Welcome!

The program will begin soon.

You will not hear audio until we begin.

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Webinars

Hydrates, Operator's Journeys

Doug Turner
Xiaoyun Li
Rogerio Leite

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AN EXPERIENCE-BASED APPROACH TO THE HYDRATE PROBLEM

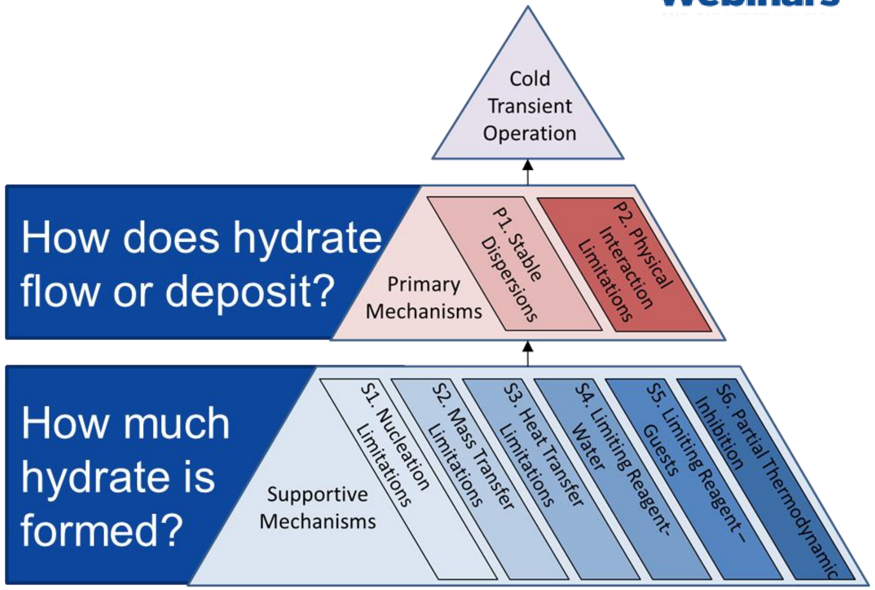
Doug Turner

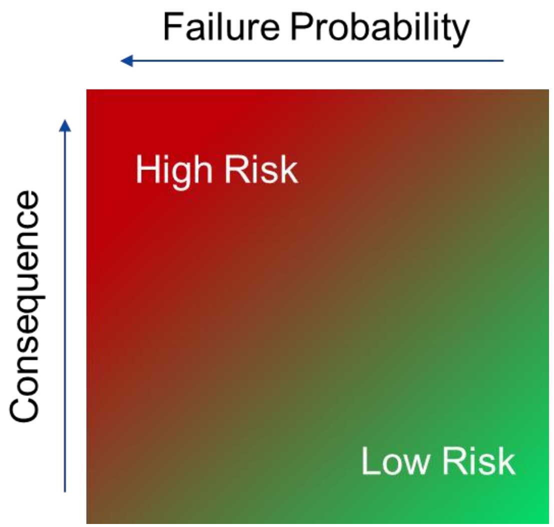
December 14, 2023

Risk-based hydrate management is essential

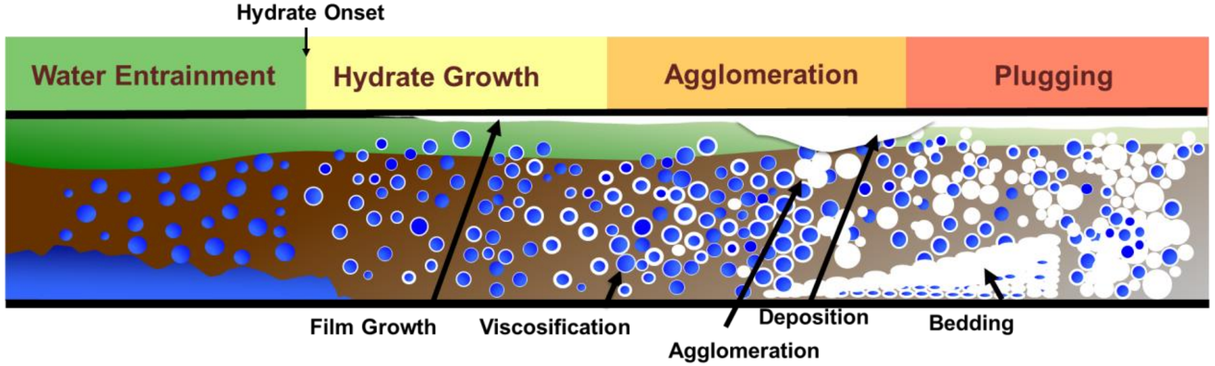
- Traditional approaches can be “project killers”
  - e.g., significant chemical and insulation requirements
  - Unachievable designs
  - Excessive waste and environmental impact
  - Unduly burdensome on operations

- Ignorance is Risk
  - Taking risk-based approaches requires additional knowledge of system behaviors in order to reduce risk
  - Risk is not only the likelihood of a hydrate event, but should consider the impact to the particular asset





Mechanistic Hydrate Modeling – "Knowledge-based" Approach

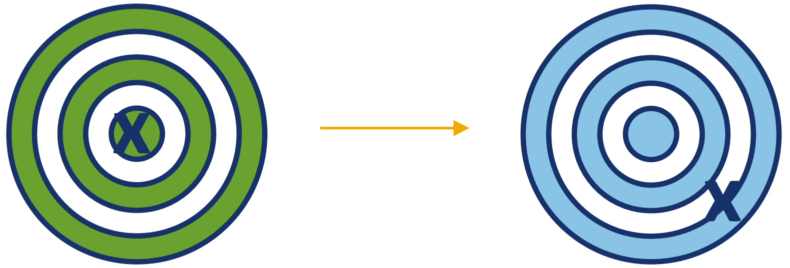


- Important tool for understanding physics and behavior of hydrate-forming systems
- Significant reliance on accuracy of both input data and physical models
- Distributive and statistical conditions result in wide error propagation
  - Droplet sizes
  - Interparticle forces
  - Sloughing
  - Jamming
- Missed physics will lead to poor extrapolation
- Complex model mechanics: increase in model complexity may lead to greater error propagation and less accurate predictions

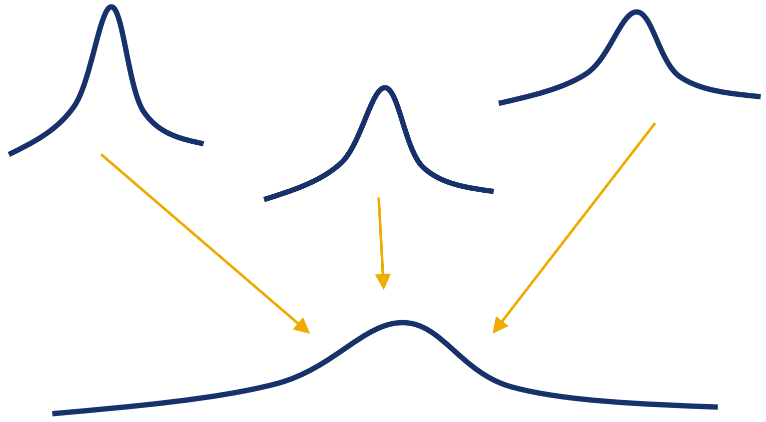
Missing or inaccurate physics

Tuned model

Modeled system

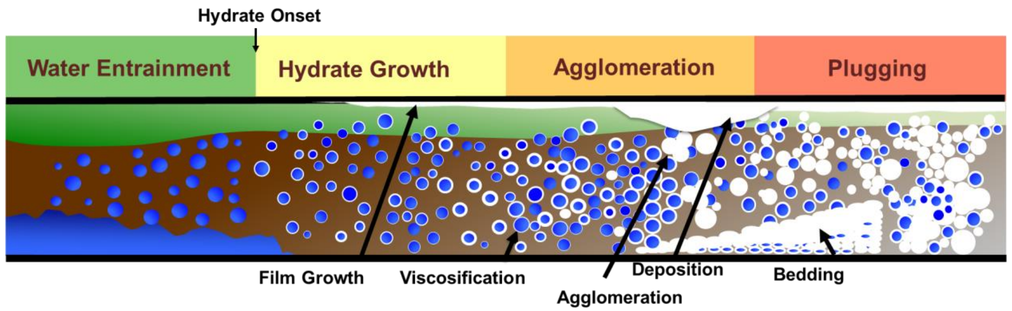


Distributive and statistical conditions



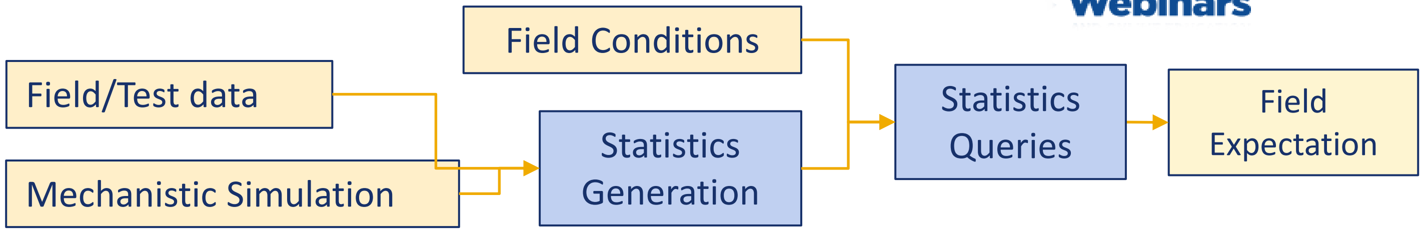
Probabilistic Hydrate Modeling – Comparison with Approach to-Date

Current approach



- Significant reliance on accuracy of both input data and physical models
- Distributive properties result in wide error propagation
- Missed physics will lead to poor extrapolation
- Complex model mechanics: increase in model complexity may lead to greater error propagation and less accurate predictions

Probabilistic approach



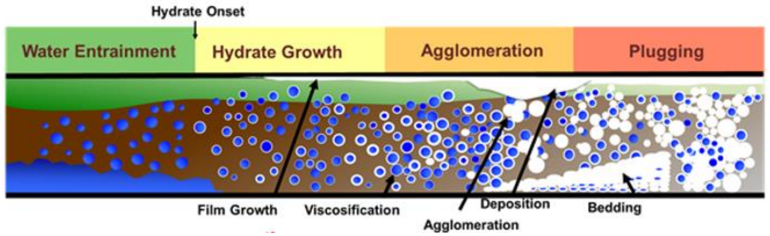
- Statistical approach to evaluating risk
- Less mechanistic dependency
- Manages margins through statistical results
- Focuses on most influential blockage factors
- Requires much data or simulations to generate statistics
- Data sets tunable to relevance for increased accuracy
- Meaningful results for any input data

Example of available input data trend:

Input field parameters	Example blockage probability results	Example blockage probability confidence
Pipe ID	<80%	5%
Pipe ID + WC	<40%	10%
Pipe ID + WC + GOR	<30%	60%
Pipe ID + WC + GOR + time	<10%	95%

Model approach knowledge requirements

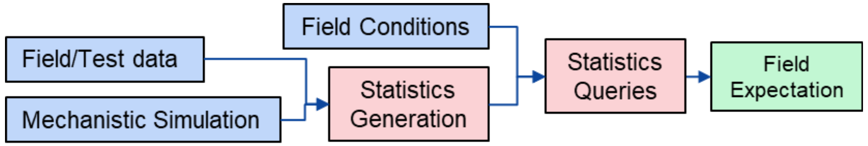
Mechanistic



Mechanistic model factors:

- Subcooling
- Pipe diameter
- Water cut
- Flow rate
- GOR
- Terrain
- Time
- Water droplet size
- Hydrate aggregate fractal dimension
- Hydrate packing fraction
- Hydrate inter-particle force
- Hydrate-wall interactive force
- Hydrate gas diffusion
- Hydrate thermal conductivity
- Oil viscosity
- Hydrate-oil slip
- Hydrate porosity
- Hydrate permeability

Probabilistic



Primary hydrate blockage factors:

- Subcooling
- Pipe diameter
- Water cut
- Flow rate
- GOR
- Terrain
- Time

Easily definable in the field

Must be approximated/ modeled/assumed outside of field

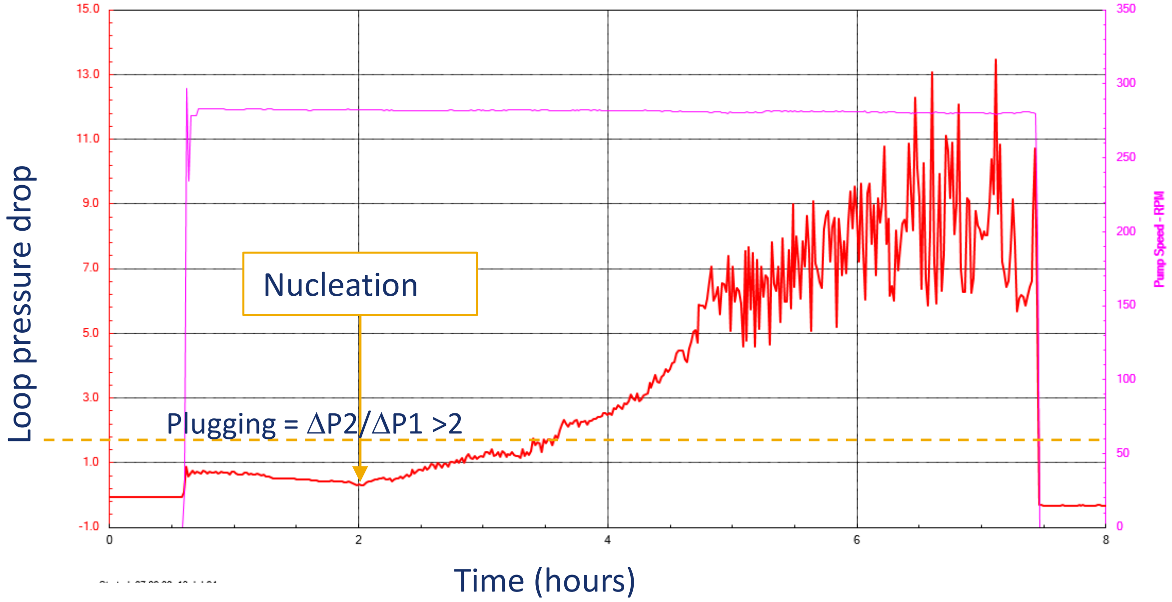
Training a model on available data

- 21 flowloop data sets spanning the ranges:
  - 3 fluids: 1 condensate, 2 light crudes

Condition	Min	Max
Water cut	5%	50%
Gas void fraction	11%	46%
Liquid velocity	0.3 m/s	3.8 m/s
Subcooling	0.1 °C	10 °C

- Each data set tested at 15 minute intervals to create a data set of **530 cases**
- Plugging criterion: relative pressure drop > 2
- Not included in training:
  - Pipe diameter
  - Terrain

Hydrate test in the XoM Friendswood flowloop



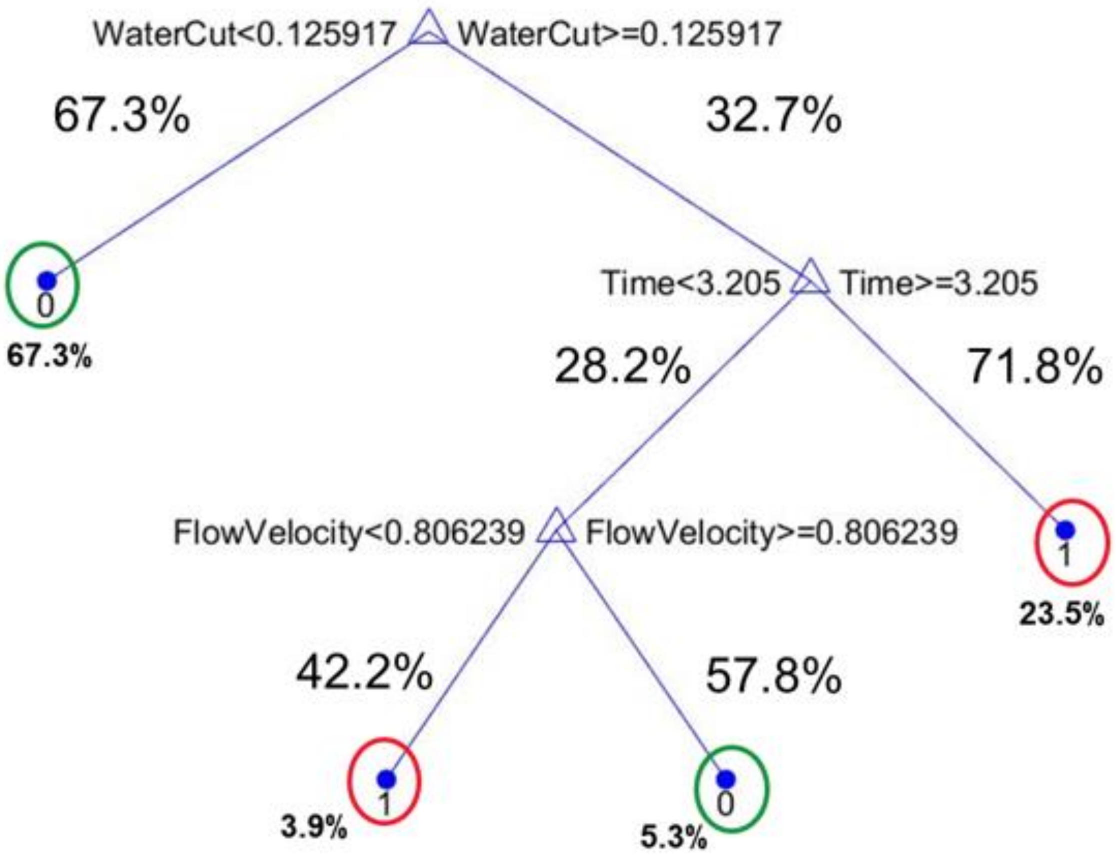
Results of initial model: Decision tree

Decision tree helps illustrate:

- What conditions lead to blockages
- The most influential parameters

Pitfalls of the decision tree:

- Limited time-set data from flowloops: Non-blocking tests would eventually block
- Flowloop data consumes water, leading to non-plugging conditions that would continue to escalate
- Semi-arbitrary pass/fail criterion: what is a blockage? Relative pressure drop = 2



Model Accuracy
- **94.3%**

Model Error
- **4.54%**

Total Incidence
- **0:**

67.3 + 5.3 = 72.6%
- **1:**

3.9 + 23.5 = 27.4%

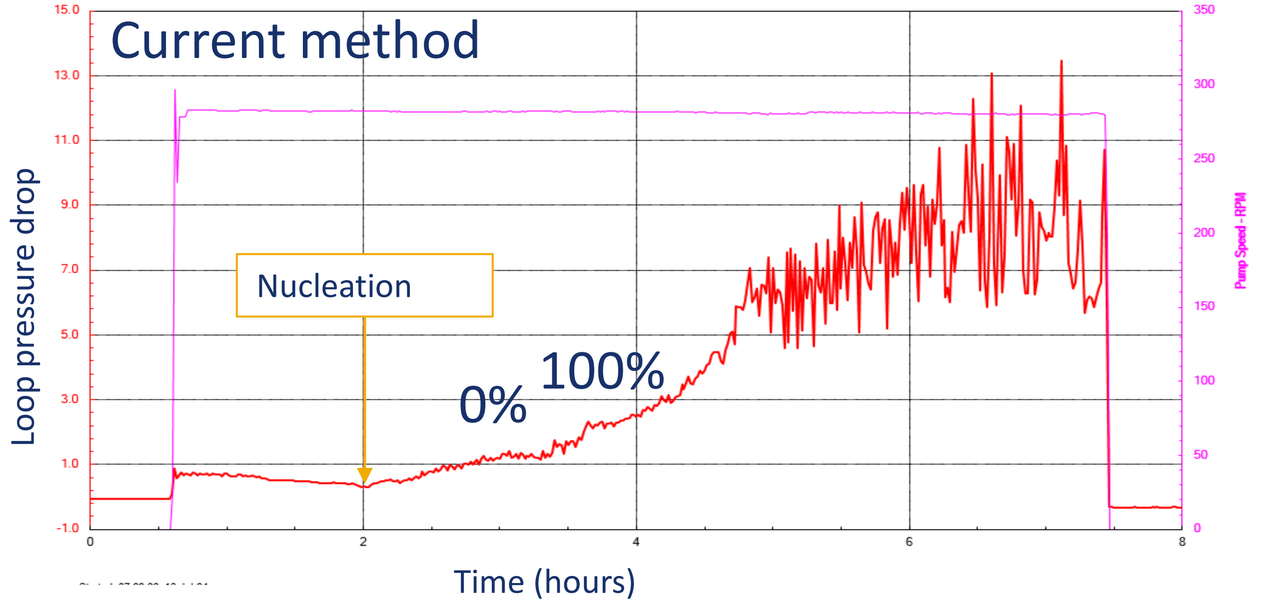
Model improvements: Plugging definition clarification

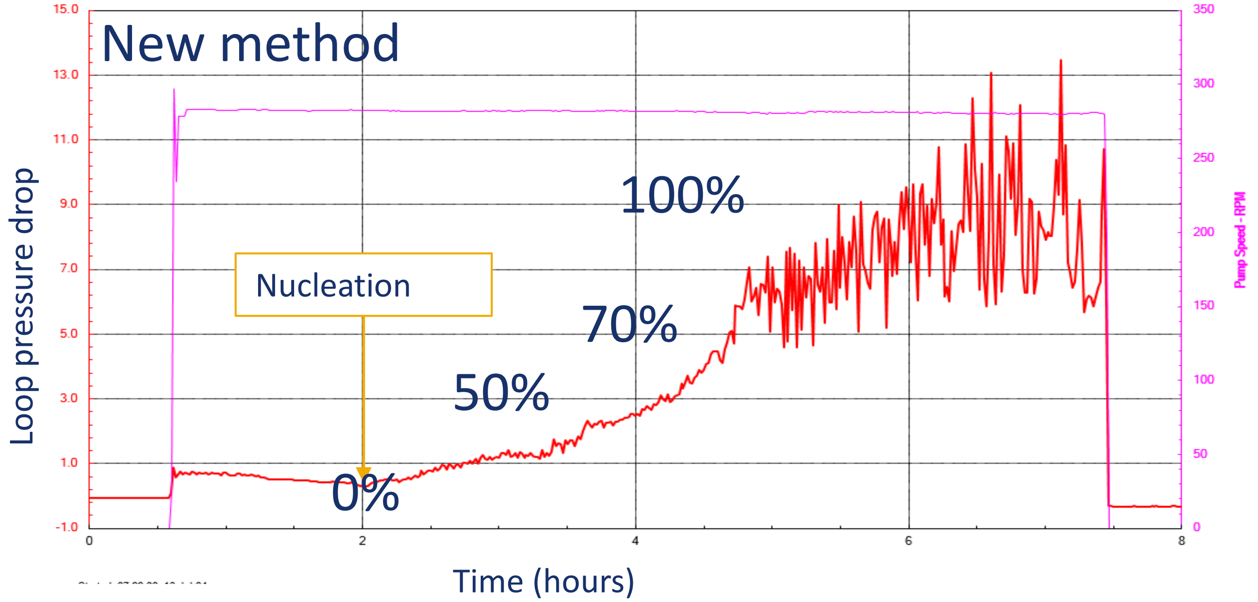
Pass-fail criterion overly-simplistic

- Semi-arbitrary criterion
- Does not communicate risk of blockage in a way that can be translated to field event tolerance

Improved method would utilize likelihood of blockage within a data set

- Will help to define exposure
- Method will reduce requirement for over and under-conservatism

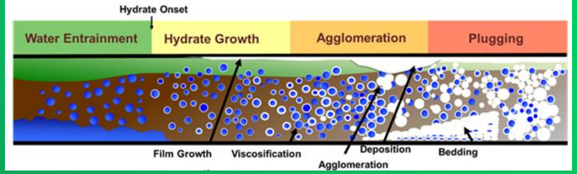




Model improvements: Other machine learning data sources

Mechanistic Models

image by Turner and Abrahamson



Flowloops

Field trials

image by Petrobras

Field events

Amount of training data

Quality of training data

Summary

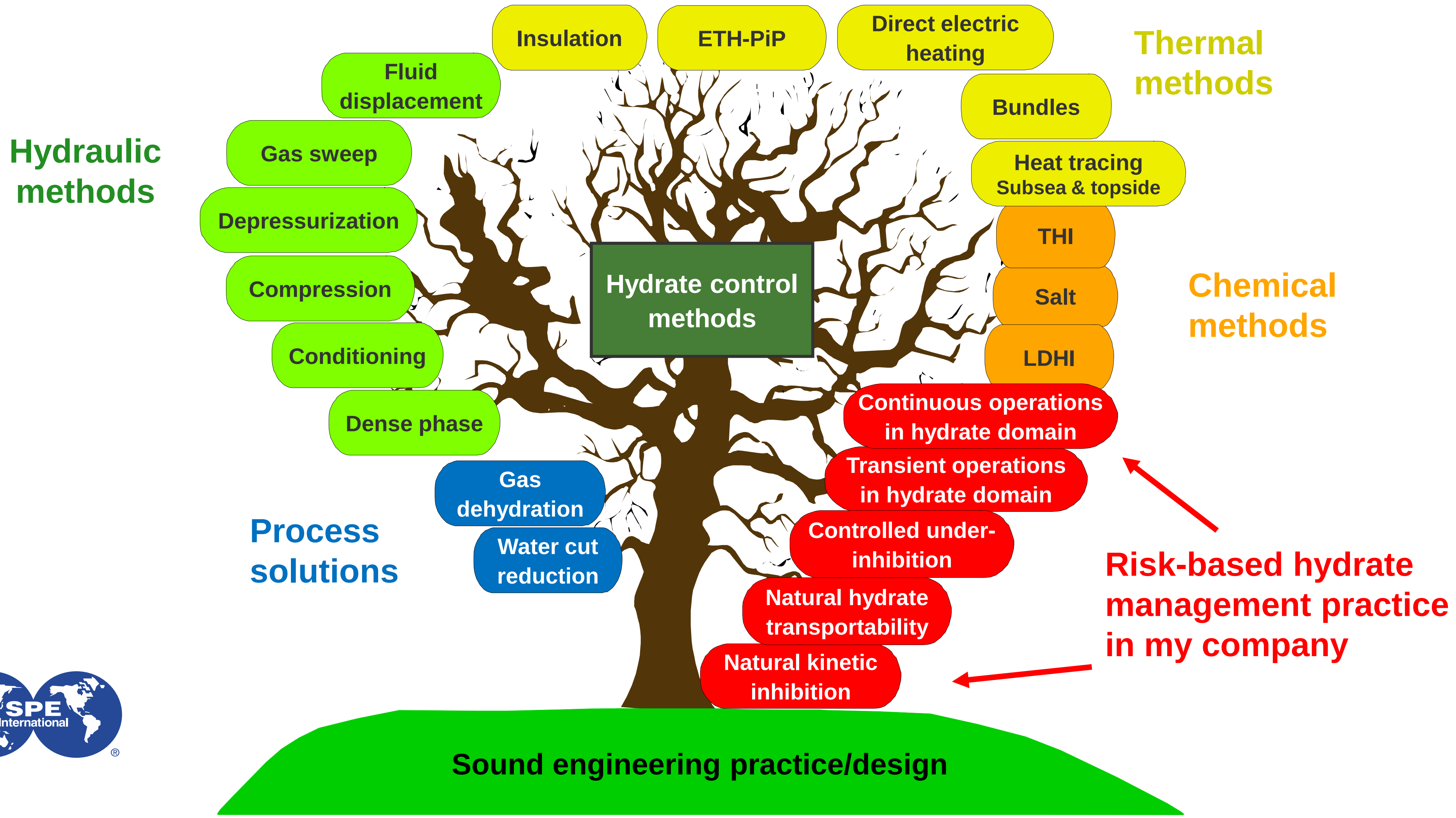
- Mechanistic models are essential for risk-based approaches to hydrate management; however, a broadly accurate model of hydrate blockage formation continues to be elusive
- Mechanistic models are can be highly subject to interpretation leaving users unsure of results
- In the digital age, utilizing a computer algorithm that captures field experiences allows for a wisdom-based approach to hydrate blockage assessment, suited for advising a practicioner
- Though not necessarily precise, by managing hydrate blockage distributions, the models can be more accurate without requiring understanding of all mechanisms at play.
- Probabilistic results also provide confidence information, which can help inform and engineer regarding risks

Best Practice on Risk-based Hydrate Management of Subsea Flowlines

Xiaoyun Li

14th December 2023

Overview of hydrate control methods



Examples of applying risk-based hydrate management during transient operations for subsea flowlines (which are outside hydrate domain during normal operations)

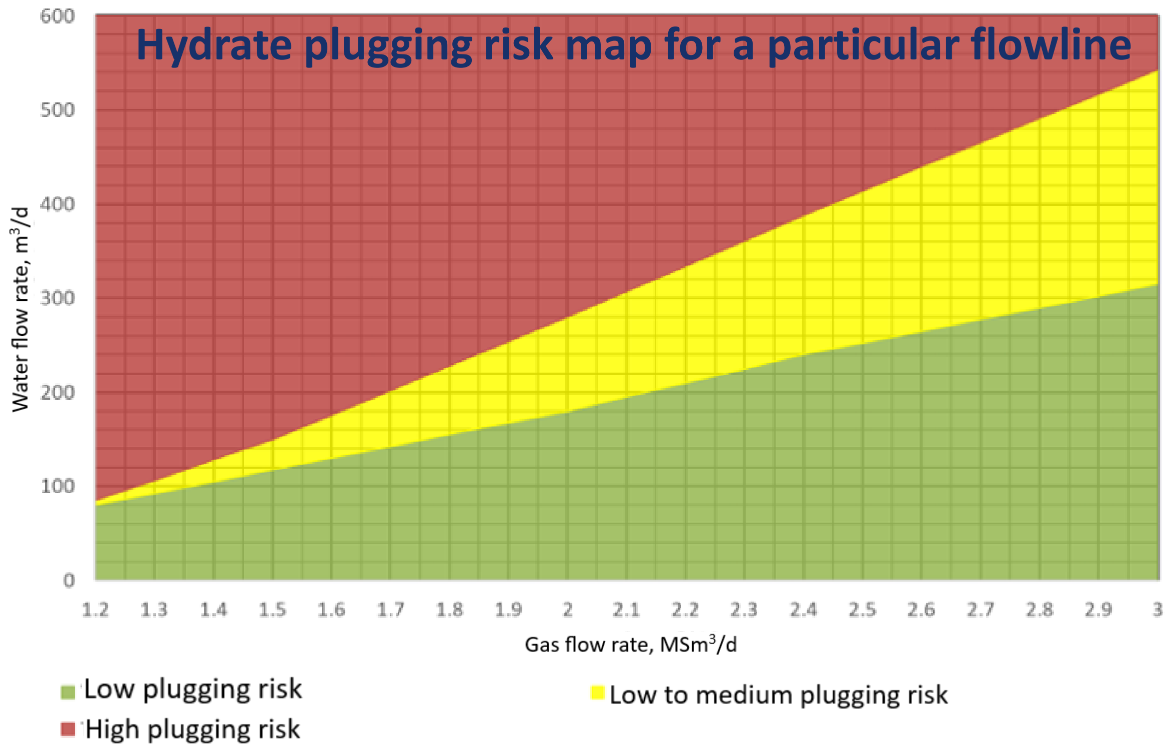
Hydrate management of transient operations

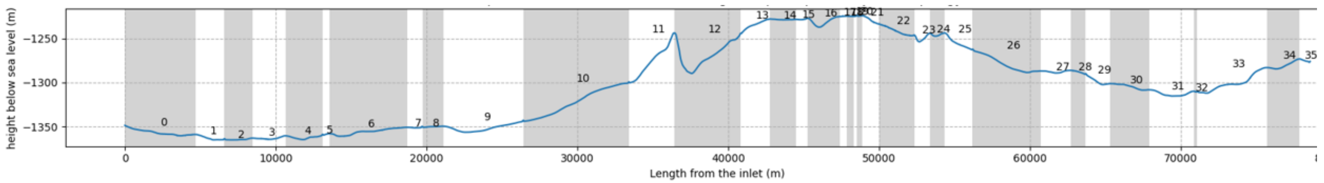
Typical systems where risk-based hydrate control have been applied:

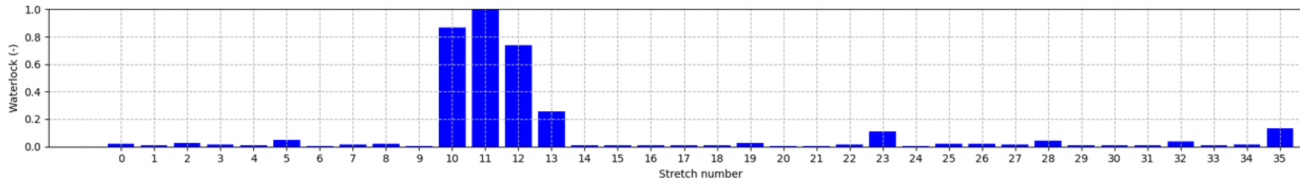
- Gas/condensate systems with low water content
  - Including the use of gas sweeping from a low water content well prior to shut-down & restart from the same low water content well
- Low GOR (gas/oil ratio) crude systems with extremely high water content
  - Including the use of fluid displacement from an extremely high water content well prior to shut-down & restart from the same high water content well
- Controlled under-inhibition (by e.g. MEG and/or high salinity)
- Naturally low plugging risk systems due to crude oil properties (hydrate transportability & formation kinetics)

No active hydrate control measures for low water content flowlines (gas-dominated systems)

- Flowlines shutting-down/restart as is in green (also possible in yellow) region
- Wells with low water content are used for gas sweeping of flowlines
- May need THI inj. upstream topside choke
- Some important parameters: local water content/fraction, arrival pressure, etc
- Field experiences are used for optimization
- Method widely applied in my company
- Work in progress to optimize the risk assessment criteria & risk indicators

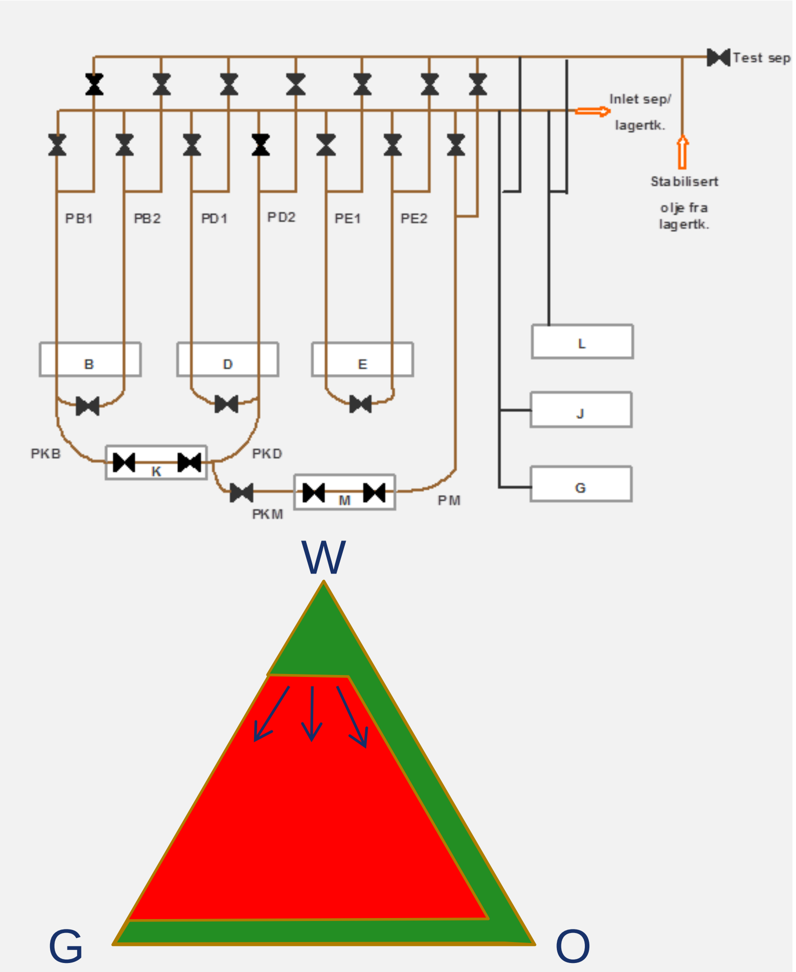






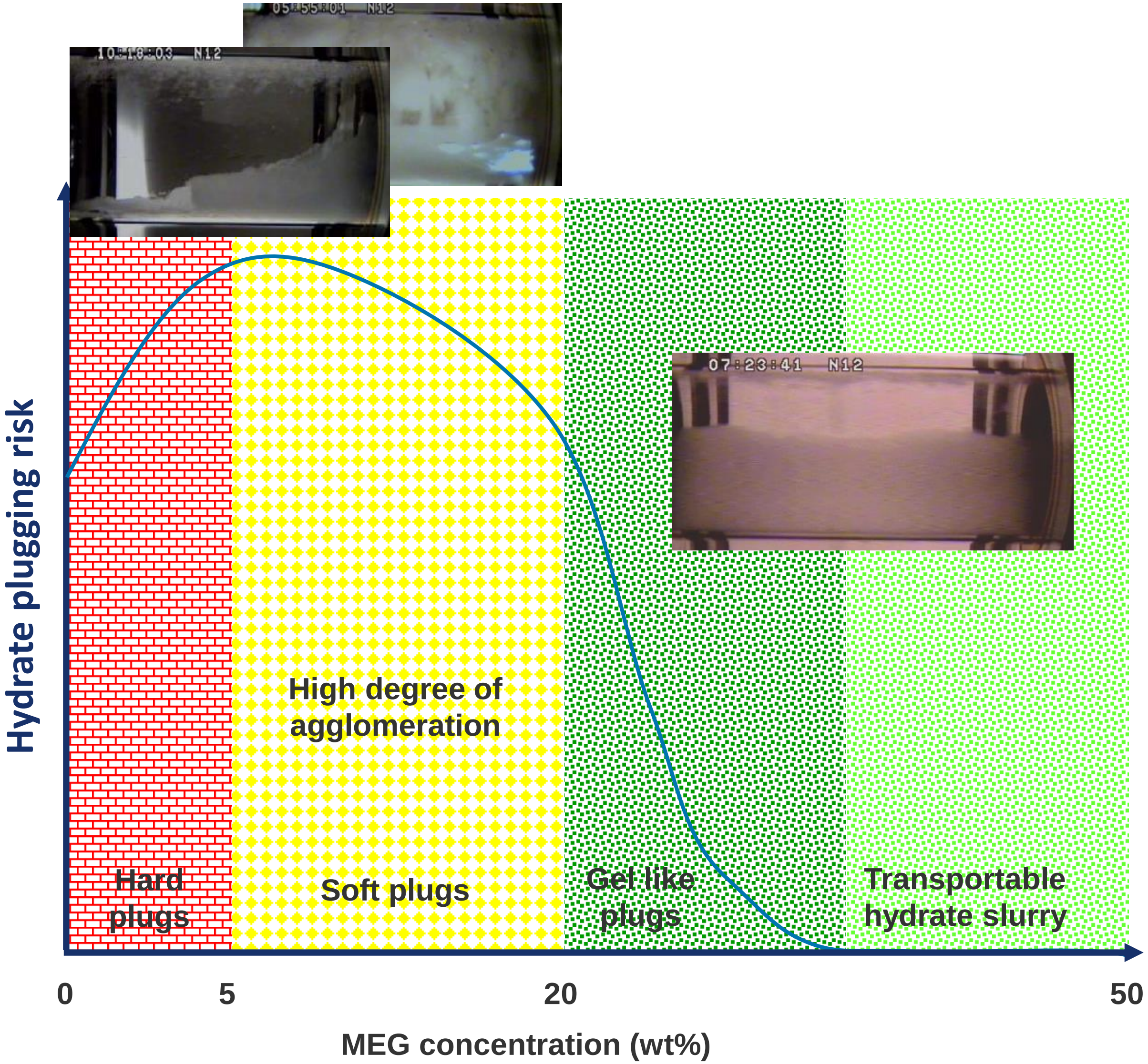
No active hydrate control measures for extremely high water content flowlines with low GOR fluids

- Flowlines shutting-down/restart as is
- Wells with extremely high water content are used for displacing/recirculating flowlines
- Current limit is around 95 vol% water cut
- Field experiences are used for optimization
- Work in progress to enlarge the operation envelope



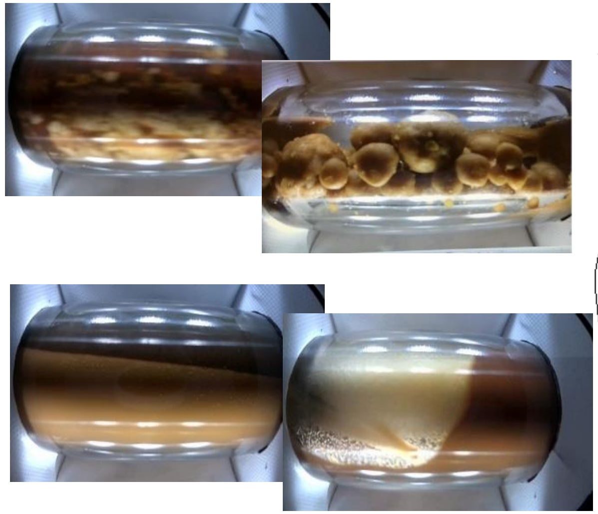
Use of controlled under-inhibition

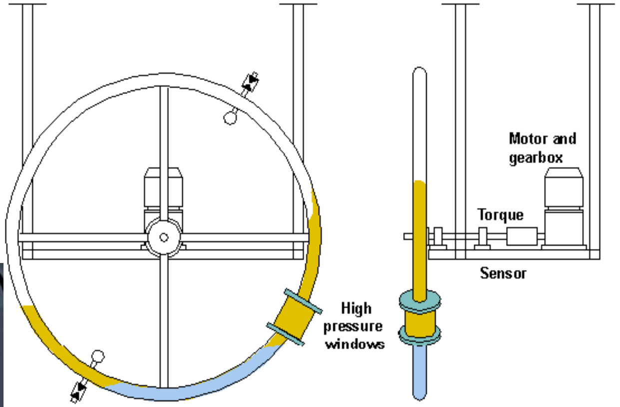
- Plugging risk depends on the initial inhibitor concentration
- Hydrate slurry is transportable at a given degree of subcooling
- Experimental studies necessary to determine the acceptable limit of under-inhibition for a given system
- Applicable for both gas/condensate and oil systems
- Field experiences are used for optimization
- Concept applied in operations, sometimes only to remove safety margins

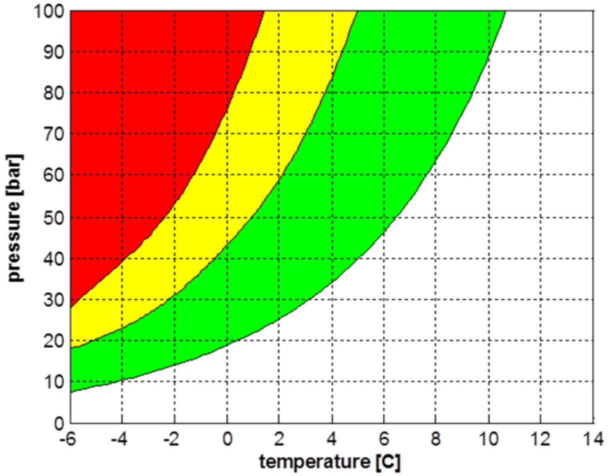


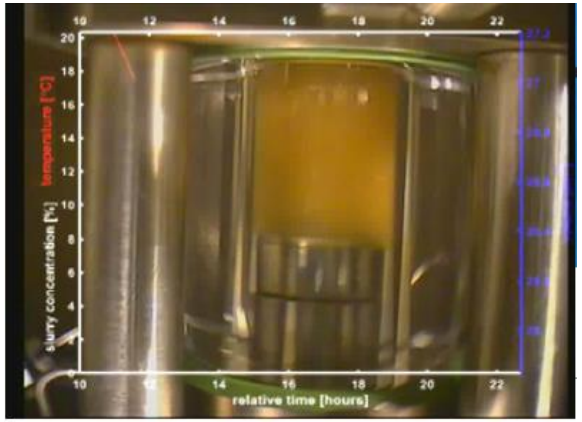
No active hydrate control measures for low plugging risk systems due to natural crude oil properties

- Experimental study of hydrate transportability
- Experimental study of hydrate formation kinetics
- Some important parameters: oil & water chemistry, WC, GOR, ΔT, etc
- Field experiences are used for optimization
- Method widely applied in my company









Summary

Examples using risk-based hydrate management for transient operations

- ➢ Gas/condensate systems with low water content
- ➢ Low GOR crude systems with extremely high water content
- ➢ Controlled under-inhibition
- ➢ Naturally low plugging risk fluid systems due to crude oil properties

- All above systems can be very dynamic and hydrate control measures need to be reevaluated/updated accordingly
- Good prediction/analysis of water content & local water distribution are important
- Field experiences are vital for the success of wide implementations

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Operational Approach to Hydrate Management in Oil Production Wells

Rogério Leite

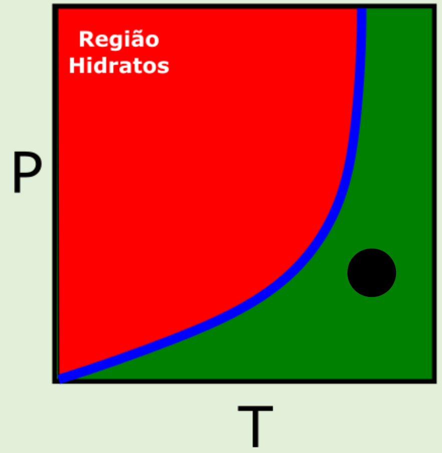
12/14/2023

SPE International

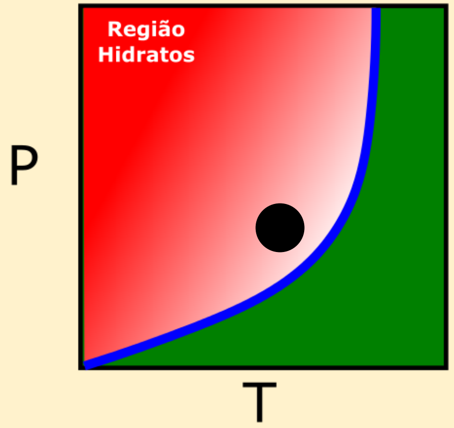
BR PETROBRAS

Hydrate Strategy

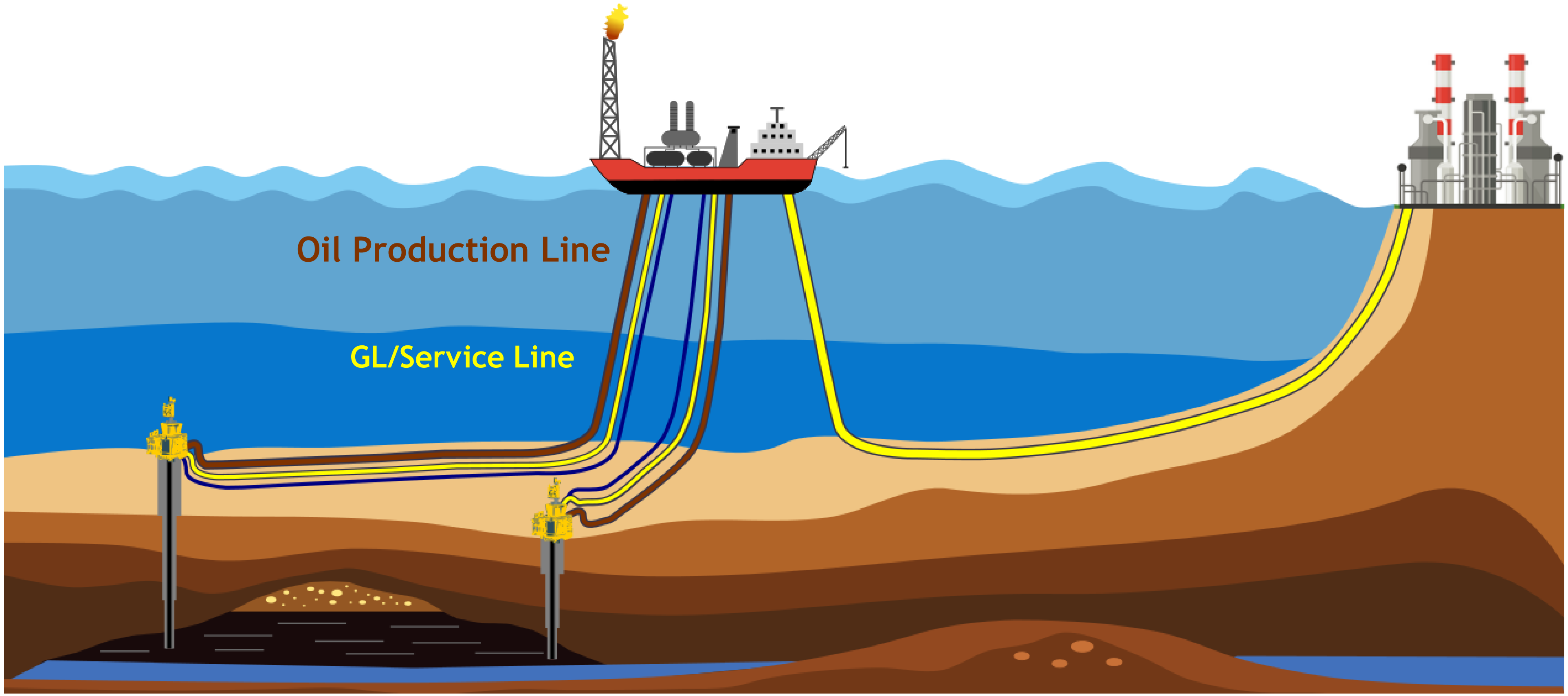
Hydrate Prevention



Hydrate Management

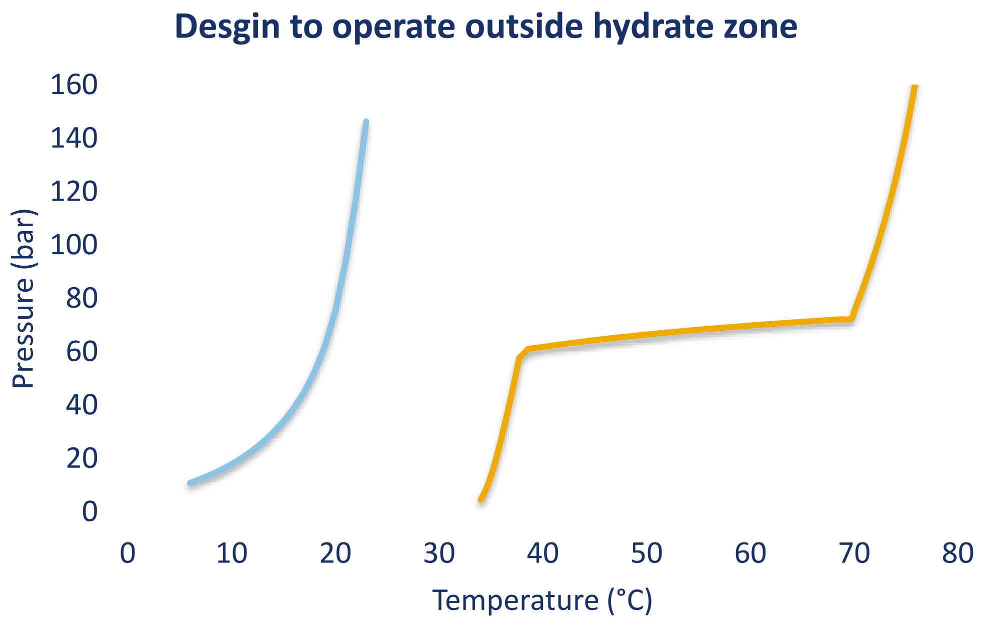


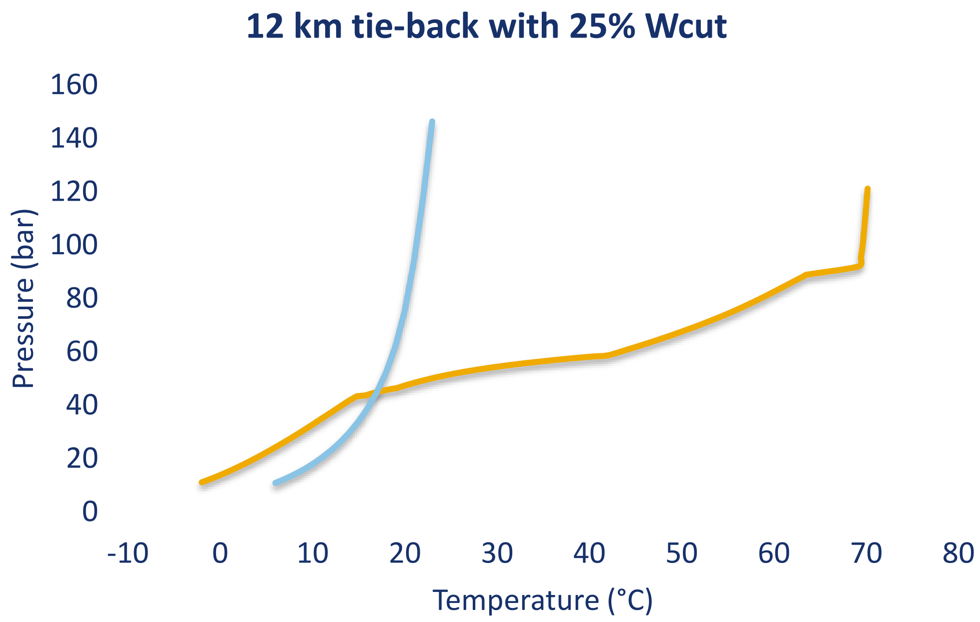
Typical offshore layout in Brazil



STEADY STATE

STEADY STATE





PREVENTION

- To operate outside hydrate zone

MANAGEMENT

- Natural Inhibbition (low Wcut, low GLR, high salinity)

SHUT-IN

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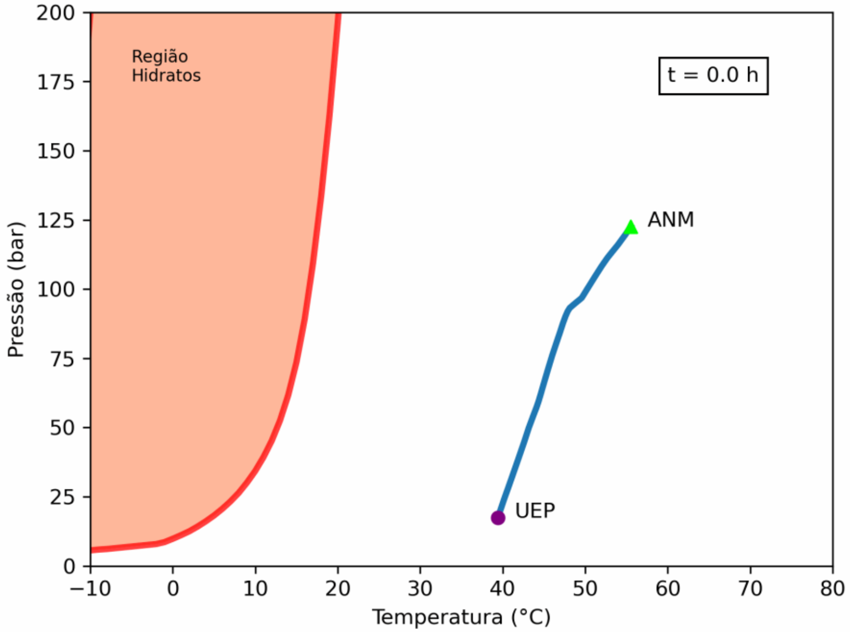
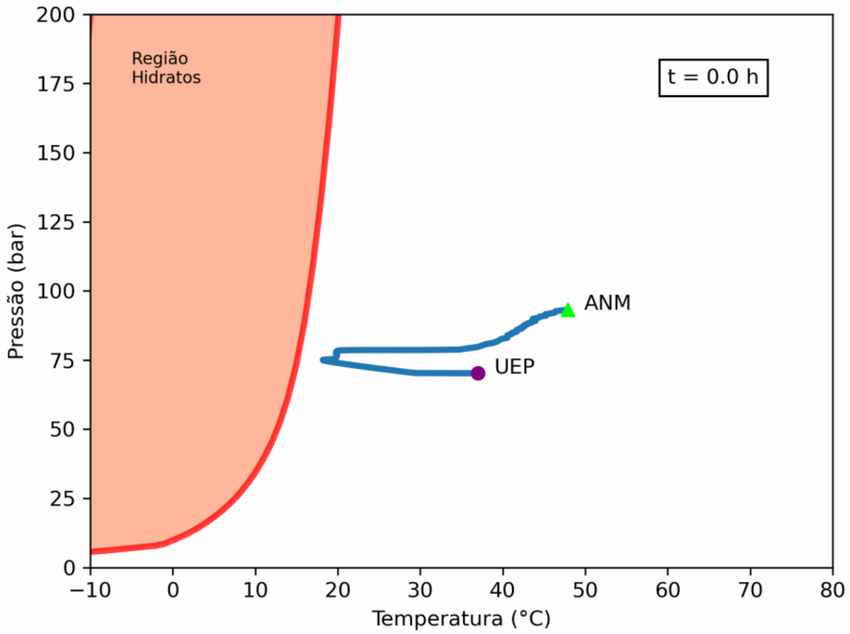
No depressurization



With despressurization



PREVENTION

- Depressurize and launch preservation before reaching hydrate zone

MANAGEMENT

- Natural Inhibition (low Wcut, low GLR, high salinity)
- Wait until last minute to begin system depressurization

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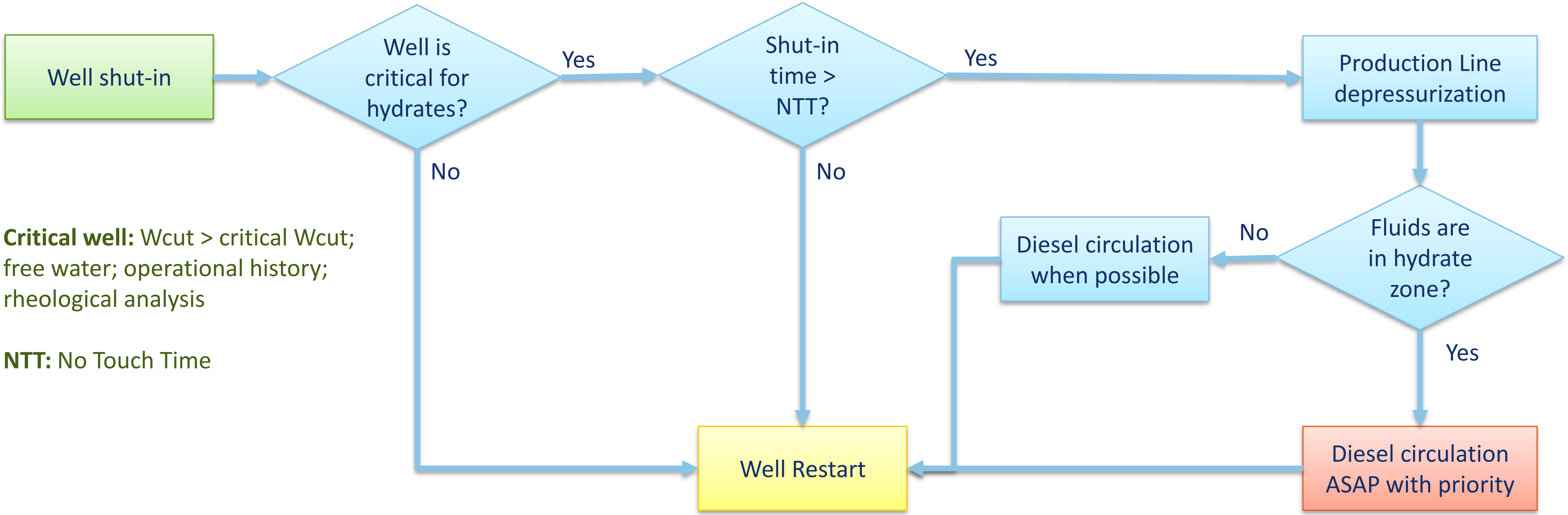
Animation credits:
Luiz Fernando Rambalducci Dalla

PROCEDURE



- **Critical well:** Wcut > critical Wcut; free water; operational history; rheological analysis
- **NTT:** No Touch Time

PREVENTION

- Depressurize and launch preservation before reaching hydrate zone

MANAGEMENT

- Critical well criteria: low Wcut
- Wait until last minute (NTT) to begin system depressurization
- Extended NTT: high salinity
- Launch preservation after reaching hydrate zone

CRITICAL WELL

Critical well

- Wcut > critical Wcut
- Free water
- Operational history
- Rheological analysis

Non-hydrate cases

Situation when it was expected to have a blockage, but it didn't.

Relevant Characteristics

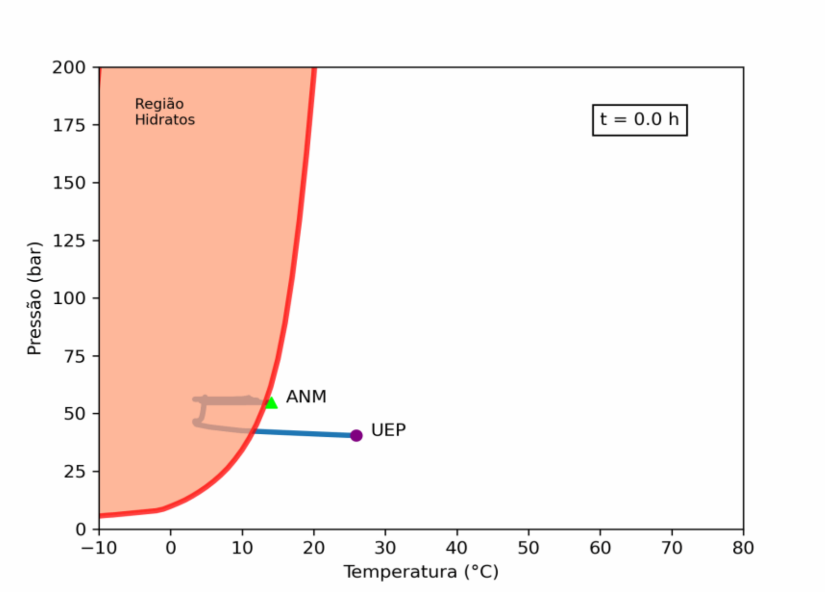
- High salinity
- Low GLR
- Low Subcooling
- Demulsifiers

New criteria for critical wells

RESTART

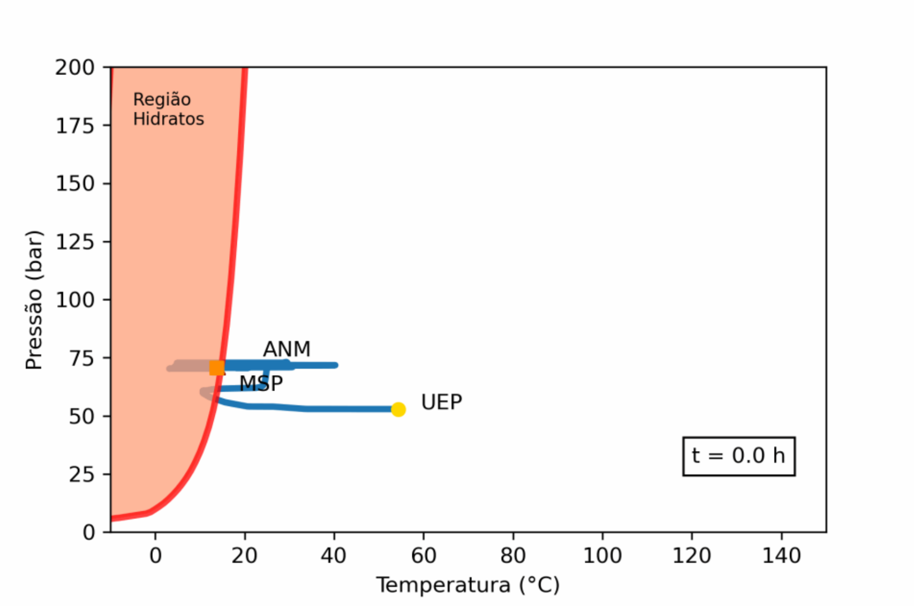
Low Productivity - Gas lift at Xmas Tree

Warm-up 8 horas



High Productivity - Natural Elevation

Warm-up 2 horas



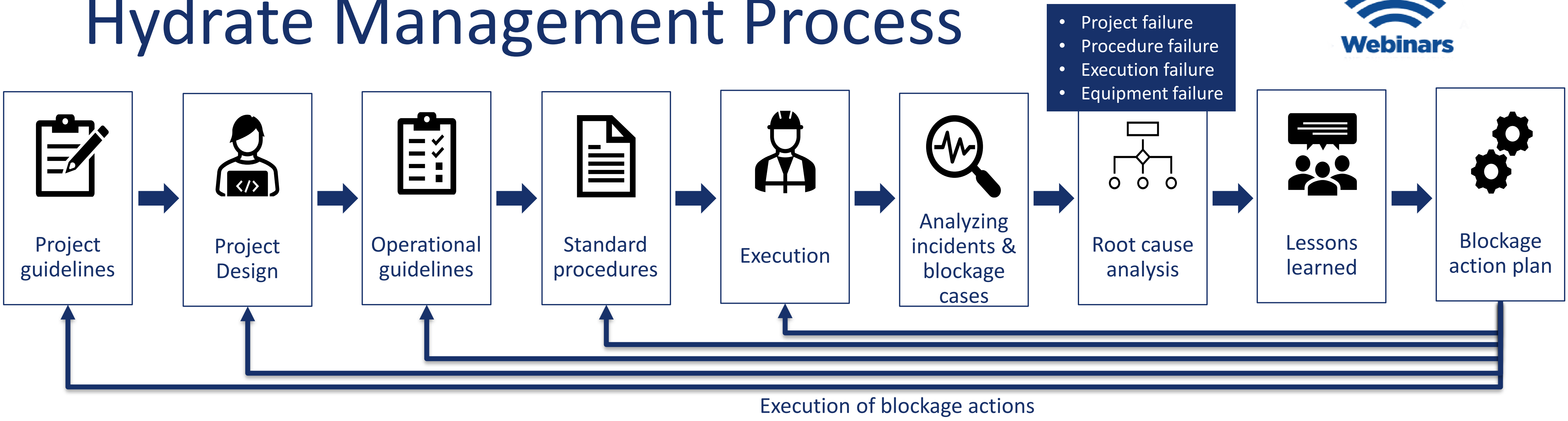
Try to **speed up** well restart procedure

Animation credits:
Luiz Fernando Rambalducci Dalla

How to ensure that hydrate management is appropriate?

By establishing a **Control Process**

Hydrate Management Process



Hydrate Database

Statistics:

- Hydrate production loss
- Number of hydrate cases
- Duration of hydrate cases
- Time waiting for rig intervention
- Duration of rig intervention
- Cost of remediation
- …

Structuring action plan

Could we expand the concept of Hydrate Management?

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Hydrate management is more than producing within the hydrate envelope with controlled risk.

Hydrate management is having a well-controlled process for risks, impacts, lessons learned, and actions to be taken.

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Design Projects – Review of Guidelines

More robust design criteria

More robust design NTT criteria

Thermal insulation of subsea equipment

Improved performance in depressurization maneuvers

Shorter time for cleaning all lines

Improvements in topside designs

Dead oil circulation as diesel alternative

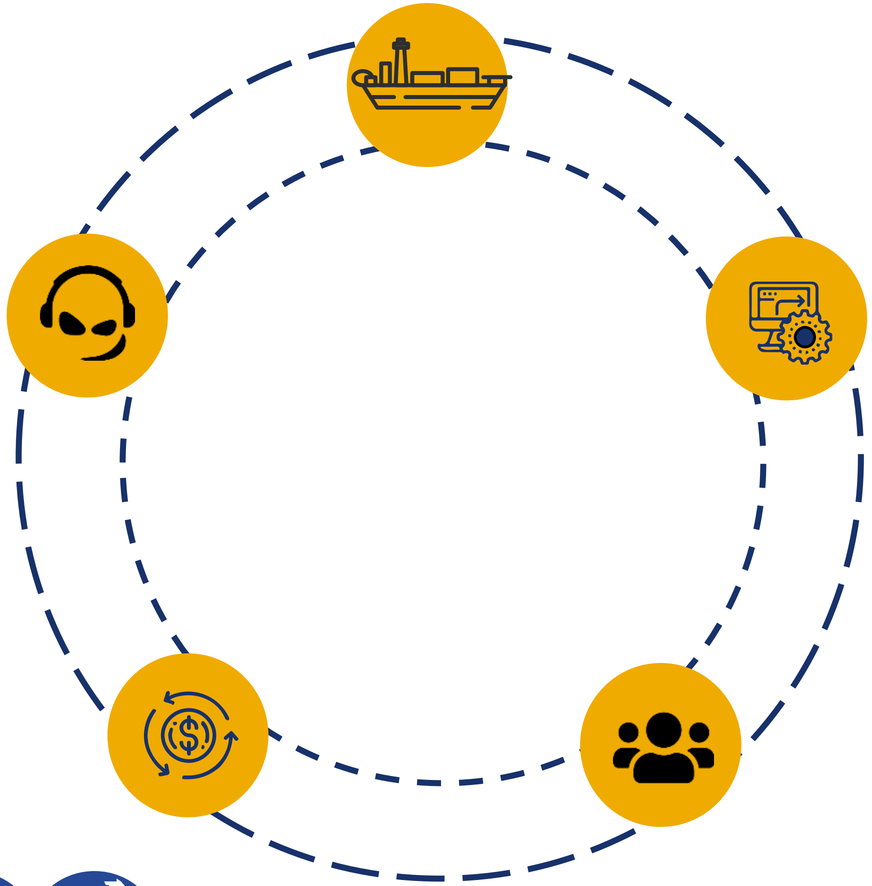
Enhancement of the Ethanol injection system

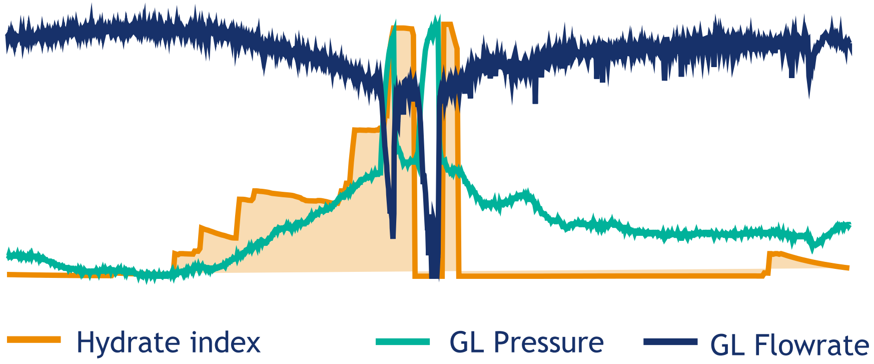
Subsea MEG injection system improvement

More flexibility for the use of nitrogen units

Slide credit:
Otávio Ciribelli Borges

Operations – Surveillance Process





Slide credit:
Otávio Ciribelli Borges

Hydrate risk assessment challenge

Challenge:
Quantifying the risk of hydrate blockage during well shut-in and restart

Hydrate Database

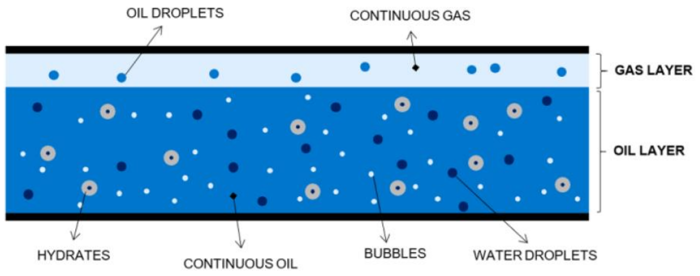
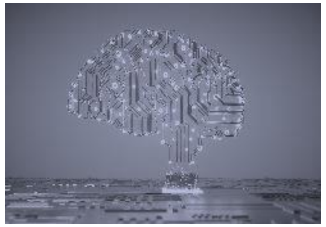
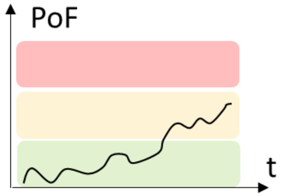


Figure 1 – Illustrative representation of an oil-dominated multiphase system considered for hydrate formation and transport.

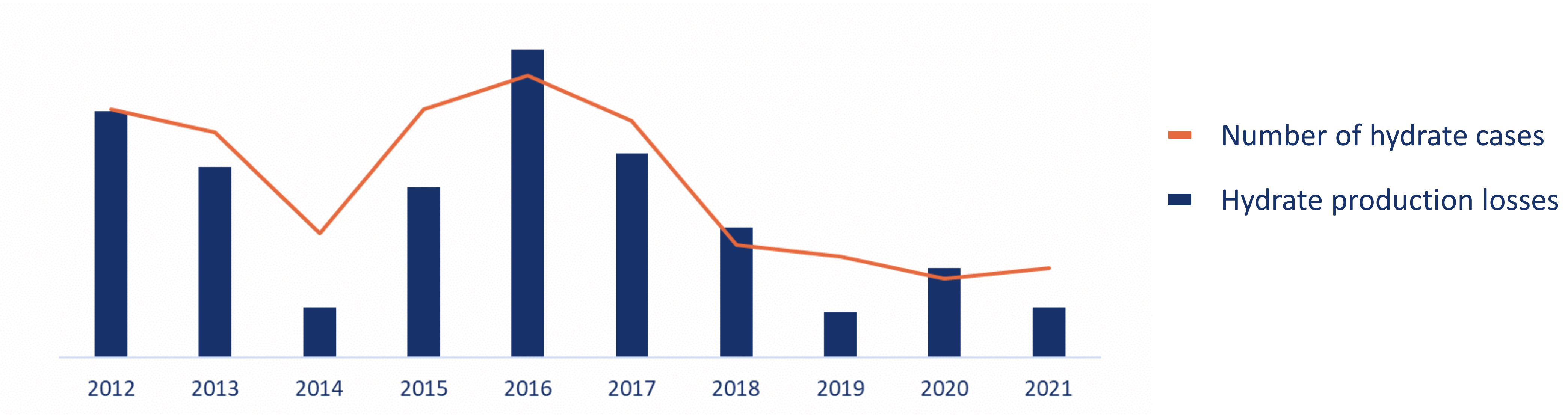




1D Numerical Simulations of Hydrate Formation and Transport in Oil-Dominated Systems with a Population Balance Framework
M.A. Pasqualette, J.N.E. Carneiro, G.G. Ribeiro, A.B. Soprana, V. Girardi, G.S. Bassani, D. Merino-Garcia

But...

Hydrate blockage happens



Is zero hydrate possible?

"Zero hydrate is possible, but the investment is very high. Is it worth it?"

— Ricardo Camargo, Master Advisor at Petrobras (retired in 2020)

"Flow assurance is like an insurance. How much are you willing to spend today to prevent future production loss?"

— Marcelo de Albuquerque Gonçalves, Senior Advisor at Petrobras

Hydrate Costs

PREVENTION vs. REMEDIATION

Hydrate Costs

But what if remediation costs are lower than prevention costs?

Prevention Costs

PROJECT

- Thermal insulation
- Electric heating
- Artificial lift method
- Dehydration plant
- Subsea separation
- Service pump capacity
- Tanks capacity
- ...

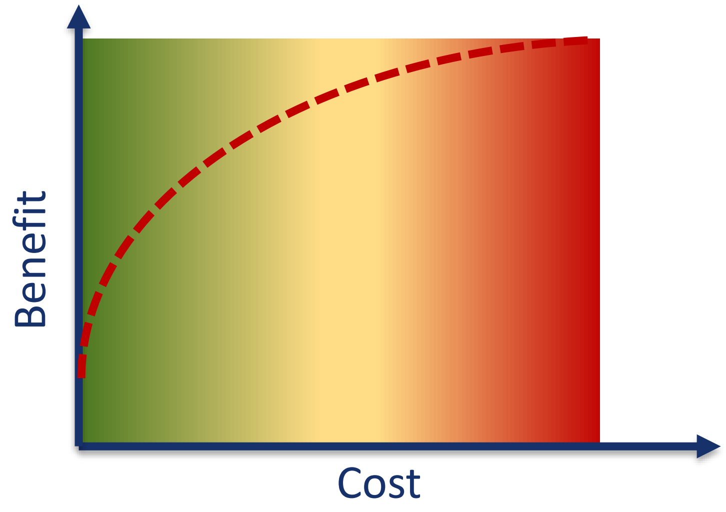
OPERATION

- Chemicals
- Diesel (dead oil)
- Energy for heating
- Prevention time
- Time waiting resources
- ...

Prevention Costs

What is the gain associated with the cost of prevention?

- $ Cost of the solution (investment)
- Reduction of hydrate cases
- Reduction of production losses due to hydrate
- Brent value
- Monetary correction



Calculation with a high level of uncertainty

Remediation Costs

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PROJECT

- Topside facilities for depressurization
- Piping alignment flexibility
- Chemical injection facilities
- Subsea depressurization
- Vertical access to risers to operate with coiled tubing
- Subsea systems for liquid removal from the riser
- …

OPERATION

- N2 units
- Subsea depressurization vessel
- Coiled Tubing
- Rig
- Chemicals
- Waiting time for resources
- Operation time
- …

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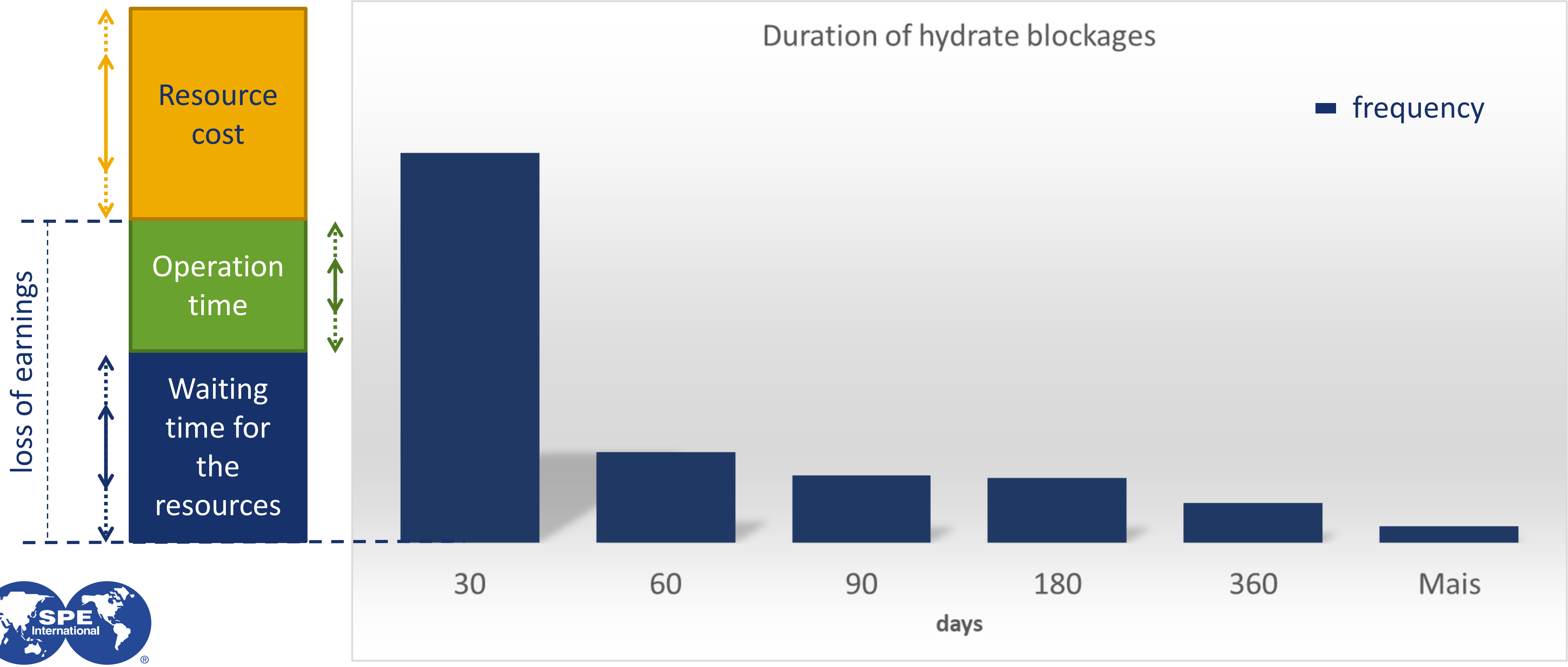
Remediation Costs



PARADIGM SHIFT

Why not invest more in **remediation?**

Remediation technique

- Efficient
- Agile
- Safe

Hydrate blockages may be acceptable

Reduce CAPEX e OPEX + hydrate blockage cases < production loss

++ financial return $

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