an aqueous phase
- The technique has been tested extensively (in various laboratories and fields)
- A technique based on measuring the amount of water in the gas phase has been developed
- **Extra safety measure against changes in the system, etc.**

Online Device
440 kg analyzer (840 kg with packing),
255x135x255 cm (WxDxH)

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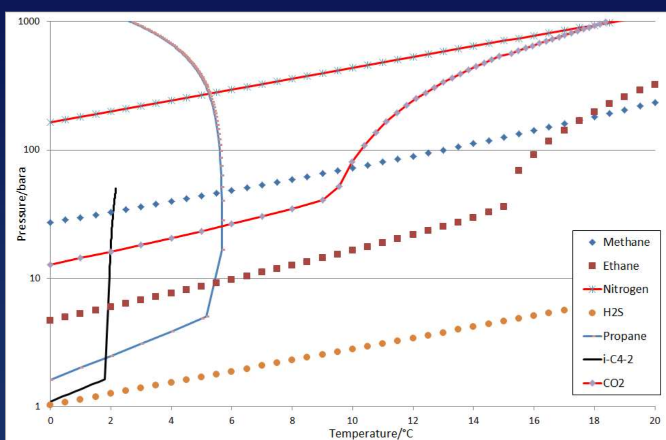
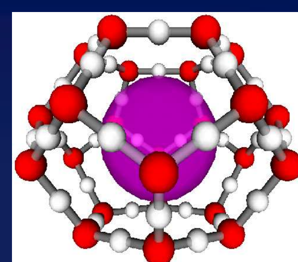
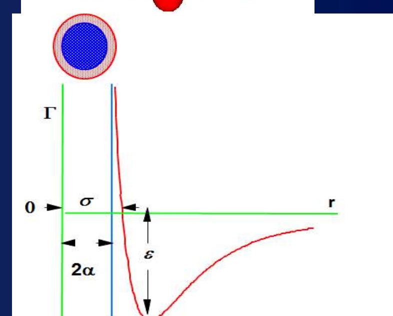
Detecting Early Signs of Hydrate Formation

- Hydrates prefer large and round molecules (e.g., C_3 and i-C_4 in sII hydrates) in their structures







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Effect of Hydrates on Gas Composition

Predictions by HydraFLASH		Fluid Phases/mole%		Hydrate/mole%	
Component(s)	**Feed**	**Vapour**	**Polar**	**Overall**	**Overall, WFB**
Methane	91.3306	91.3854	0.0571	7.9486	62.4718
Ethane	5.6430	5.6078	0.0057	1.9568	15.3794
Propane	**1.0690**	**1.0144**	**0.0009**	**2.2150**	**17.4087**
i-Butane	**0.1546**	**0.1441**	**0.0000**	**0.4207**	**3.3065**
n-Butane	0.1938	0.1917	0.0001	0.0973	0.7645
i-Pentane	0.0592	0.0594	0.0000	0.0000	0.0000
CO2	0.7819	0.7785	0.0172	0.0698	0.5490
Nitrogen	0.7679	0.7698	0.0000	0.0153	0.1201
WATER		0.0488	99.9189	87.2765	
Amount of water converted to Hydrates					**10.2%**
C1/C3	**85.436**	**90.088**			**3.589**
C1/iC4	**590.659**	**634.180**			**18.894**
Hydrate density (g/cc):	0.944354				
Hydrate mf:	0.020728				
Molar phase fraction		0.797604	0.181668	0.020728	

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Case Study, using Historical Data

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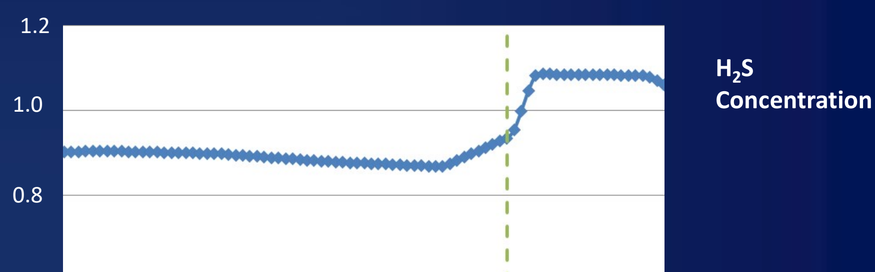
Case Study (Middle East)

- Produced gas from an offshore reservoir is transported to onshore facilities through a subsea pipeline
- Hydrate formation is expected in the pipeline during winter Changes in H_2S concentration can be explained by hydrate formation and dissociation



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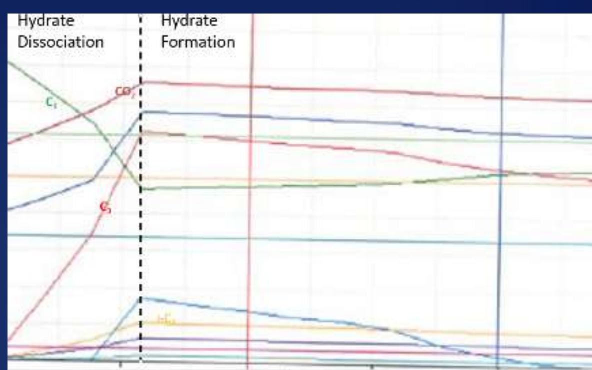
Case Study, using Historical Data

Case Study (Europe)

- A depleted gas reservoir is used for gas storage
- Hydrate formation is causing an interruption in gas supply
- Inhibitor injection is used for removing hydrate blockage
- Gas composition is monitored for fiscal regulations
- Historical data show hydrate dissociation and formation



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