Overview of Flow Assurance

2023

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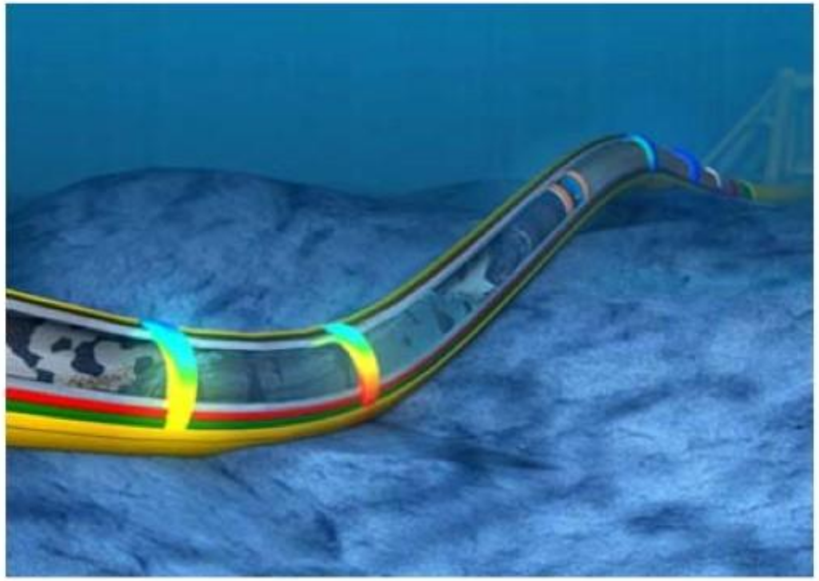
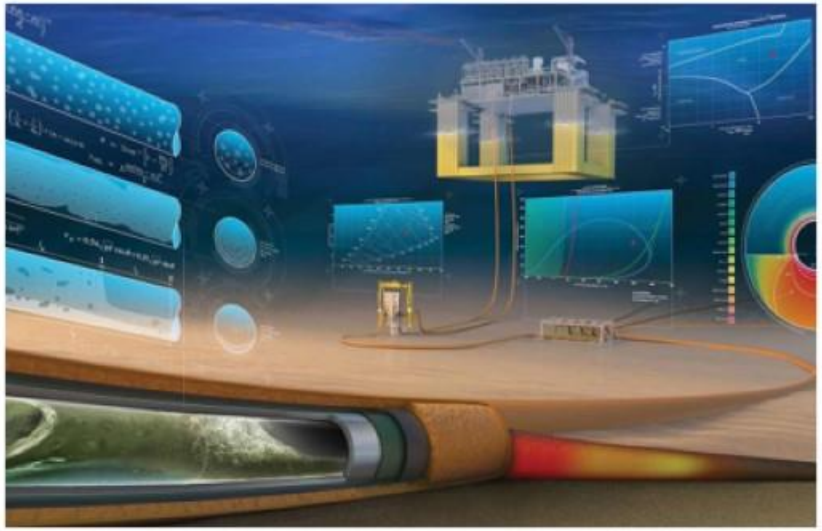
What is Flow Assurance?

- **Flow assurance is to take precaution to ensure deliverability and operability.**
- Analysis of the entire production system to ensure that the produced fluids continue to flow throughout the life of the field.
- Optimization of the design and operating procedures to cost effectively prevent or mitigate slugging, surge volumes, wax deposition, gelling, hydrates, Asphaltene, etc.



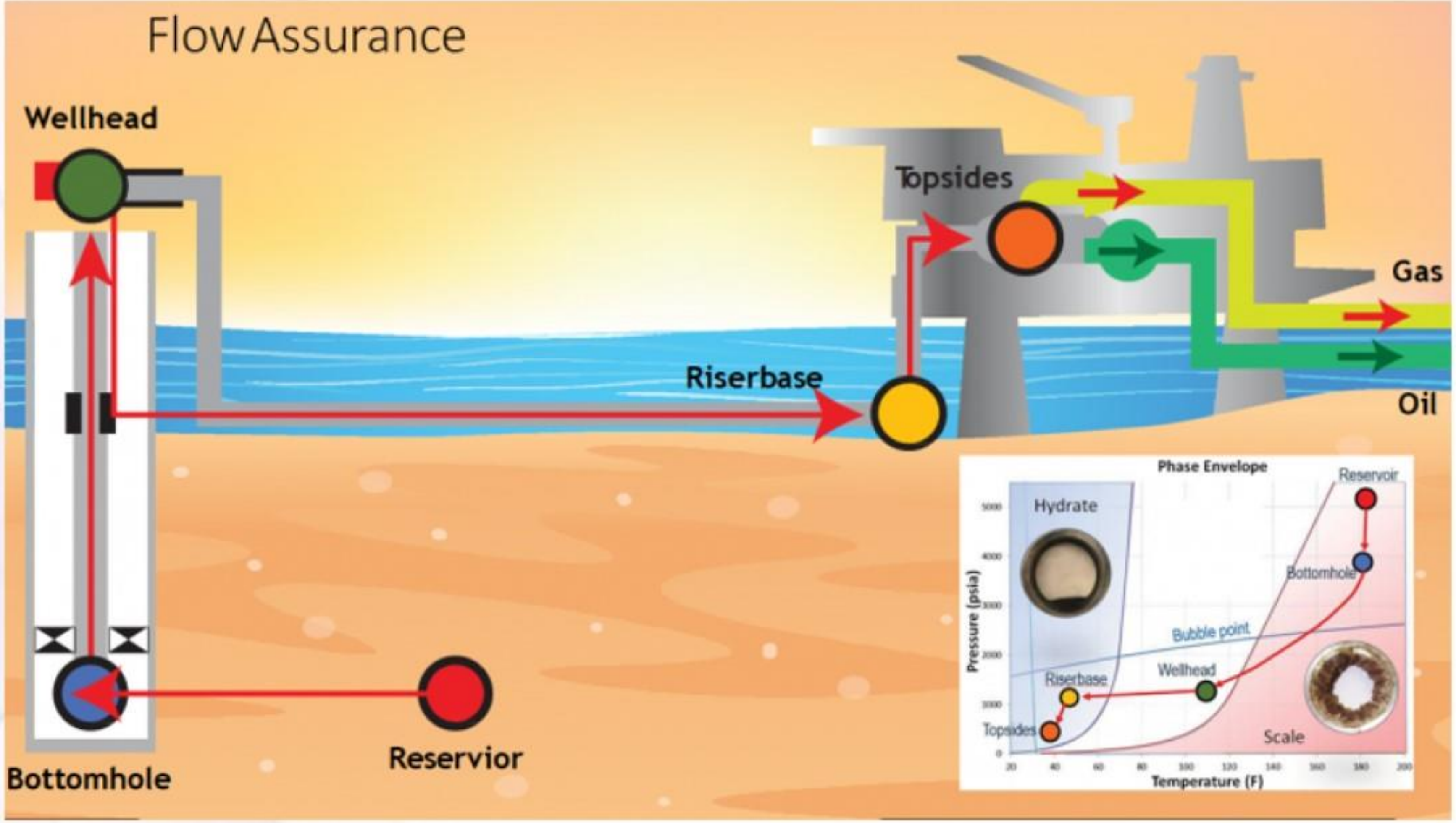


Flow Assurance: What Does It Mean?

- Flow assurance is a new term in the oil and gas industry, originating in the 1990s, and coined by Petrobras.
- Translated from the Portuguese, this meant **'guarantee of flow'** – or the ensuring that fluids produced by a fuel reservoir consistently and reliably reach the point of separation into discrete compounds.
- More recently, the term has come to encompass **the entire supply chain**, from source to end-user.
- Despite its various definitions in the past twenty-five years, it broadly involves the identification of potential oil and gas fields and wells, and the logistics behind transporting any fuels to storage or processing facilities as efficiently as possible.
- Flow assurance is therefore particularly important (and difficult) with offshore operations.
- In a sentence: flow assurance is the process by which **production is guaranteed** through the minimizing of restrictions on physical fuel flow.

Flow Assurance Challenges

- Transporting fluids from a reservoir to processing facilities, whether single or multiphase, presents many challenges.
- **Major challenges:**
  - Gas hydrates
  - Wax
  - Asphaltene
  - Liquid accumulation (water, condensates, etc.)
  - Corrosion related to flow conditions (temperature and pressure, stratified flow, slugging flow).

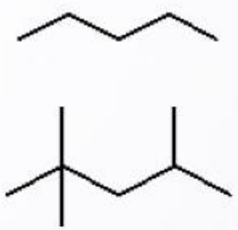


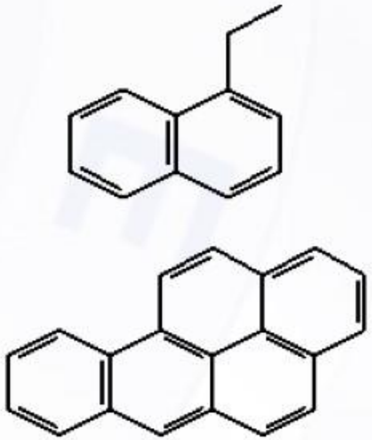
Composition of Crude Oil

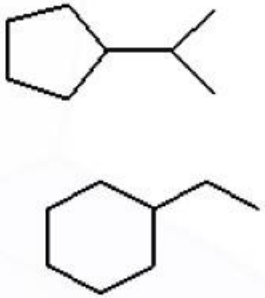
CRUDE OIL

HYDROCARBONS

ALIPHATICS	AROMATICS	NAPHTHENES
25%	17%	50%
C_1 - C_{60}	$(C_6H_5)_n$	CYCLOALKANES

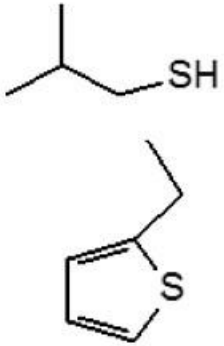


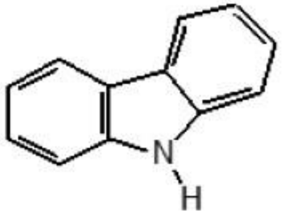


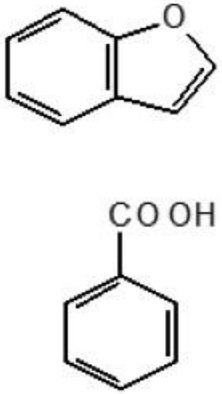


NON-HYDROCARBONS

SULFURS	NITROGENS	OXYGENS	METALLICS
<8%	<1%	<3%	<100PPM



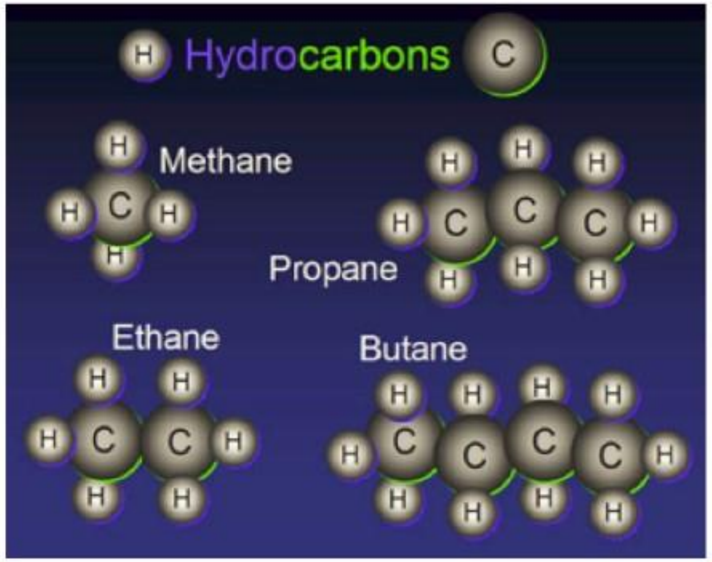


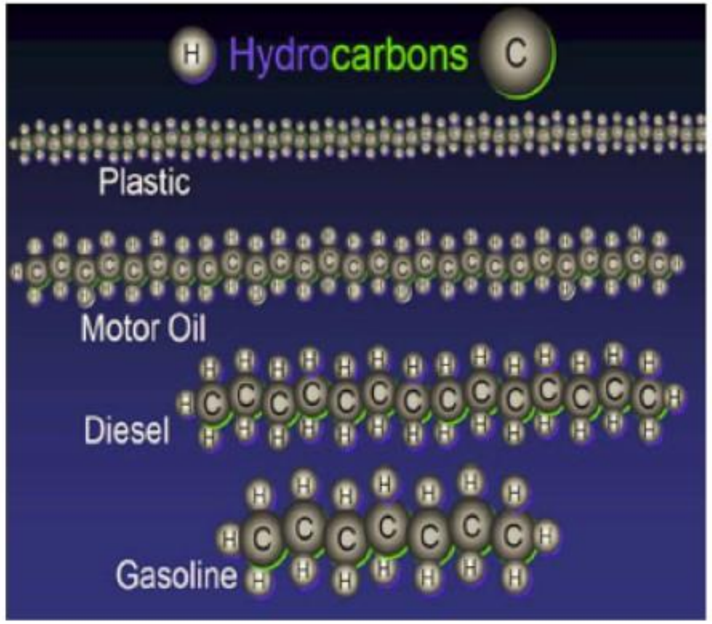


The Hydrocarbons

- **Hydrocarbons are the simplest of the organic compounds.**
- They are made from **Hydrogen** & **Carbon**.
- The basic building block is **1 Carbon** with **2 Hydrogens** attached, except at the ends where 3 Hydrogens are attached.

- **Hydrocarbons forms:**
  - When the chain is between 5 & 9 carbons, the hydrocarbon is **Gasoline**.
  - About a dozen carbons: **Diesel**.
  - Around 20 carbons: **Motor Oil**.
  - A chain of hundreds to thousands of carbon and hydrogens: **Plastic** (**Polyethylene**).

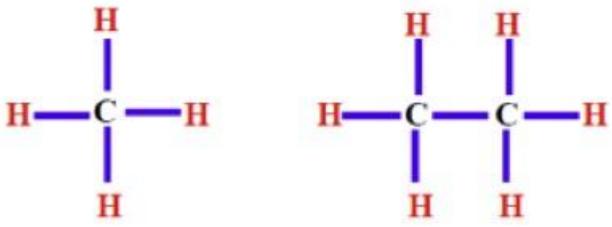




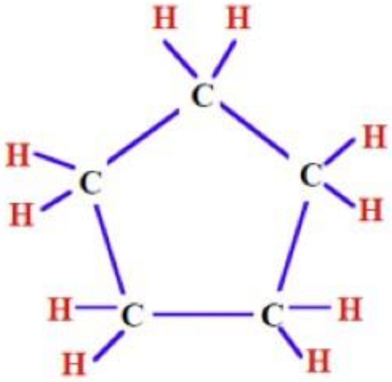
Hydrocarbon Structures

- The simplest and most abundant is the **paraffin series**: chains of **Carbon** atoms with **Hydrogen** attached.
- The chemical formula of paraffins: C_nH_{2n+2}.
- The major constituent of hydrocarbons is the **paraffin group**.
- They range from a **dry gas** which is mostly C1 (Methane) to **tar** which is mostly the heavier fractions.
- The black oil normally found is between the two extremes, C1 and heavier fractions (C7+).
- The hydrocarbon extracted from reservoirs varies in **composition from place to place**.

- The more complex ring structures: **Naphthalene** and **Benzenes** occur in varying proportions.

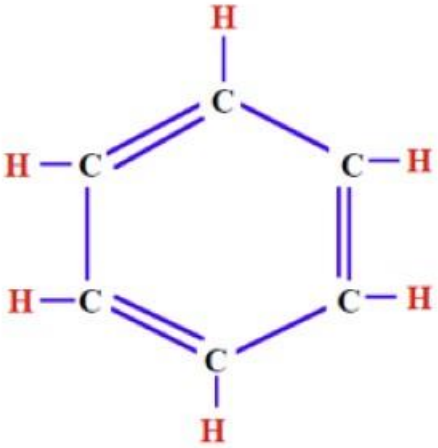


PARAFFIN SERIES, METHANE AND ETHANE



NAPTHALENE SERIES

CYCLOPENTANE

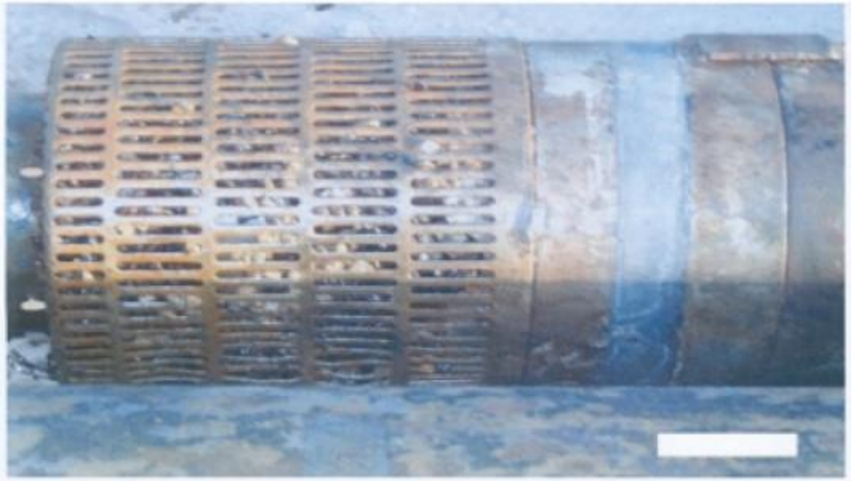


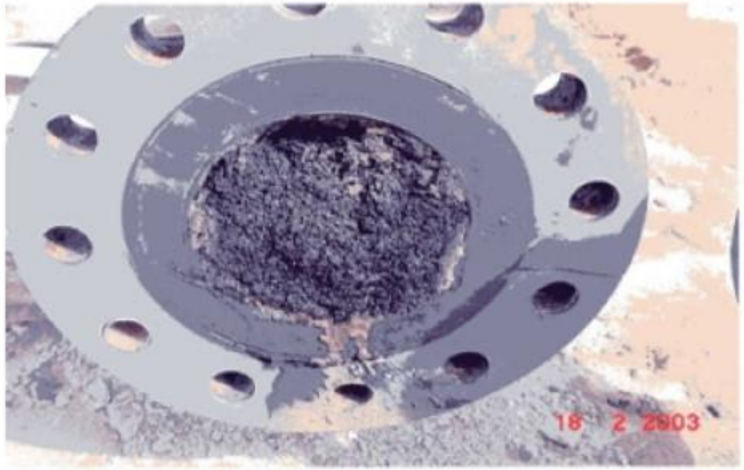
AROMATIC SERIES

BENZENE

PVT & Flow Assurance

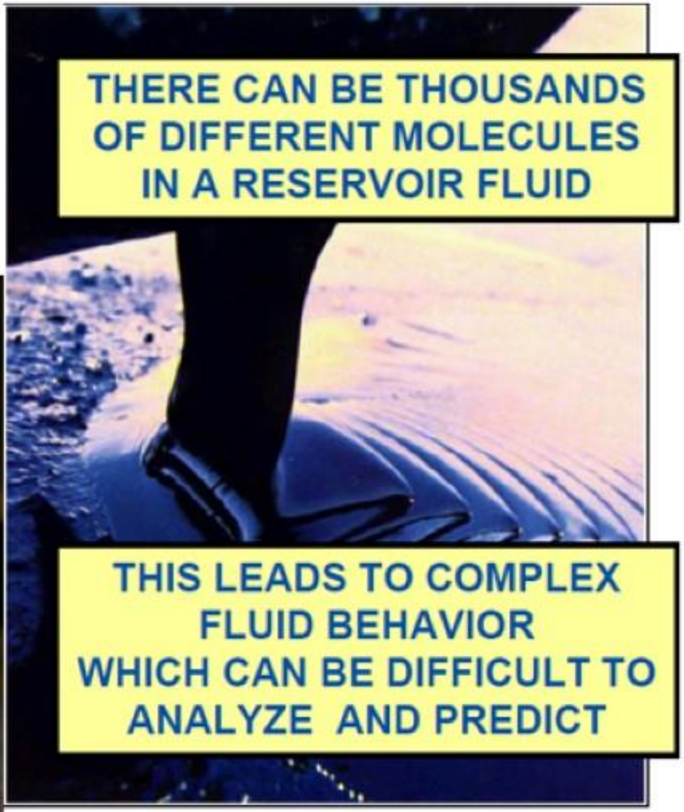
- **Issues:**
  - Hydrate formation: to provide hydrate curves for operating conditions
  - Waxes: to provide wax appearance temperature (WAT)
  - Asphaltenes: to provide asphaltene percipitation tendency (SARA analysis)
  - Corrosion: (Sulphur - H_2S – CO_2)





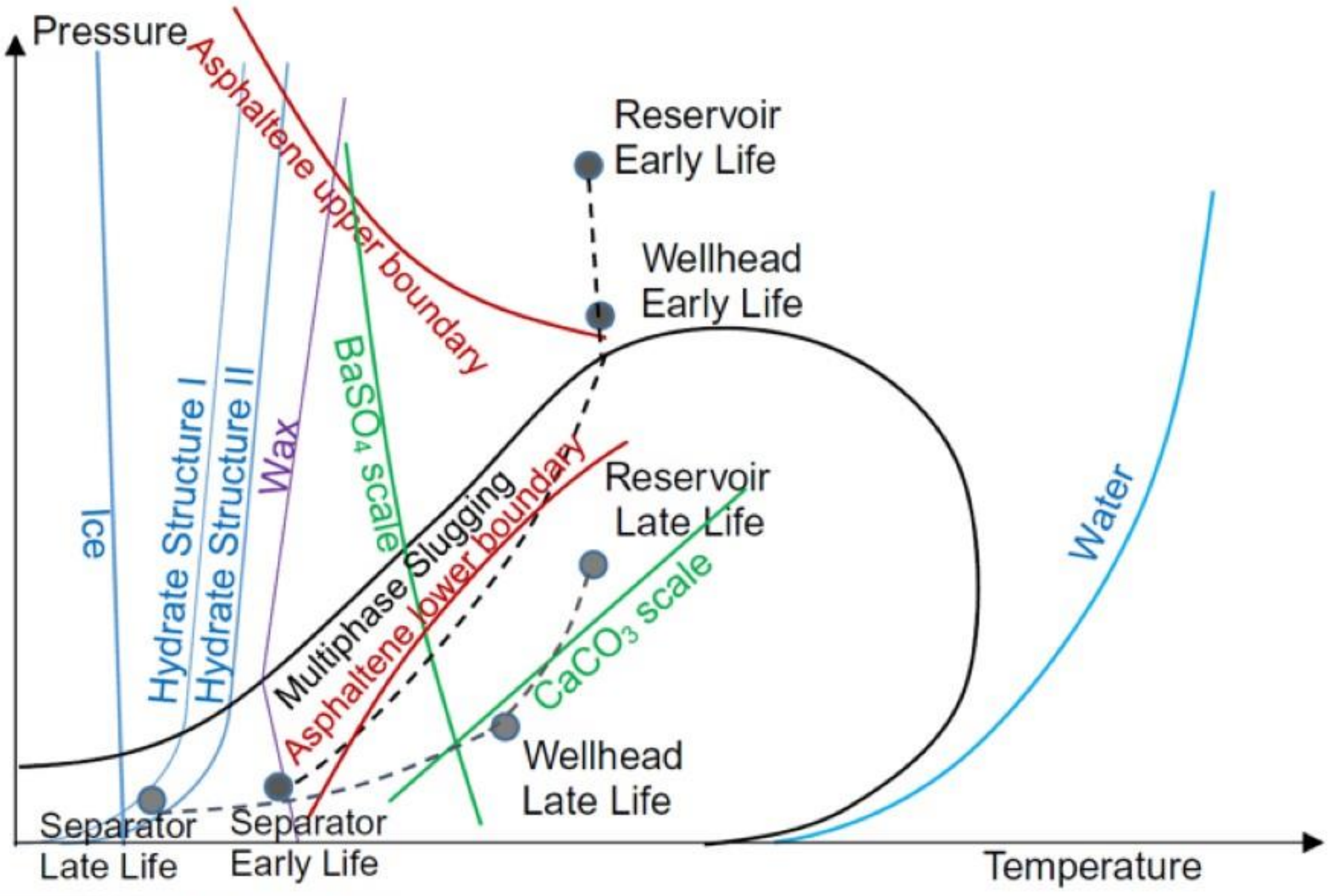
Reservoir Fluids

- Hydrocarbons
  - Saturates / Paraffins / Alkanes
  - Aromatics
  - Resins
  - Asphaltenes
- Non-hydrocarbons
  - Water
  - Mineral salts
  - CO2, H2S, mercaptans, N2, He
  - Metals
  - Microorgansims



Phase Diagram of Flow Assurance Issues

- Liquid and solid phases: water, sand, hydrate, Asphaltene, scale.
- Several solid phases can be present simultaneously if there are both sufficient fluid and appropriate conditions present to form those solids.
- Solids usually form from liquids by crystallization or by amorphous freezing.
- Examples of crystals are hydrate, ice, paraffin wax.
- Examples of amorphous solids are Asphaltene and some forms of wax and naphthenates.
- Scales are also crystals.



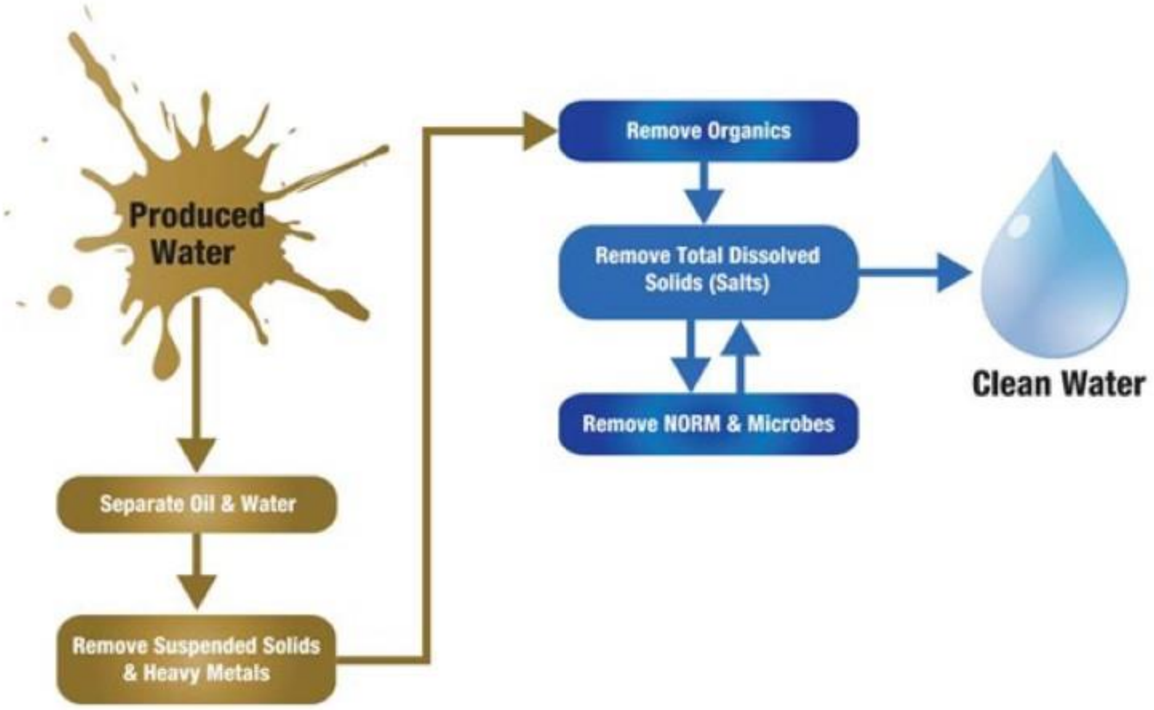
Handbook of Multiphase Flow Assurance
https://doi.org/10.1016/B978-0-12-813062-9.00001-4

Production Chemistry

- **Chemical reactions of water directly influence Flow Assurance**
- Reaction of completion fluids (mostly filtered brine) and well fluids can cause water blocks / emulsions, initiate corrosion and can even turn a sweet reservoir in to sour!
- **Scale / Wax deposition** in the production tubing shall adversely influence the effective flow area for hydrocarbon reducing the well deliverability.

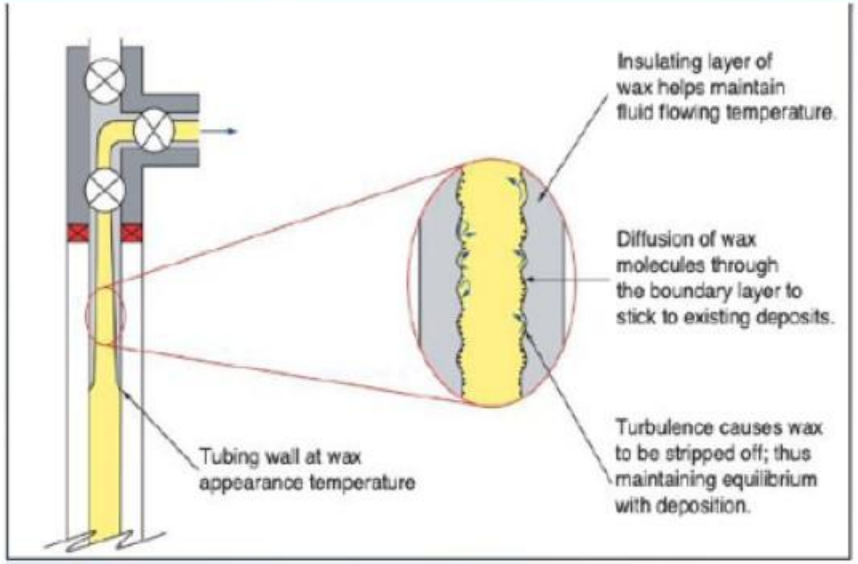
Production Chemistry

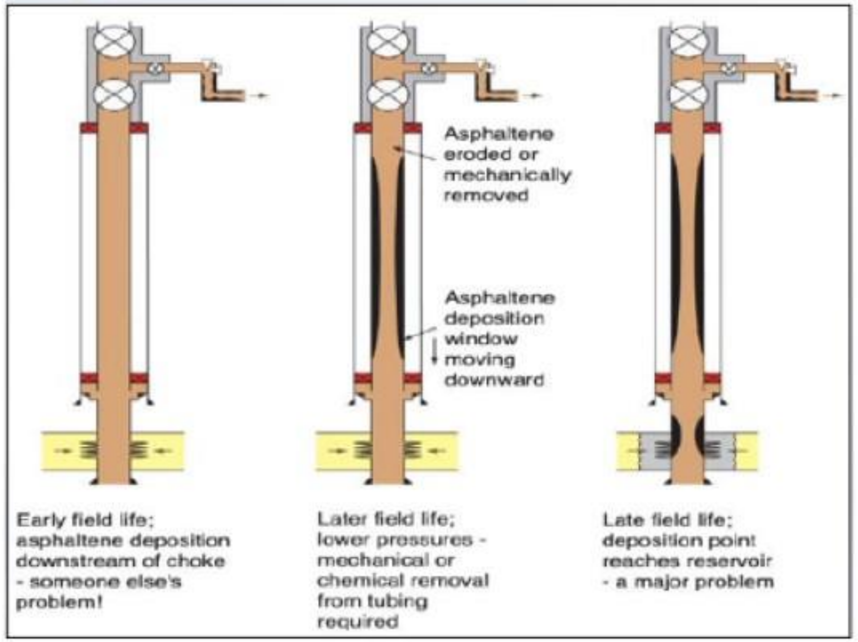
- **Water Blocks / Emulsions:**
  - Incompatible completion fluids / corrosion inhibitors / surfactants used in completion fluids will react with reservoir fluids / chemicals left during drilling and stimulation / wellbore clean up treatment
- **Scales:**
  - Produced water chemistry must be studied for assessing the risk of scale deposition
  - Simpler scale: CaCO3s
  - Harder scale: **Barium / Strontium Sulphate** require downhole tools to remove.
  - Scales can also be radioactive and its is quite customary to have **Naturally Occurring Radioactive Material (NORM)** surveys



Production Chemistry

- **Wax Deposition:**
  - Wax is formed by linear chains of Alkanes (C 10 to C 60) having a range of melting points from -22 F to 212 F and can cause following problems based on the temperature.
- **Asphaltene Deposition**:
  - **Asphaltene are complex aromatic compounds.**
  - They start impacting the flow lines first and then the well starts loading with Asphaltene.
  - Treatment to be done in time, else once it reaches reservoir level can be a huge problem.
  - **Xylene Solvent** can help alleviate Asphaltene problem, but it's very critical to handle Xylene not only due to the lower flash point, but also due to toxicity.





Production Chemistry Issues

Corrosion
System integrity and structure deterioration

Wax
Formation and facility damage, flow restrictions and blockage

Asphaltene
Flow restrictions and blockage, emulsion, and stabilization

Emulsion
Fluid flow and phase separation

Scale
Formation and facility damage, flow restrictions and blockage

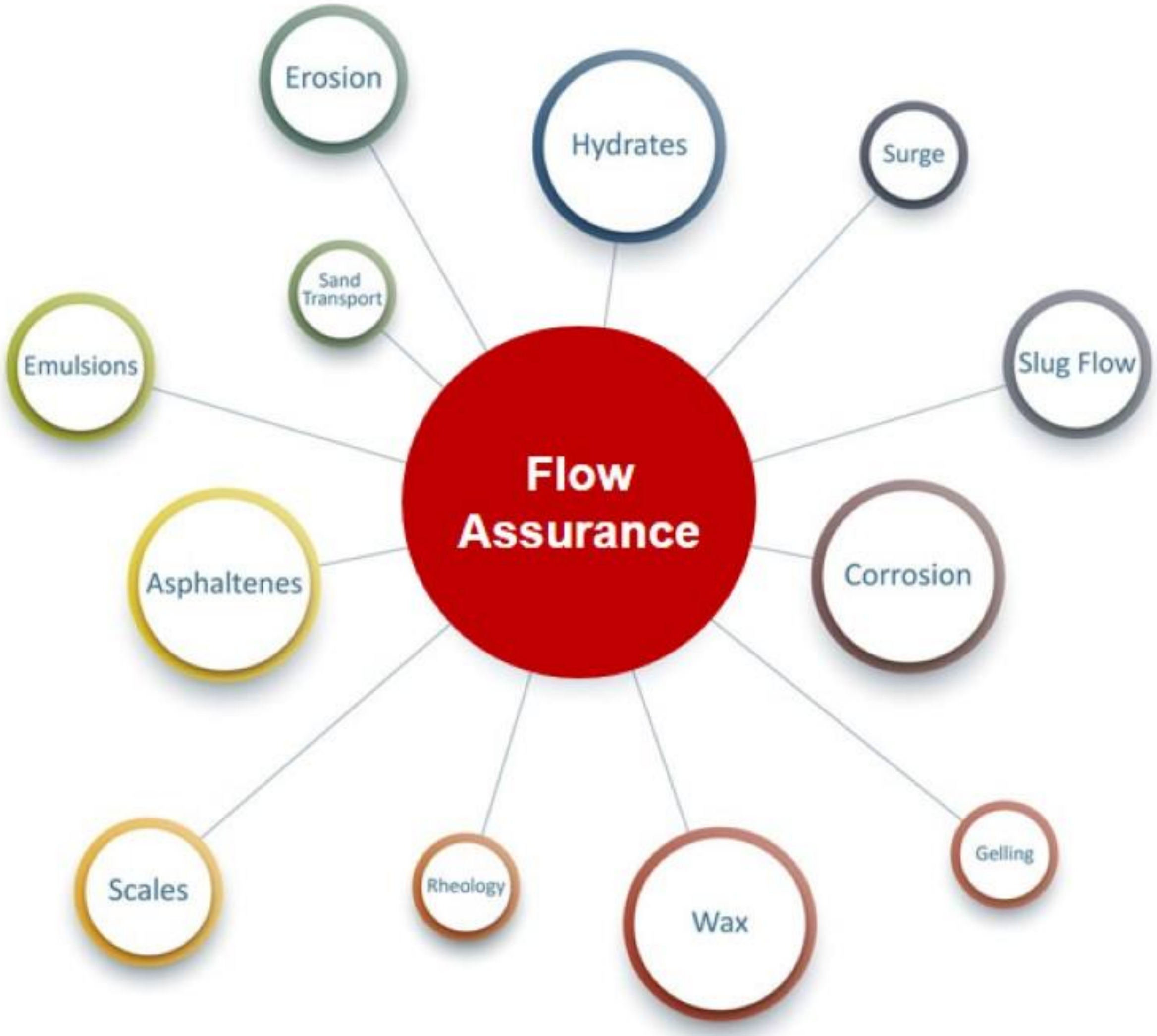
Hydrate
Flow restrictions and blockage, and safety issues

Microbes
Bio-corrosion, biofouling, reservoir scouring, chemical degradation

After Chemdustry

Flow Assurance Challenges

- Flow Assurance aims to address a number of threats related to design and operation of any system that conveys hydrocarbon fluid, with consideration also given to ancillary systems (injection or artificial lift).
- **Developments and operations challenges:**
  - Solids deposits: wax, hydrates or Asphaltene
  - Problems associated with multiphase flow behavior: slugging
  - Corrosion and erosion can affect the integrity of the system, particularly if velocities and shear rates are not managed, while sand transport/deposition can exasperate these issues.
  - Fluid rheology can impact the thermo-hydraulic performance of a system: emulsions lead to elevated viscosities at increased water-cuts until the inversion point is reached.



Challenges

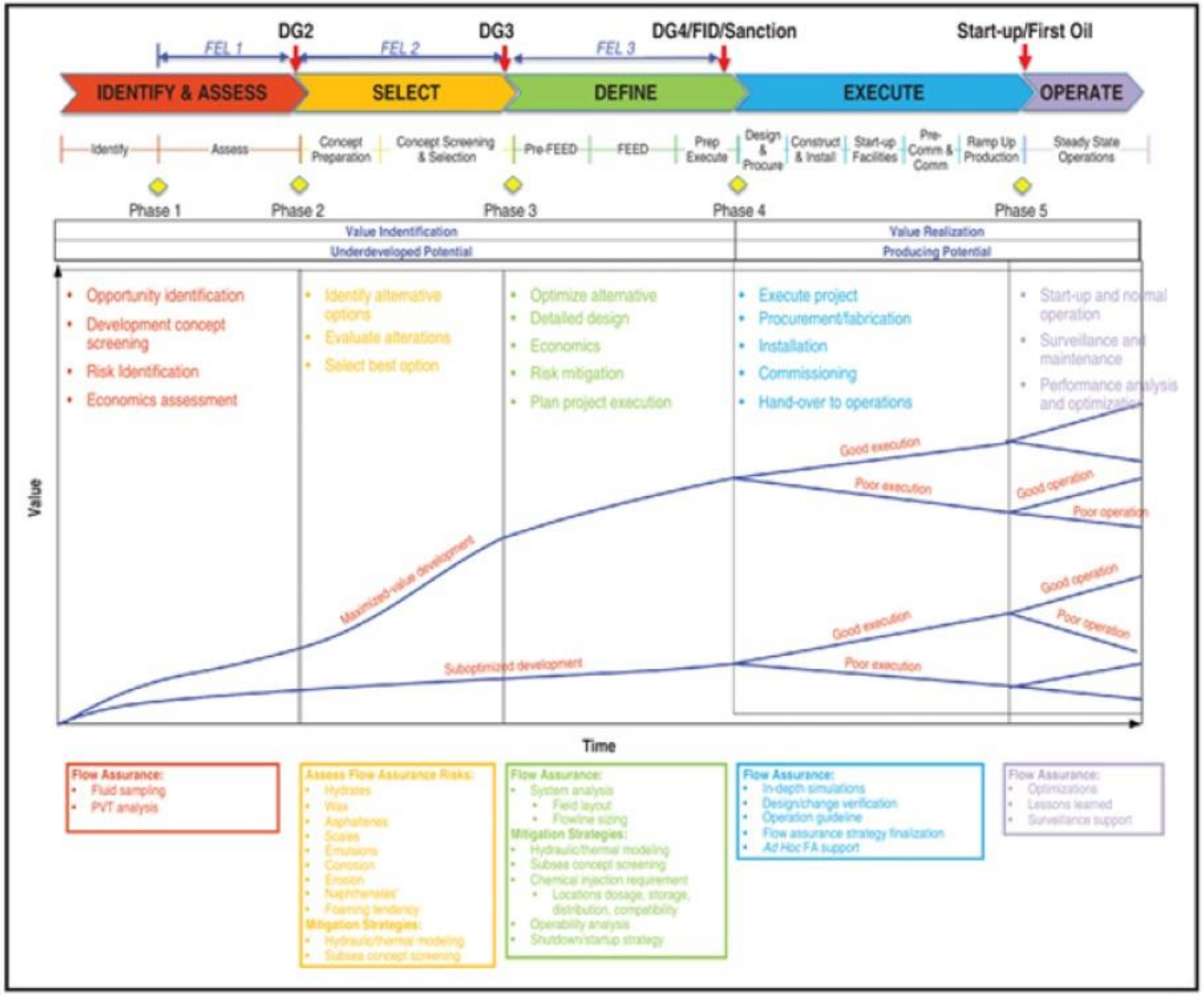
- With offshore development migrating into ever-deeper waters, the industry is relying on subsea technology to facilitate increased oil and gas recovery while lowering costs and improving safety and operating efficiencies.
- The deepwater reservoirs being developed today also are becoming more challenging, with greater subsurface depths, higher pressures and temperatures, and more complex fluid systems.
- Given these trends, the need has never been greater to understand flow assurance risks and design effective strategies to mitigate those risks.
- Flow assurance can be expressed as the coupling of multiphase flow and fluid phase behavior.
- It requires understanding both steady-state and transient multiphase flows, as well as fluid properties, fluid compositions, pressure volume temperature (PVT) characteristics, and other fluid phase behaviors from the reservoir to the topsides process equipment throughout the life of field to prevent upset conditions.

Challenges

- Flow assurance strategies are on the critical path to reducing overall development costs and ensuring safe and reliable subsea production operations.
- Since it has such a significant impact on field development and production system design, it is important to establish at an early phase of project planning whether flow assurance is needed.
- From the earliest stages onward, flow assurance operating philosophy should permeate each phase of field development engineering and project execution revealed as flow assurance design requirements. System modeling helps identify design limits and potential production issues.
- The best opportunity to make a positive impact on the life cycle of a major subsea capital project is during the early conceptual and planning stages before a financial investment decision has been made.
- Front-end loading (FEL) is the process for the conceptual development of a project and refers to the preproject planning stage, feasibility analysis to verify the project is technically and commercially viable, conceptual planning, front-end engineering design (FEED) to determine the basic specifications for the production facility and early project execution planning.

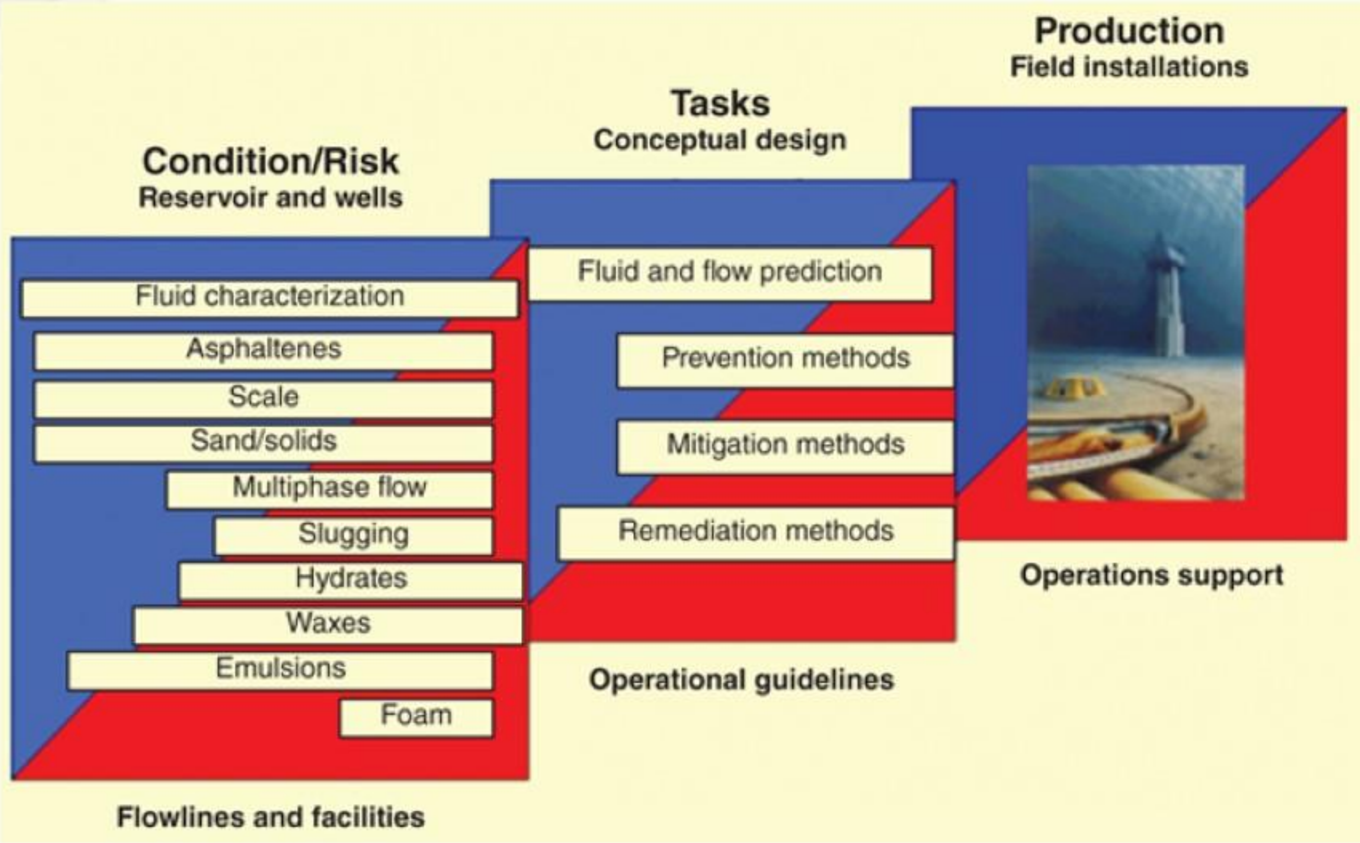
Flow Assurance in Project Development

- The early stage in a development project's life cycle is the time when the ability to influence changes in design is relatively high and the cost to make those changes is relatively low.
- Develop sufficient strategic information and engineering analyses to address risks and guide decision making for concept screening exercises.
- Then the FEED can maximize the potential for success.
- Sufficient FEL is the key to any successful project, and early engagement of flow assurance is critical for field development and production system concept selection.



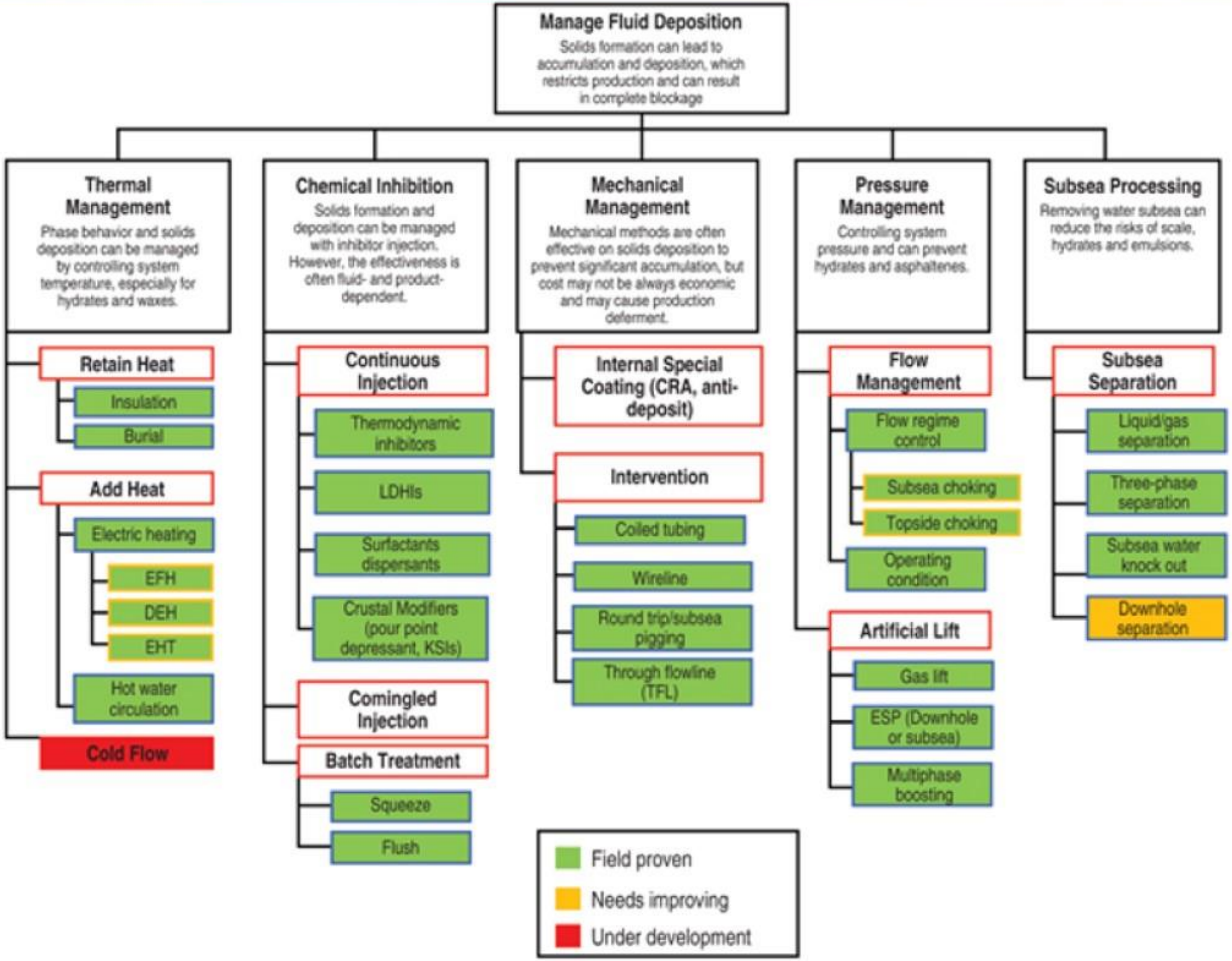
Flow Assurance Matrix

- Three questions to be answered for problems that can impede flow over the life of a development project:
- **Are there flow assurance risks in any operational scenarios?**
- **How often will the risks require treatment?**
  - If the risk is hydrates, for example, answering this question will require investigating how often flowline conditions would allow hydrates to form and require remediation based on flow simulations for steady-state conditions as well as startup/shutdown conditions.
- **Can the potential problem be managed effectively by thermal, mechanical and/or chemical means?**
  - For hydrates, the solution could be thermal (insulation or heat tracing), mechanical (pigging), chemical (inhibitor) or a combination.



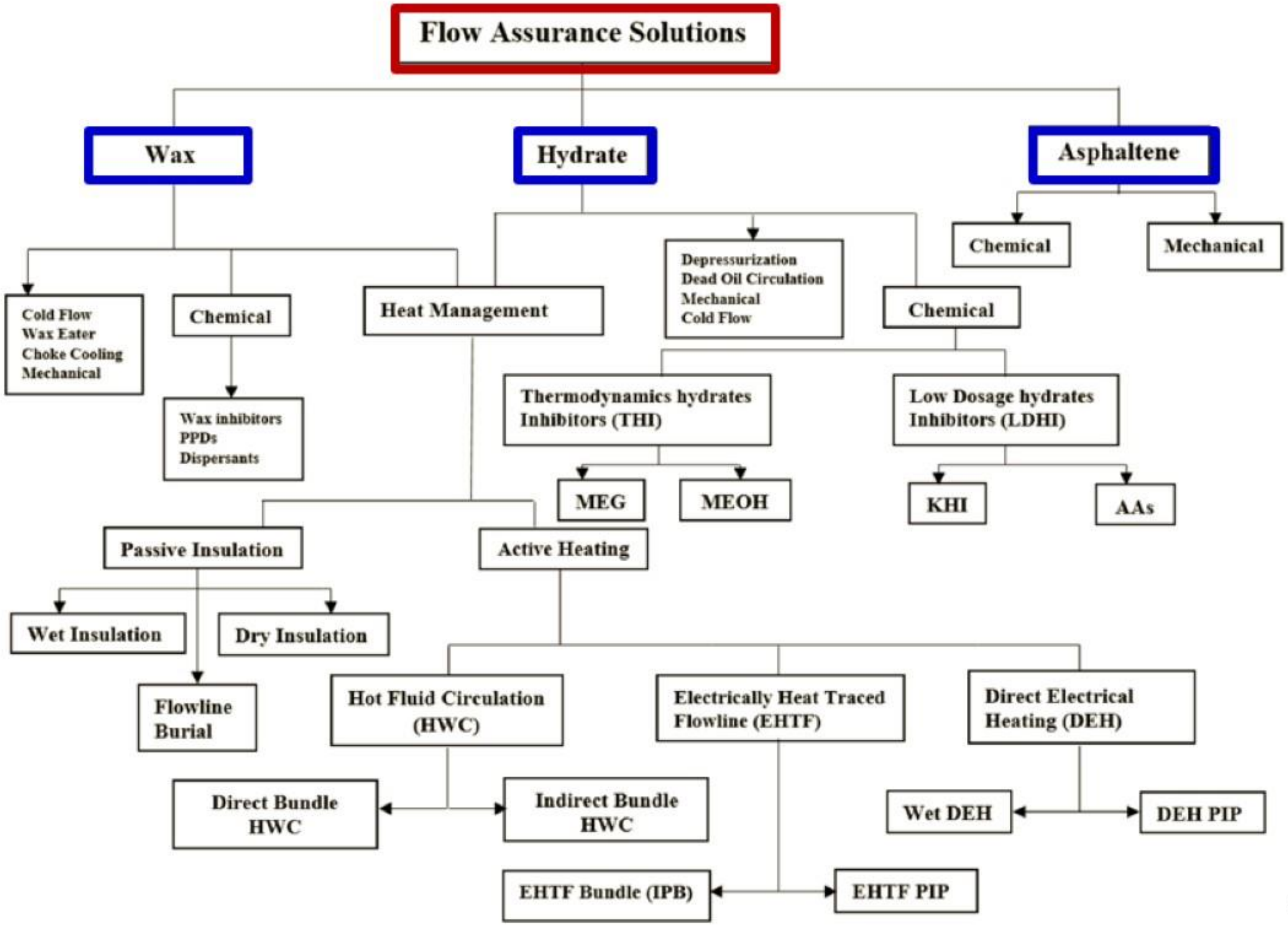
Fluid Deposition Management

- Techniques to manage flow assurance risks, including preventing problems related to the deposition of hydrates, paraffin, scales and other solids.



Flow Assurance Solutions

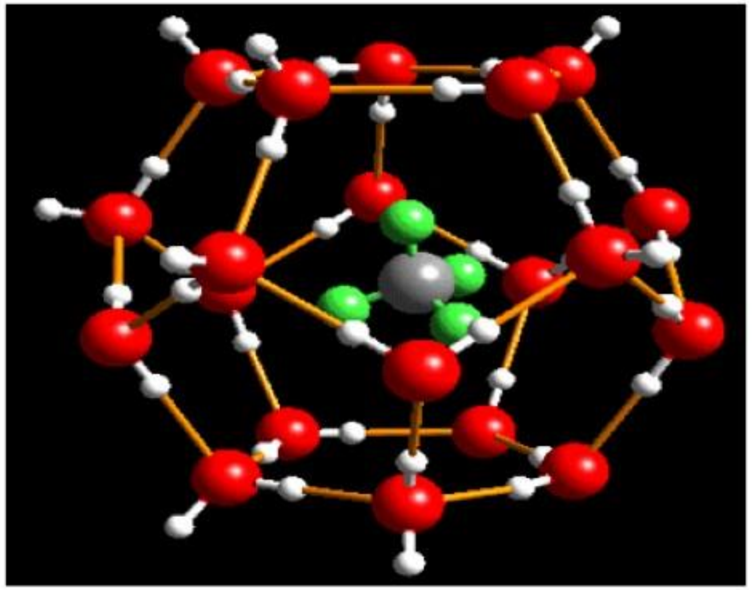
- Figure summarizes the flow assurance's solution flowchart for wax, hydrates, and Asphaltene.



What is Gas Hydrates?

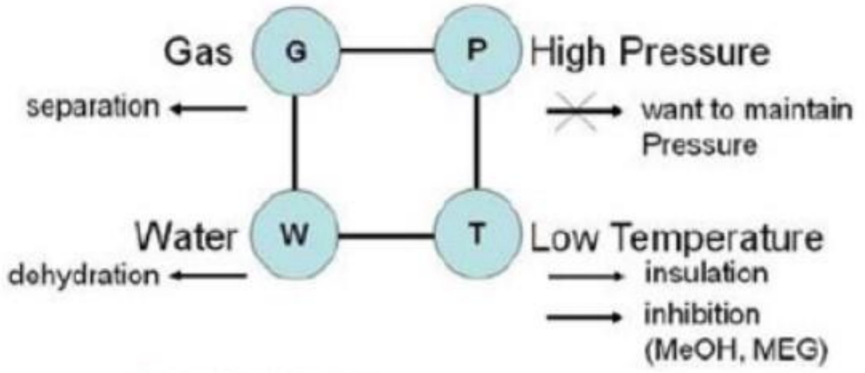
- **Gas hydrates are solid crystalline compounds, resembling ice or wet snow in appearance, but much less dense than ice.**

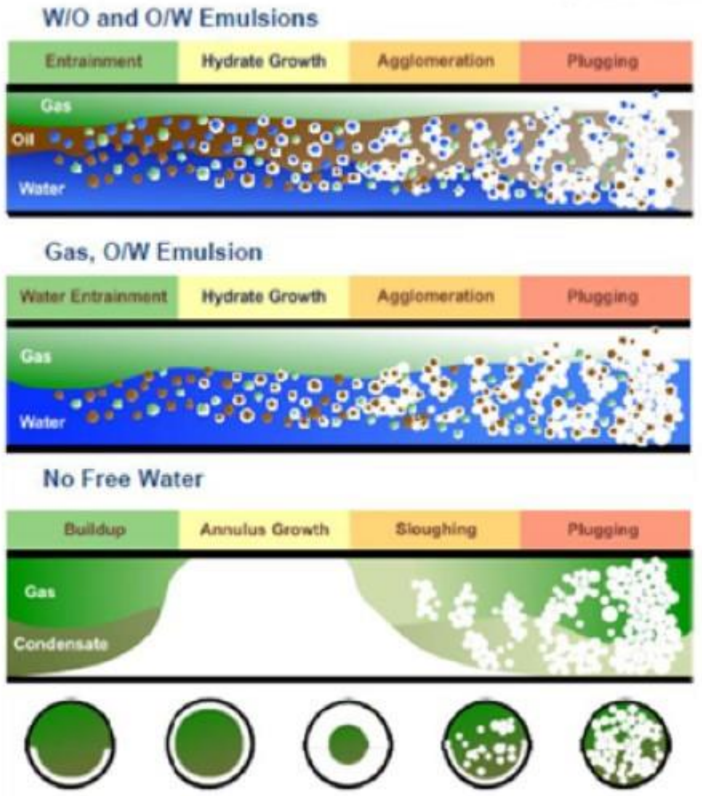
- **How Gas Hydrates are Formed:**
  - Natural gas hydrates are formed when natural gas components enter the water lattice and occupy the vacant lattice causing the water to solidify at temperatures higher than the freezing point of water
  - Hydrate is a crystalline solid consisting of gas molecules (C1 and CO2) each surrounded by a cage of water molecules



Hydrates

- An ice-like solid that forms when
  - Sufficient water is present
  - Hydrate former is present (C1, C2, and C3)
  - Right combination of P and T
- Control strategy
  - Maintaining temperature above hydrate formation conditions (Insulation, DEH, etc.)
  - Decreasing the pressure outside the area of possible hydrate formation (for remediation)
  - Removing the water (Subsea processing)
  - Continuous injection of chemicals
    - MEG is the most popular hydrate inhibition strategy for long distance tie-back systems





Hydrate Mitigation

- Insulation
  - Pipe-in-pipe
  - Wet Insulation
- Active heating systems
  - Hot Water
  - Electric
- Subsea Chemicals Injection
  - Methanol, MEG
  - LDHI
- Flowline Pressure Reduction

Thermodynamic Hydrate Inhibitors (THI)

Methanol

- Pros:
  - Low cost
  - Low viscosity
  - No fouling
- Cons:
  - More toxic
  - Too little can be worse than none at low levels
  - Inefficient to recover
  - Reduce hydrocarbon sales value
  - High loss to gas phase

MEG

- Pros:
  - Less toxic
  - Under-treating not as bad
  - Efficient to recover
  - Does not affect hydrocarbon value
  - Loss to gas phase negligible
- Cons:
  - High viscosity
  - Salts precipitation
  - Fouling by salt deposition

Hydrate Prediction & Prevention

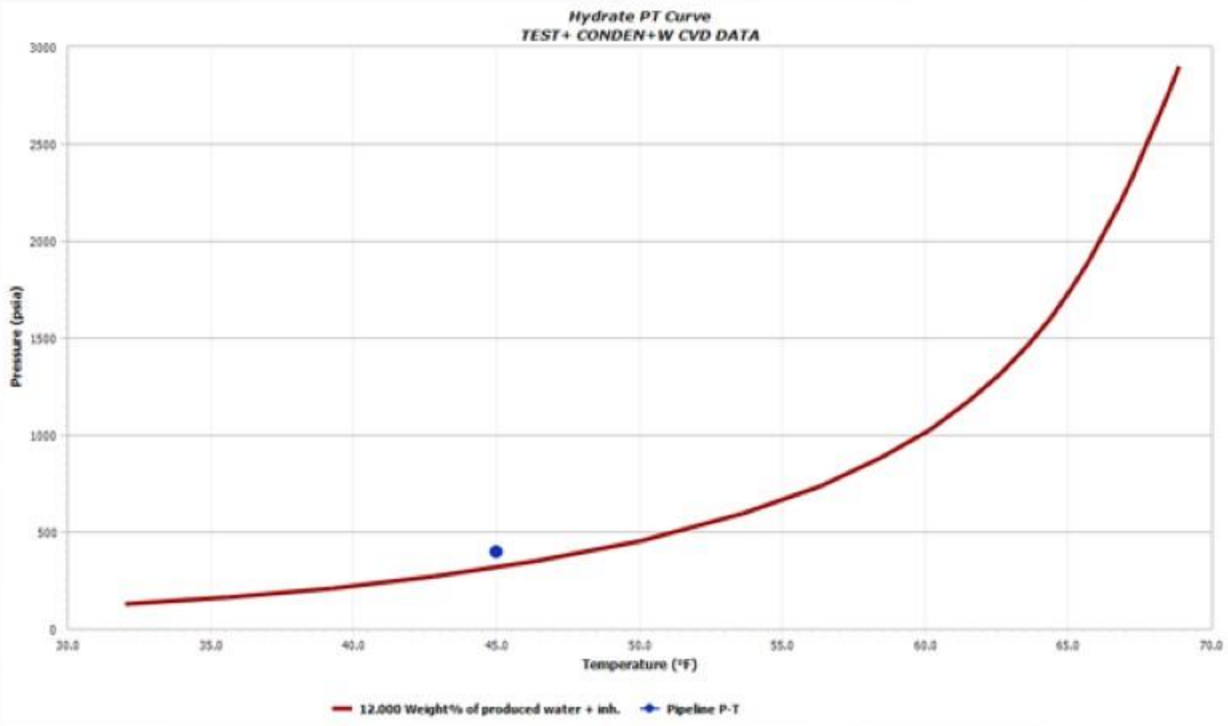
- **The amount of water phase may be defined as:**
  - %Water cut:
    - Water volume% of the total liquid at standard conditions.
    - If the water contains salts, the entered salt concentrations are in the water phase at standard conditions. Inhibitor components do not influence the water cut.
  - Mol produced water/mol feed (the selected fluid)
  - Mole% of feed + produced water
  - Weight% of feed + produced water

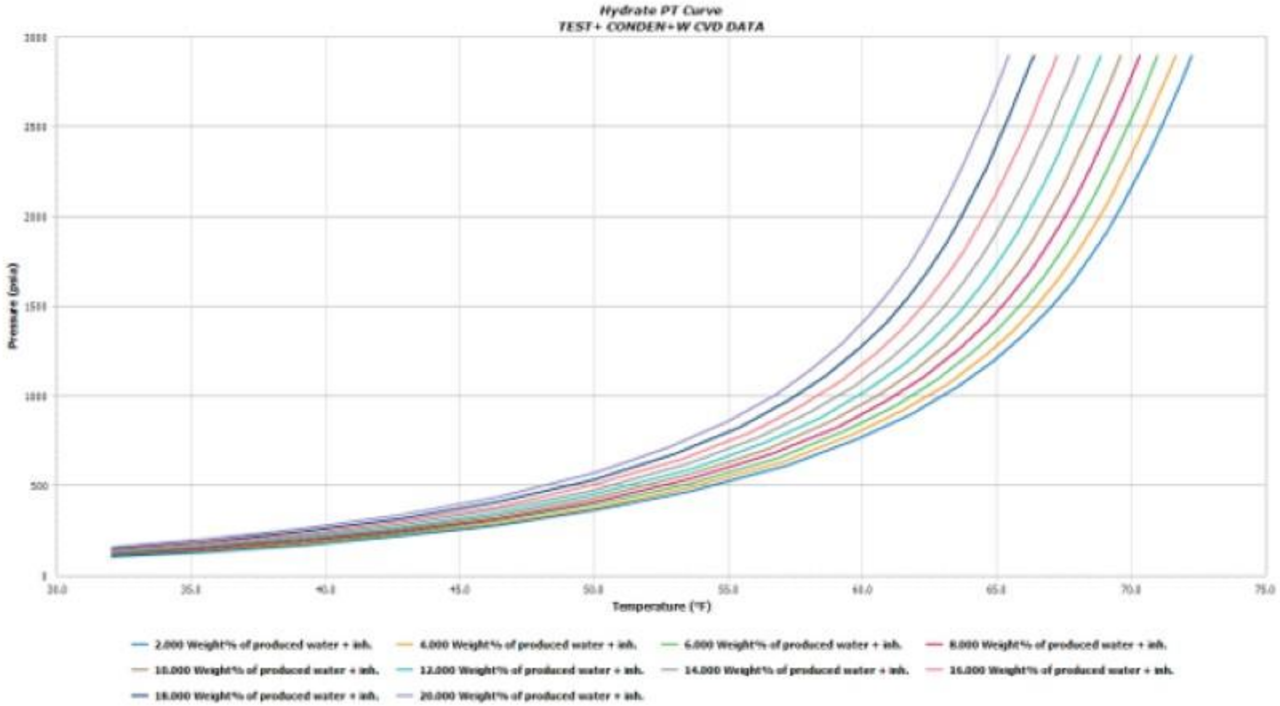
Hydrate Prediction & Prevention

- **Hydrate inhibitors may optionally be specified.**
- **If the selected fluid contains inhibitors, the Inhibitor Specification frame will be disabled.**
- The inhibitor amount may be specified as:
  - Mol inhibitor/mol produced water
  - Mole% of produced water + inh(ibitor)
  - Kg inhib(itor)/kg produced water
  - Weight% of produced water+inh(ibitor)

PHydrate PT Curve

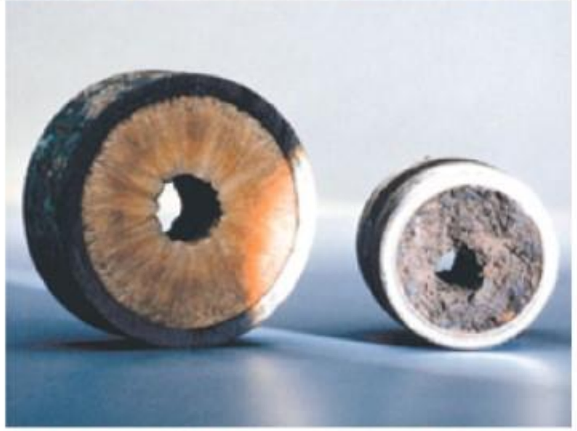
- Effect of hydrate inhibitor concentration on hydrate forming conditions.





Wax/Paraffins

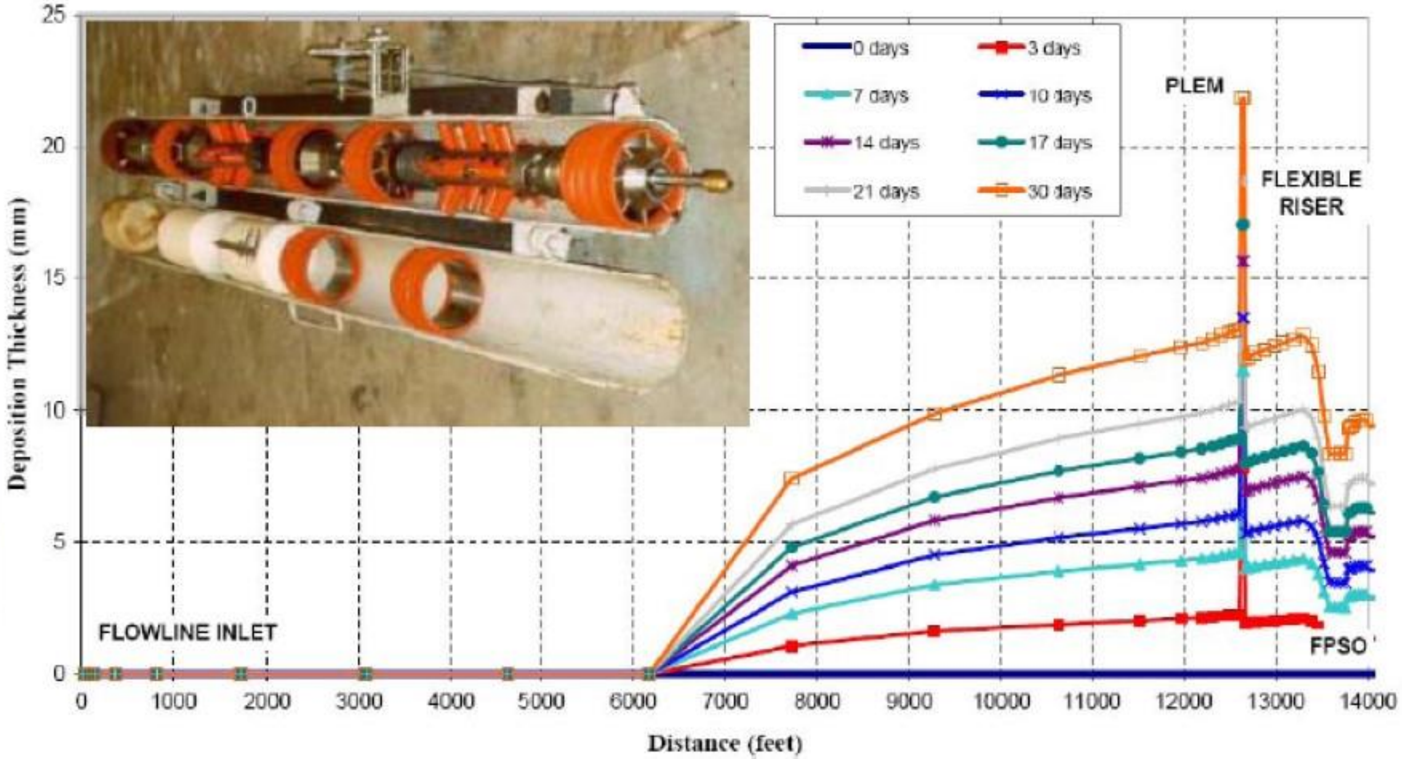
- Wide range of high molecular weight paraffins (alkanes or saturated hydrocarbons) in crude oil.
- Wax Appearance Temperature (WAT) or Cloud Point is the temperature at which the first wax crystals form.
- Pour Point is the lowest temperature at which an oil can be poured under gravity.
- Three major concerns:
  - **Wax deposition** on tubing or pipe walls during normal operation
  - **Gelling of the oil** during shutdown and subsequent restart
  - **Increases in viscosity** due to wax particles suspended in the oil during normal operation, low flow or turndown operation, or restart



Wax

- Paraffinic hydrocarbons (candle?)
  - A solid paraffinic hydrocarbon which precipitate from a produced fluid
  - Forms when the fluid temperature drops below the Wax Appearance Temperature (WAT)
  - Melts at elevated temperature (20 °F above the WAT)
- Control strategy
  - Rate of deposition can be predicted to calculate pigging frequency
  - Flowline insulation
  - Wax inhibitor
  - Major factors
    - WAT
    - Fluid temperature
    - Overall U-value
    - Deposition rate

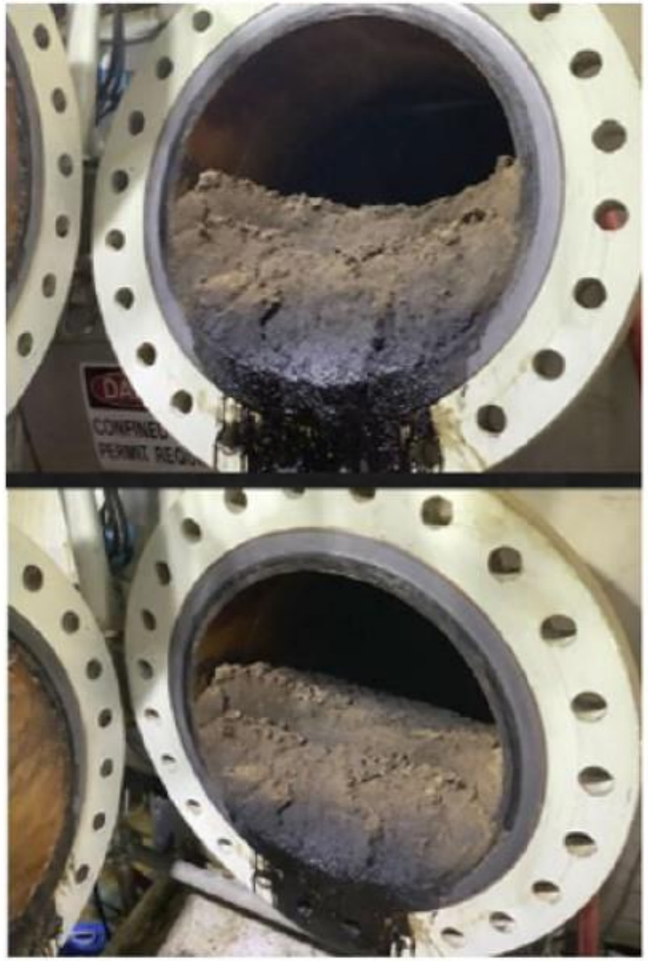


Asphaltenes

- Heavy molecules, highly heterogeneous.
- Difficult to predict, particularly deposition.
- Asphaltenes can deposit in formation, wellbore tubing, flowlines, and topsides.
- Asphaltenes can precipitate due to
  - Drop in pressure
  - Mixing of two different fluids
  - Gas lift
- Asphaltenes can cause emulsion problems

Sand Production

- Small quantities of sand are typically produced from oil and gas reservoirs
- Sand can have detrimental impacts on production
- Erosion
- Increase corrosion
- Can form restrictions or plugging
- Settle in topsides equipment
- Sand transport
- Defines the minimum velocity can be defined for keeping the sand flowing with the produced fluid



Scale & Formation Water

- Deposit of inorganic compounds from formation water that becomes supersaturated due to P-T changes, or from the mixing of incompatible waters.
- Generally inorganic salts such as carbonates and sulfates of the metals calcium, strontium and barium
- May also be the complex salts of iron such as sulfides, hydrous oxides and carbonates

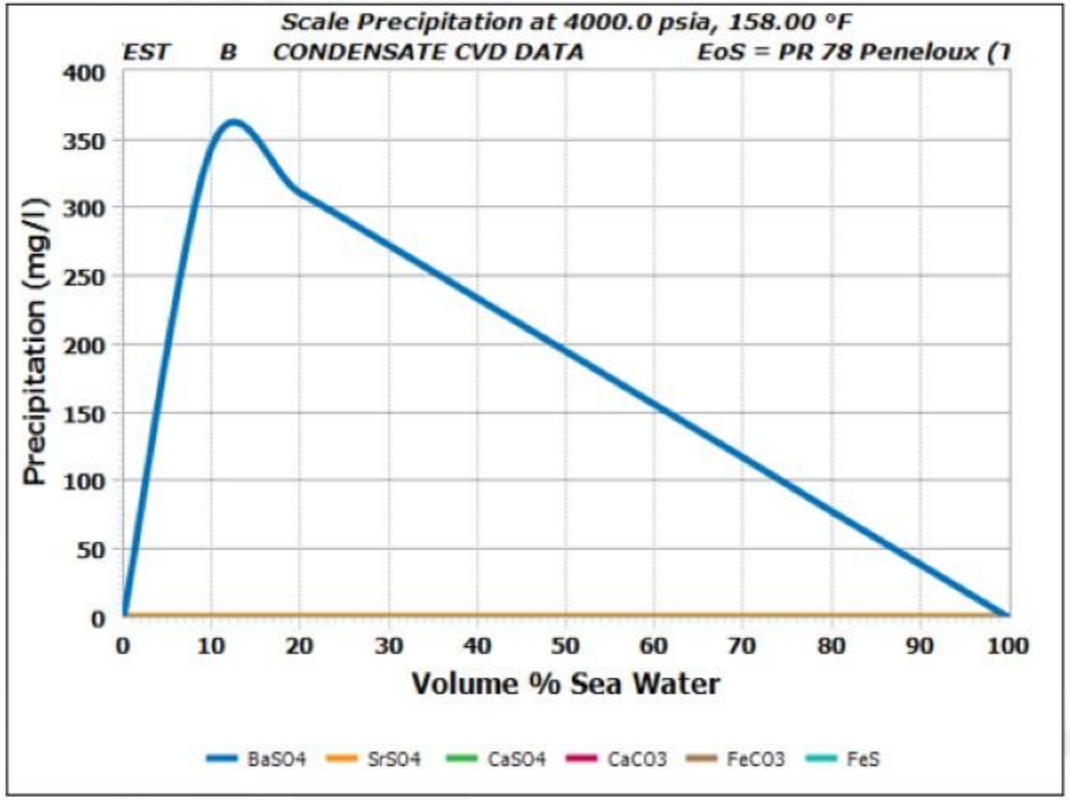
Barium Sulfate – BaSO4 (Barite)

- **Barium Sulfate** is the least soluble of the water formed scale types.
- Barium sulfate solubility increases with temperature.
- Because of this property, it may be more of a problem in source and producing wells.
- Its solubility also increases as the total dissolved solids content increases.
- Barium sulfate scales are non-reactive to acid treatment for the exception of hot, concentrated sulfuric acid.
- Barium sulfate is also non-responsive to forming coordination complexes.
- Due to these two "inert" characteristics, Barium Sulfate scales present large and expensive problems in the oil and gas production industry by plugging flow lines, piping, exchangers and other surface equipment.

Comparative Solubility	
Scale	**Solubility, mg/l**
Gypsum	2080
Calcium Carbonate	53
Barium Sulfate	2.3
It compares the solubility of the three scales discussed thus after in distilled water at 77°F.	

Scale Prediction

- An example of a formation water and a seawater analysis.
- The formation water will precipitate $CaCO_3$ at atmospheric pressure and for example 70 °C/ 158 °F.
- Mixing in seawater at these conditions will further lead to precipitation of $BaSO_4$ and $SrSO_4$.



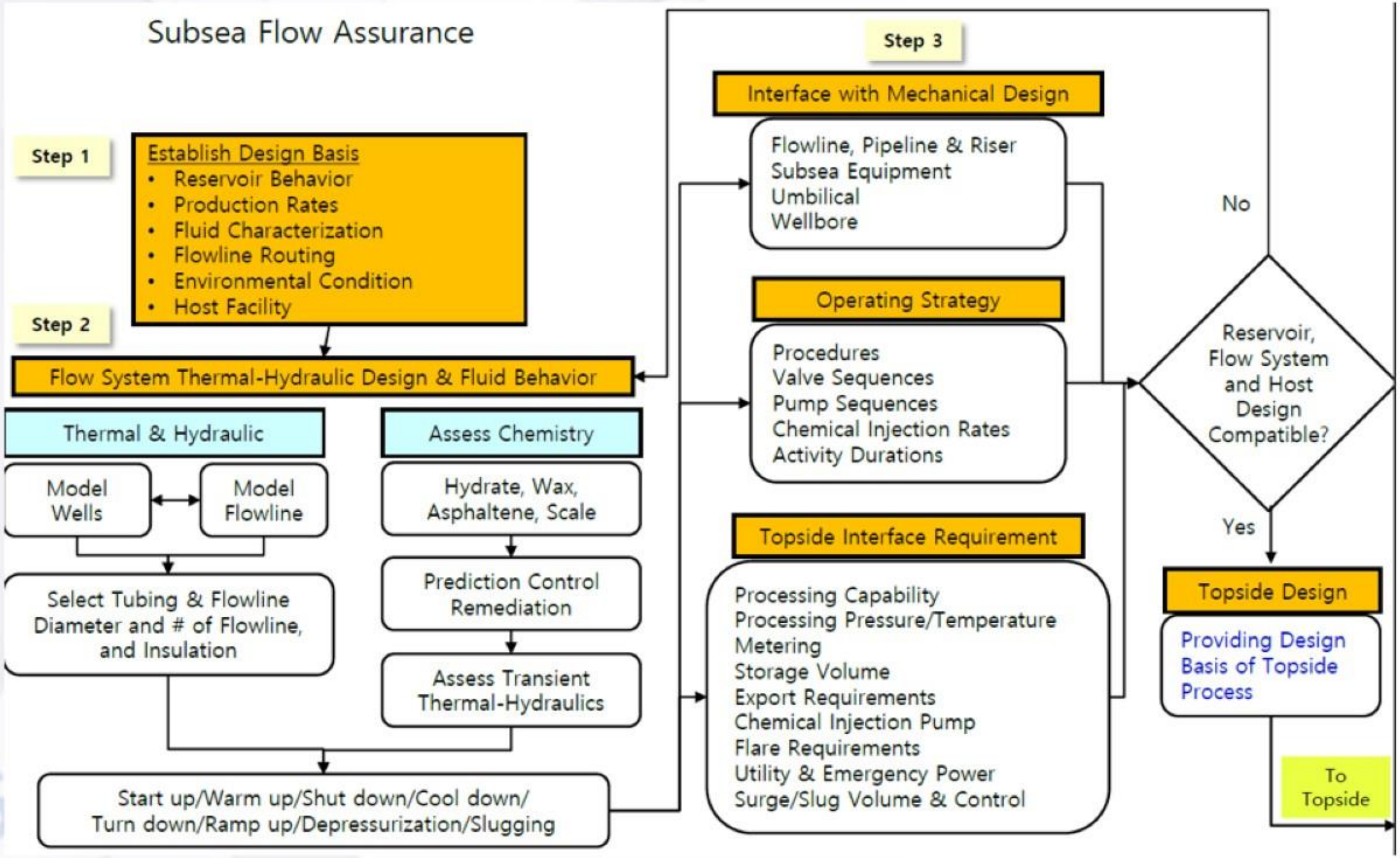
Ion	Formation Water	Seawater
	mg/l	mg/l
Na	15200	12100
K	380	0
Ca	1100	450
Mg	210	1130
Ba	230	0
Sr	0	9
Fe(II)	0	0
Cl	28000	20950
SO4	0	2300
Alk	250	170
HAc	0	0

Summary – Flow Assurance

- Simulation of subsea systems becomes an important discipline for design and operation of offshore platforms.
- It demands comprehensive understanding of multiphase flow and solid deposition.
- The simulation results are linked together in matrix form, thus stage work process is required.

Fluid characterization	Hydraulic analysis	Thermal analysis	Solid deposition	Production facilities
PVT data PVT modeling	Pipeline ΔP Inlet P - Arrival P	Steady-state Transient	Hydrate, Wax Asphaltene, Scale, corrosion, erosion	Subsea production Topside processing
Thermodynamic model: Equation of State Model Parameter Software: - PVTSim - Multiflash	-Topside Ultimate pressure, flow rate. -liquid holdup -Reservoir -manifold Prediction of pressure maximum production period.	Selection of pipeline insulation material and thickness. - Topside Calculation of temperature.	Selection of inhibitor injection amount, injection location, and pressure - MEG/MeOH - Wax, corrosion, asphaltene inhibitors.	Pipeline Inner Diameter Selection - Slug catcher Design - MEG spec - Inhibitor injection station

Flow Assurance Framework



THANK YOU

Hesham Mokhtar