Introduction to Scale Management and Flow Assurance

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Agenda

- **Flow Assurance:** Definition, Challenges, Sources, Scope, etc.
- **Hydrate:** Formation, Location, Risk, Detection Method, and Management
- **Paraffin:** Definition, Deposition, Affecting Factors, and Effects
- **Asphaltene:** Deposition and Stability
- **Scale:** Types, Deposition, Causes, Monitoring, and Inhibition
- **Corrosion:** Definition, Mechanisms, Prevention, and Evaluation
- Flow Assurance Remedial Actions

Webinar Assessment

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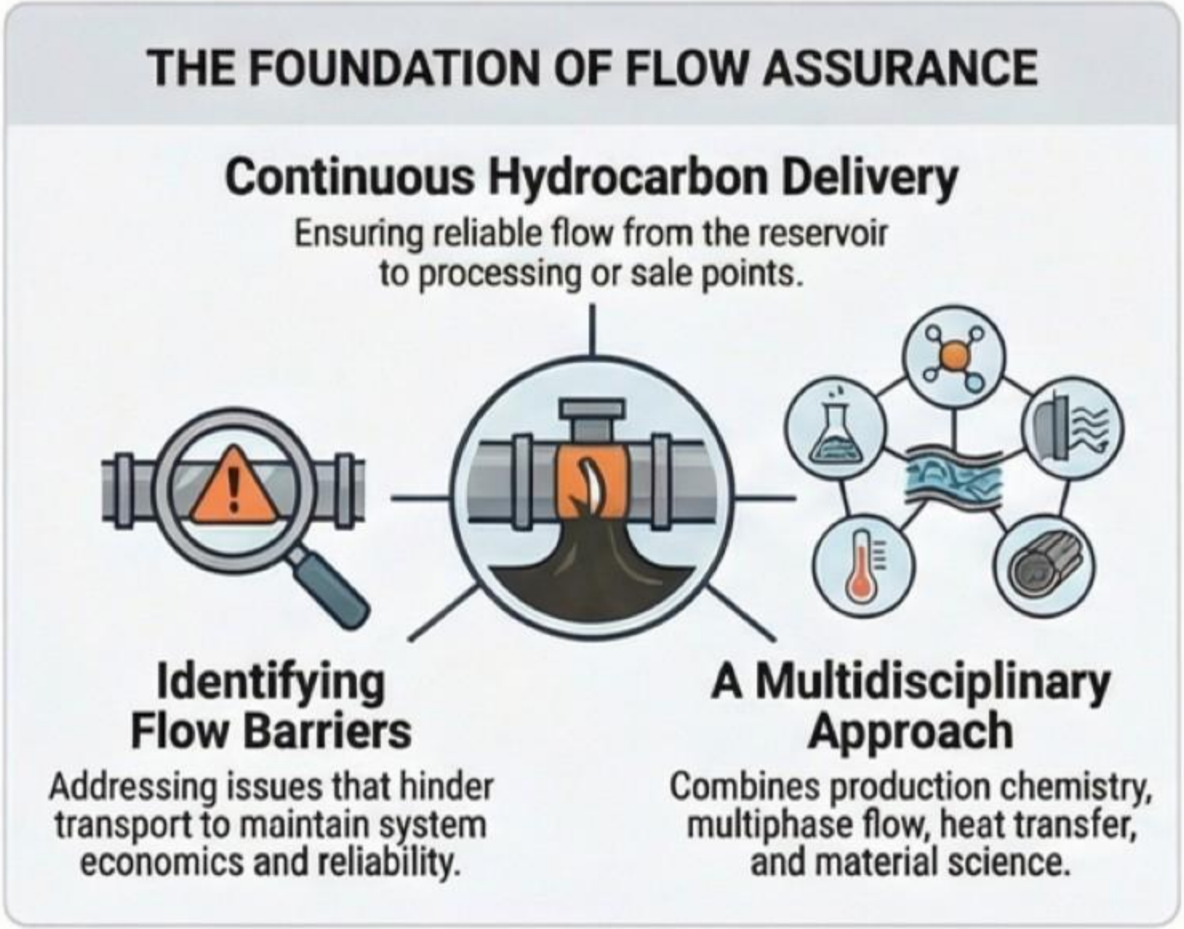
Oil and Gas Production and Transportation

- Oil and gas **production** operations involve the **extraction** of petroleum and natural gas from the Earth and the **separation and treatment** of these fluids at production facilities.
- The process starts with site preparation and **drilling**, followed by **well completion**.
- The whole process utilizes various equipment, chemicals, and ongoing monitoring to ensure safety and efficiency.

Flow Assurance Definition and Foundation

Flow assurance is a multidisciplinary process dedicated to maintaining the continuous and economical flow of hydrocarbons from the reservoir to the point of sale.

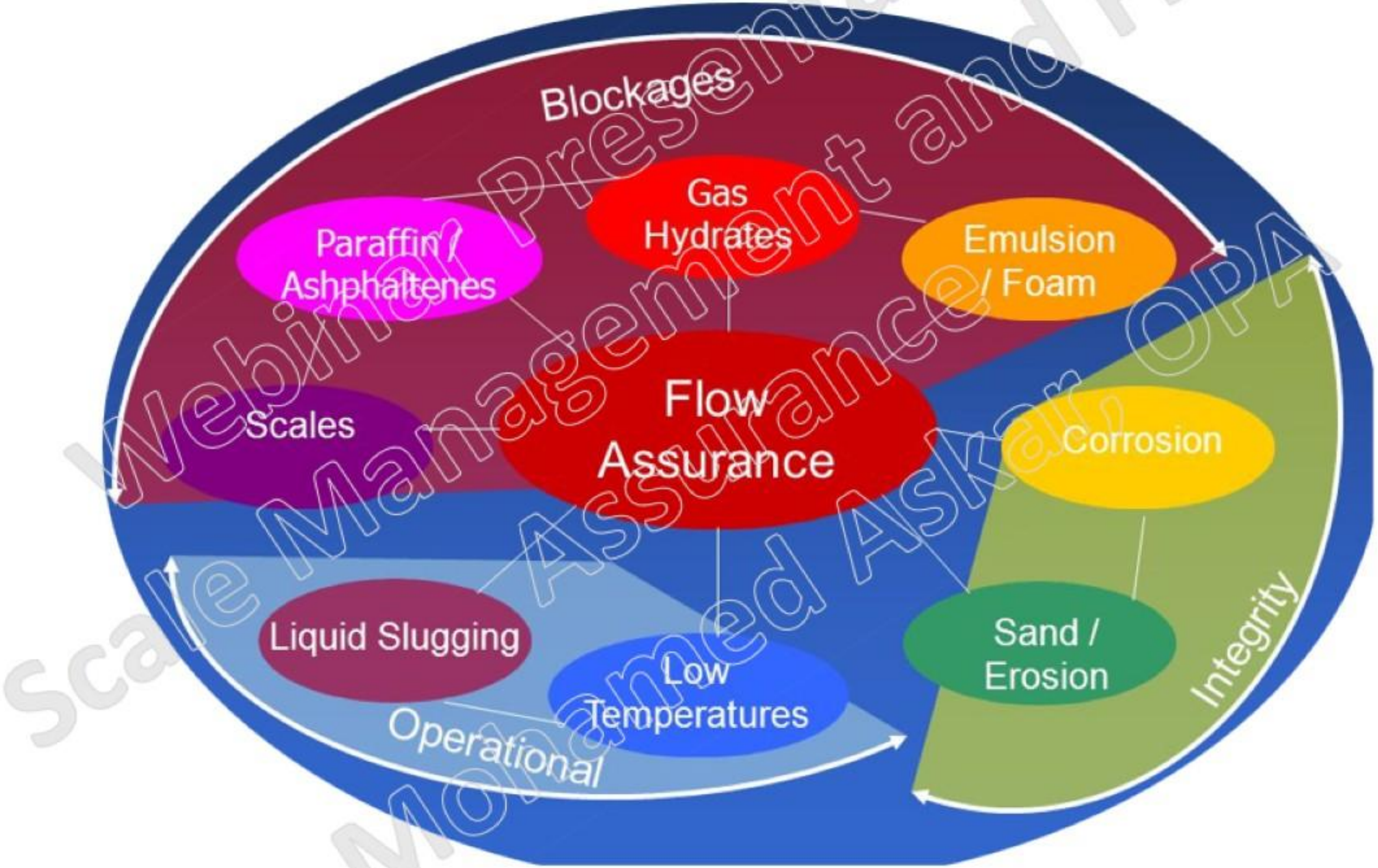
By combining chemistry, heat transfer, and material science, it identifies and mitigates various physical and chemical barriers within pipelines.



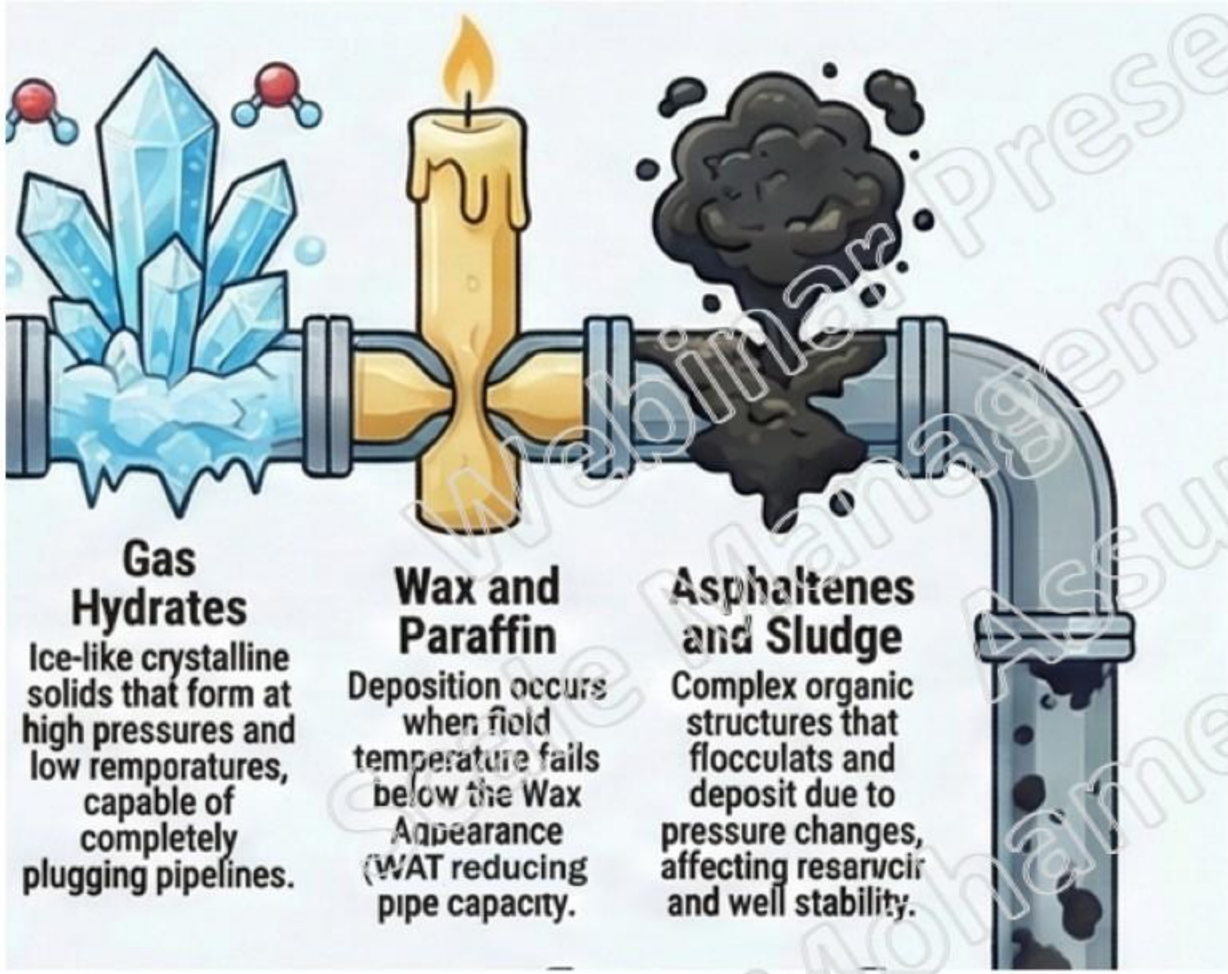
Definition of Flow Assurance

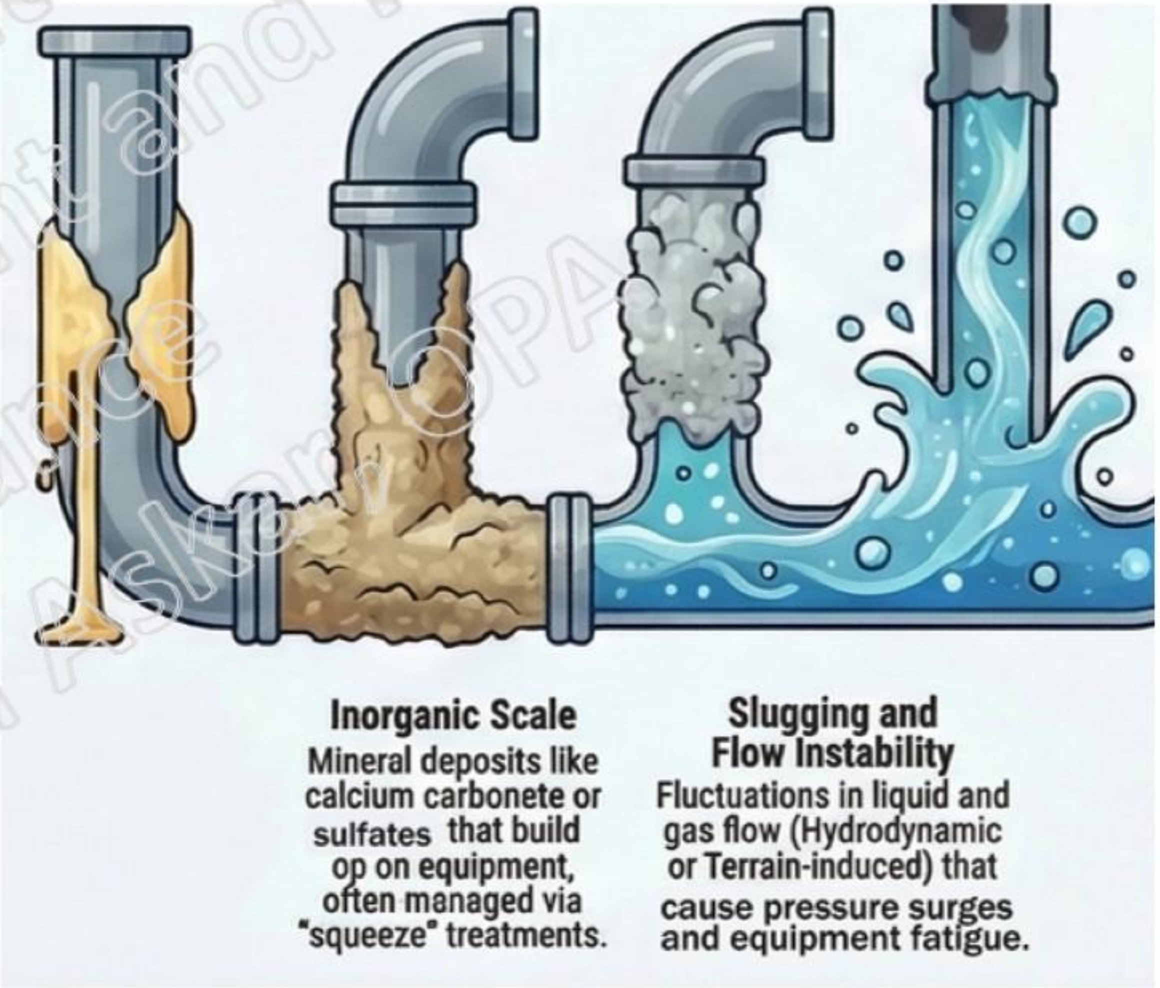
- Flow assurance is the process of ensuring the **continuous, reliable, and economical flow of hydrocarbons** (like oil and natural gas) from the **reservoir to the point** of sale or processing.
- It's a multidisciplinary field that combines **production chemistry, multiphase flow, heat transfer, and material science** to address potential issues that can hinder this flow.
- These issues include **hydrate** formation, **wax** deposition, **asphaltene** flocculation, **scale** build-up, **solid** transport, **emulsion, foaming, corrosion**, and **erosion.**

Potential Problems or Issues of Flow Assurance (Challenges of Flow Assurance)

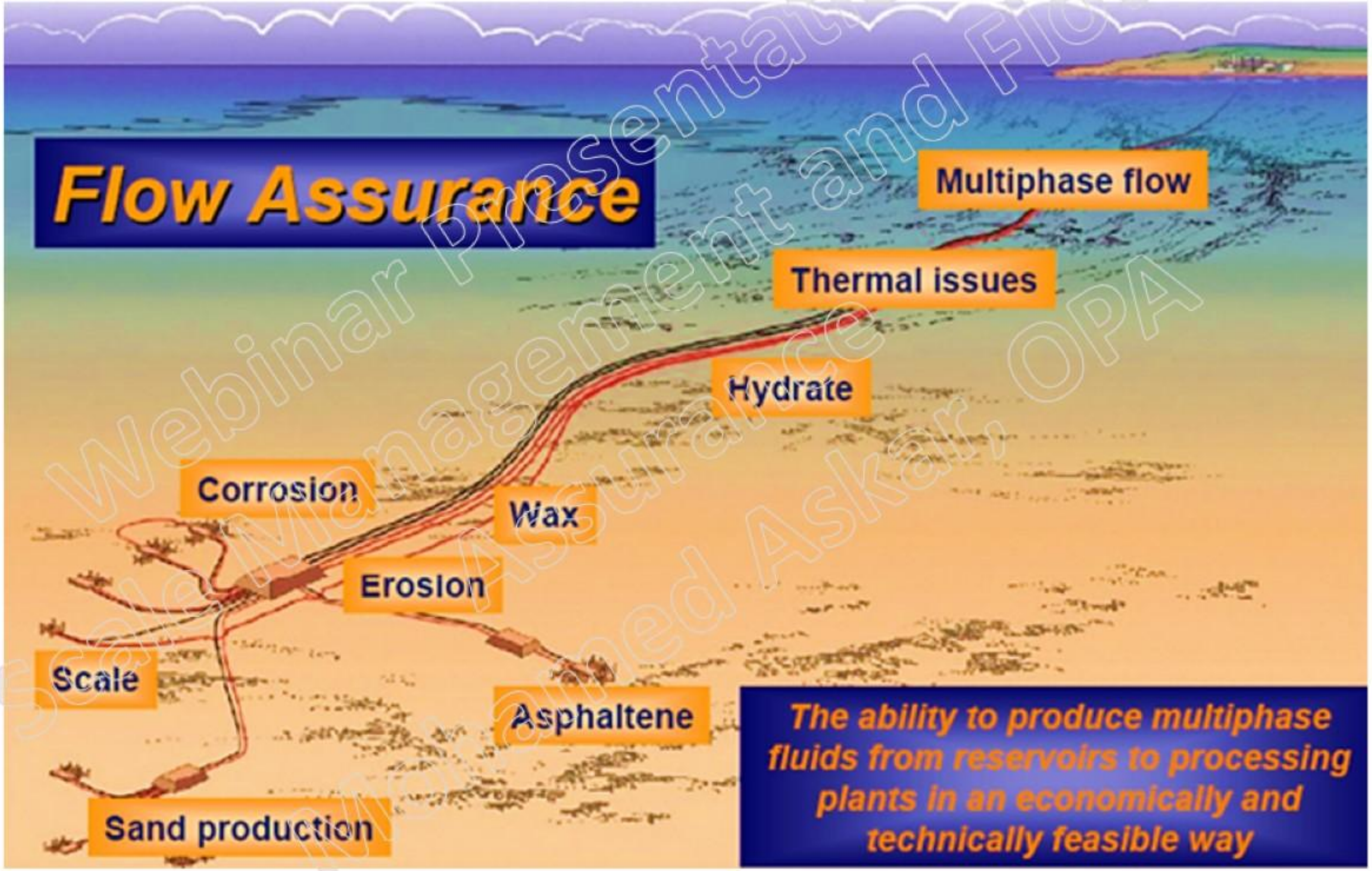


Definition of Flow Assurance





Challenges of Flow Assurance



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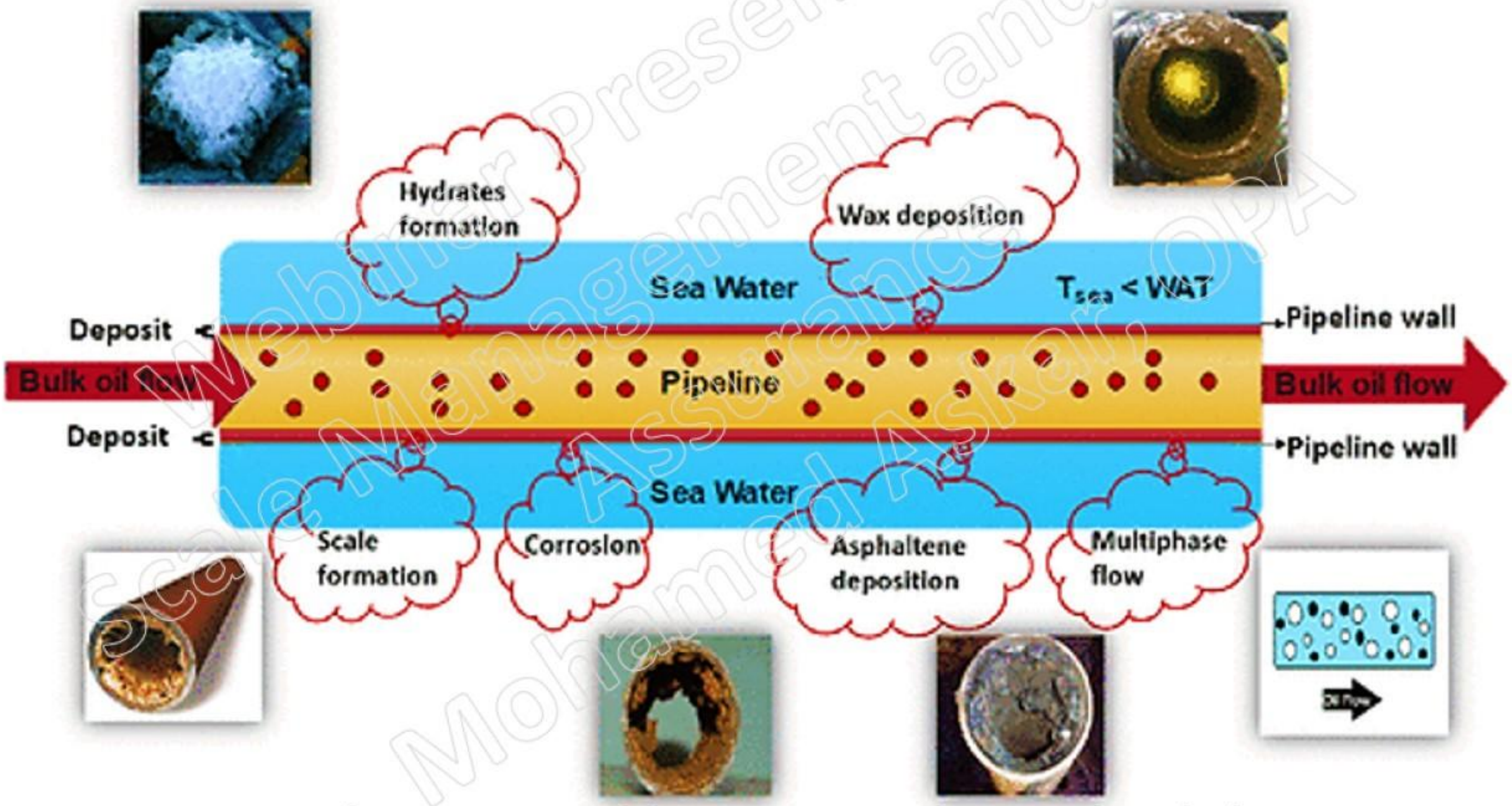
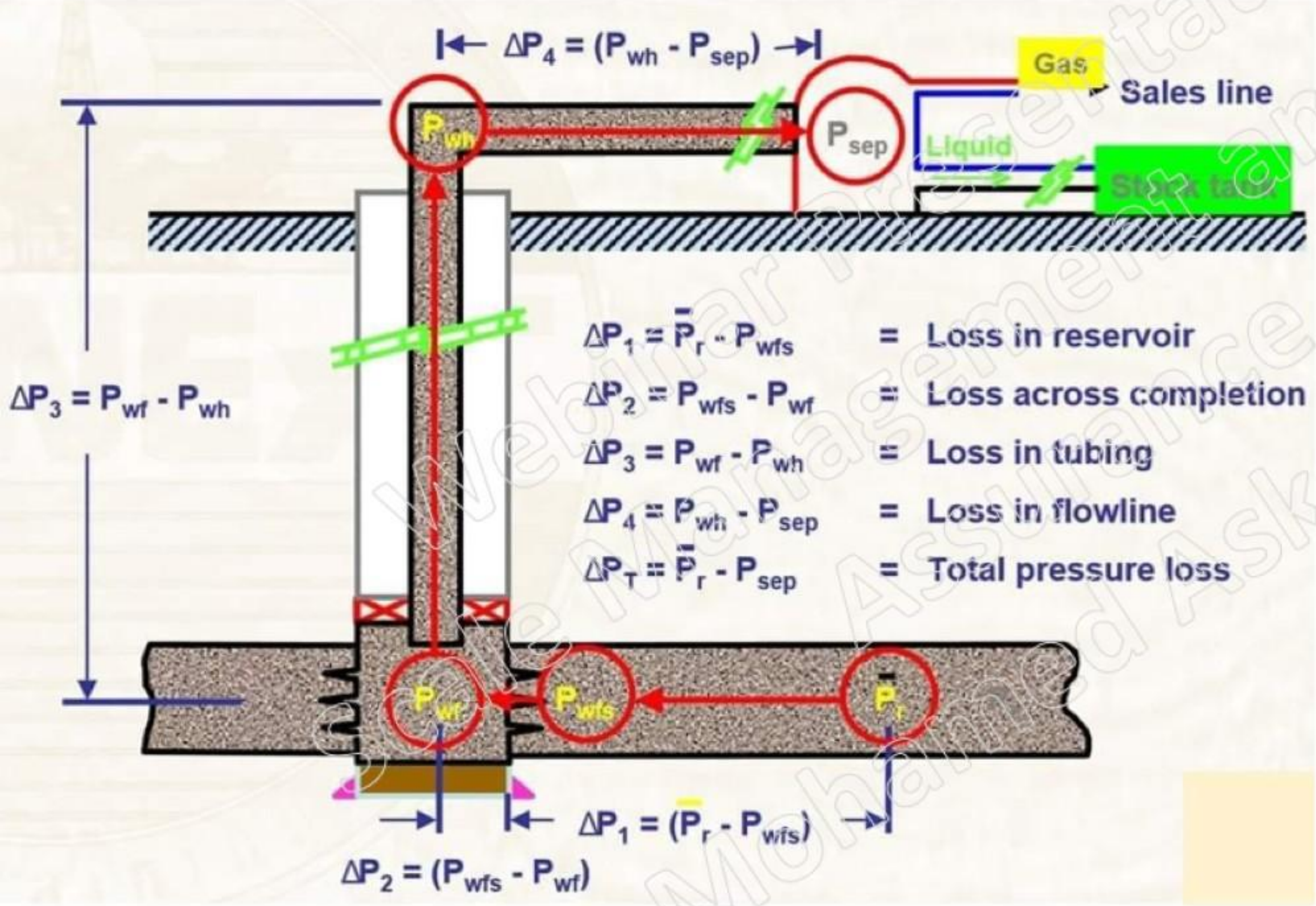
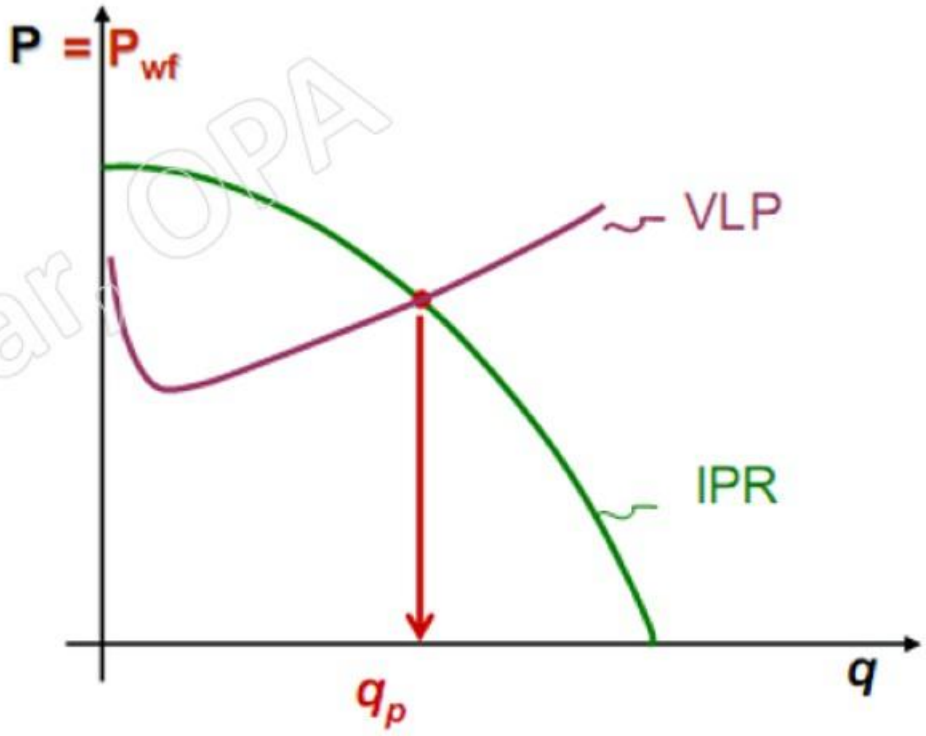
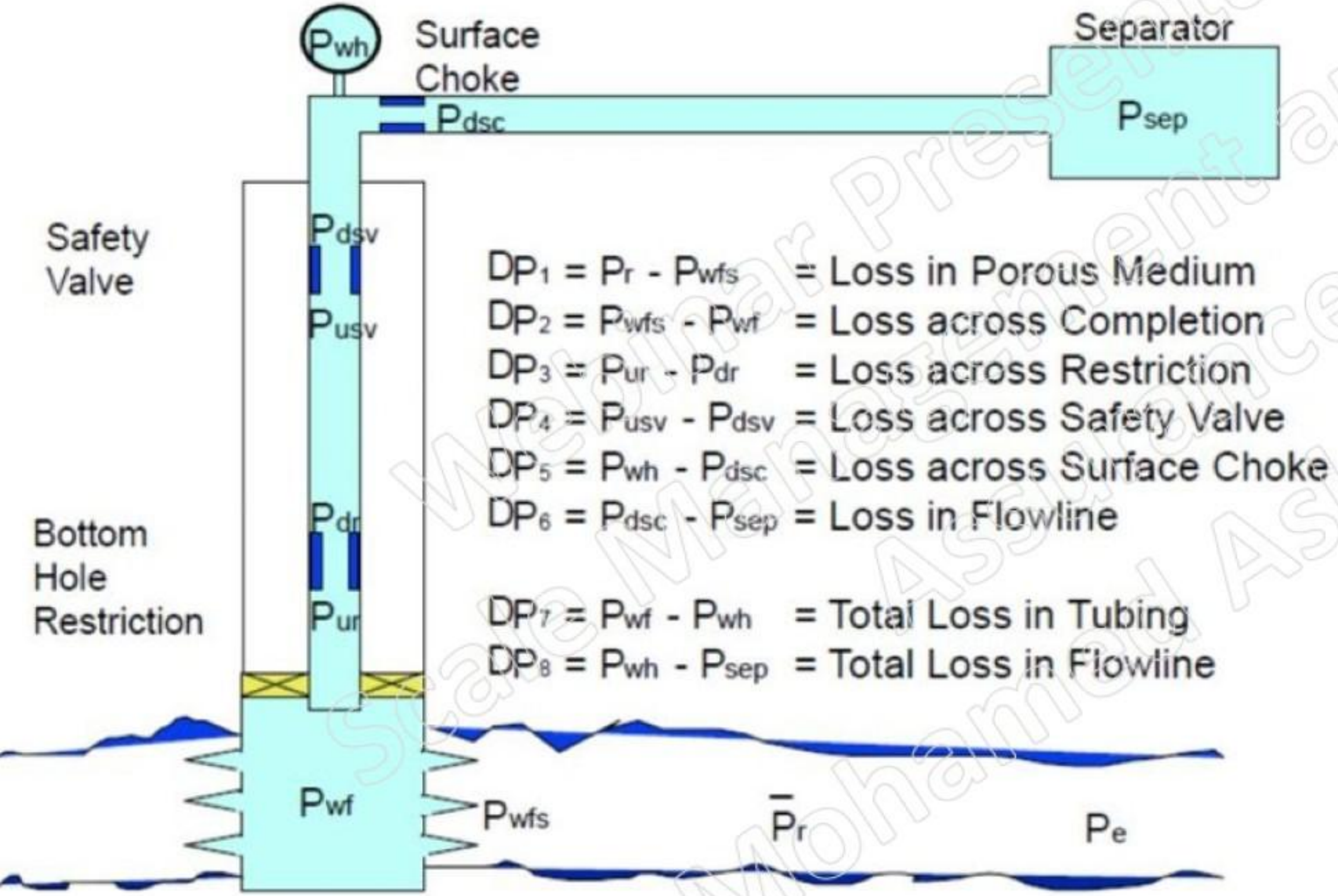


Impact of Flow Restrictions and Pressure Losses



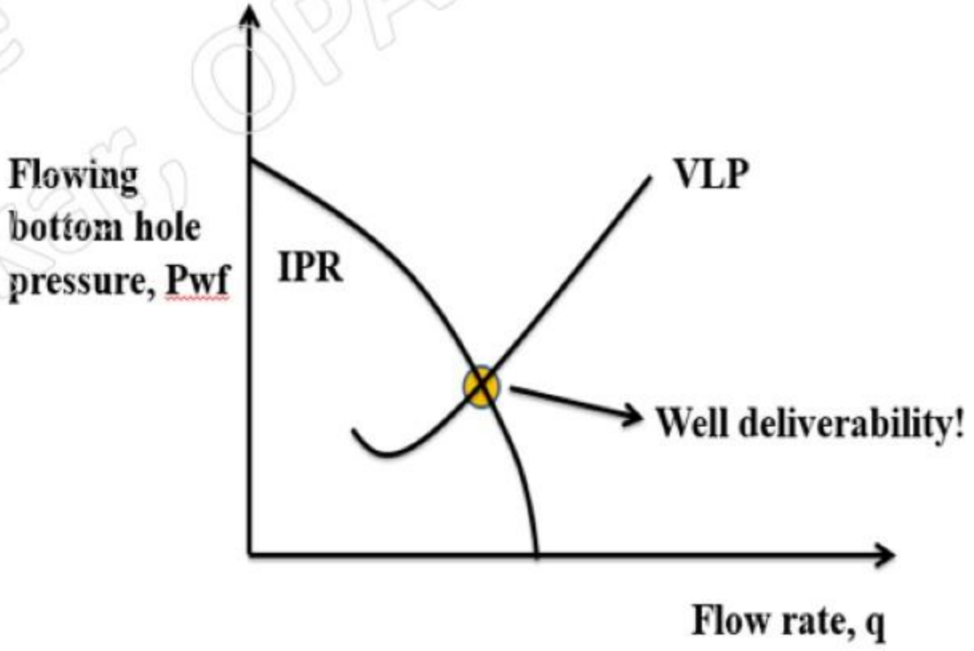


Impact of Flow Restrictions and Pressure Losses

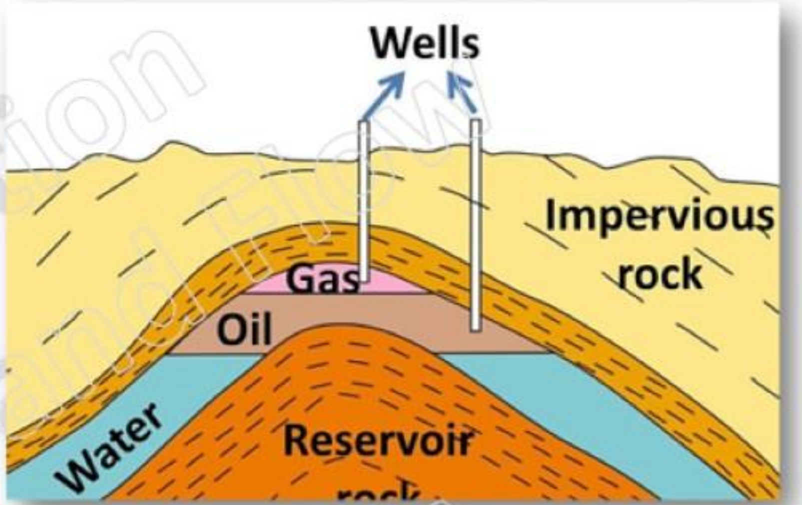


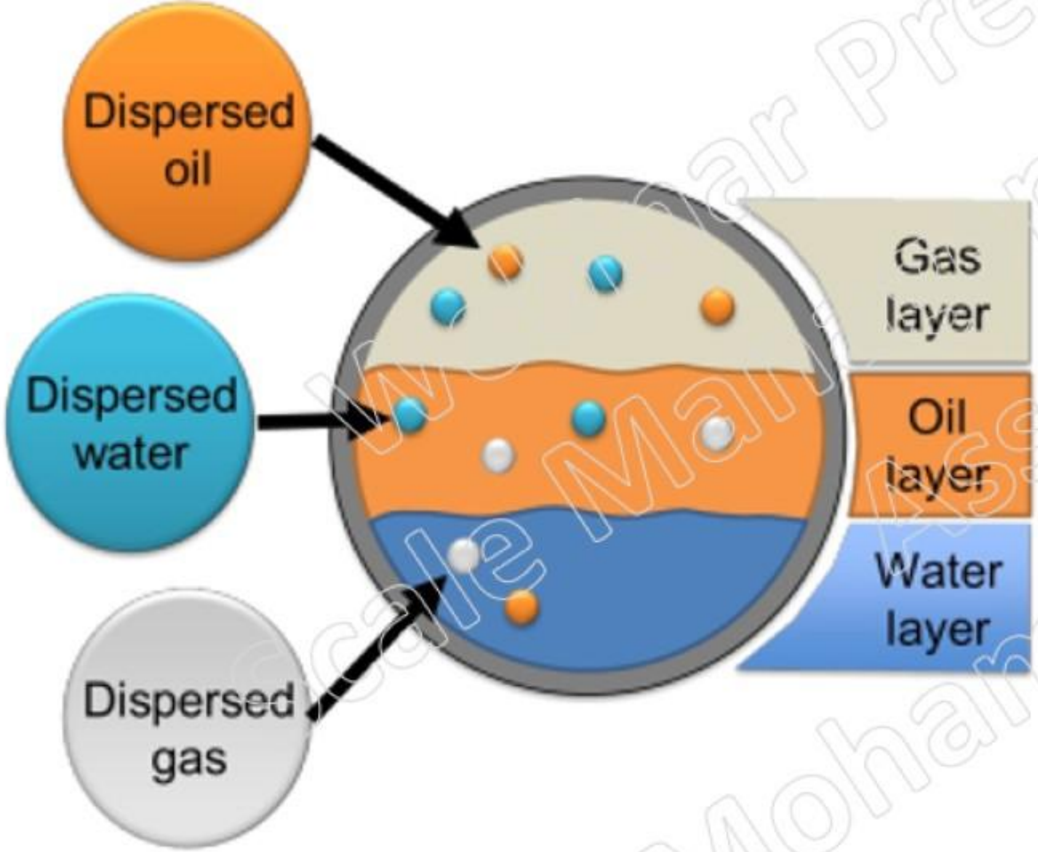
$DP_1 = P_r - P_{wfs}$ = Loss in Porous Medium
$DP_2 = P_{wfs} - P_{wf}$ = Loss across Completion
$DP_3 = P_{ur} - P_{dr}$ = Loss across Restriction
$DP_4 = P_{usv} - P_{dsv}$ = Loss across Safety Valve
$DP_5 = P_{wh} - P_{dsc}$ = Loss across Surface Choke
$DP_6 = P_{dsc} - P_{sep}$ = Loss in Flowline

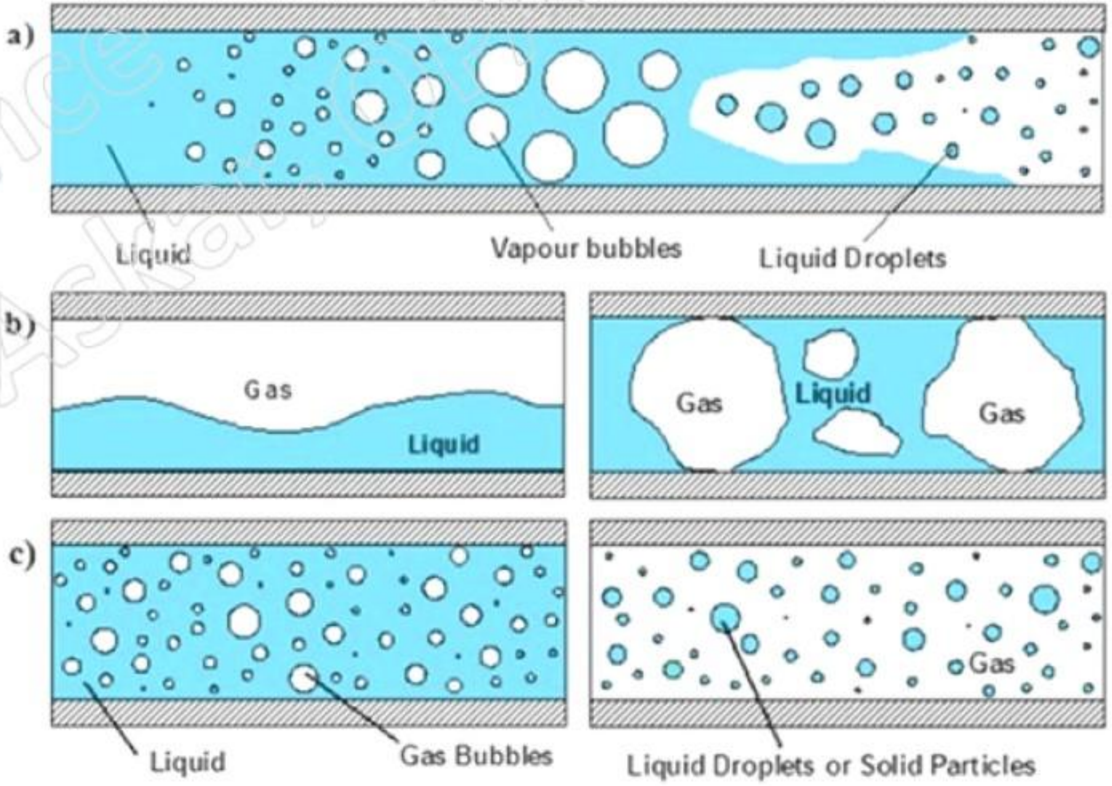
$DP_7 = P_{wf} - P_{wh}$ = Total Loss in Tubing
$DP_8 = P_{wh} - P_{sep}$ = Total Loss in Flowline



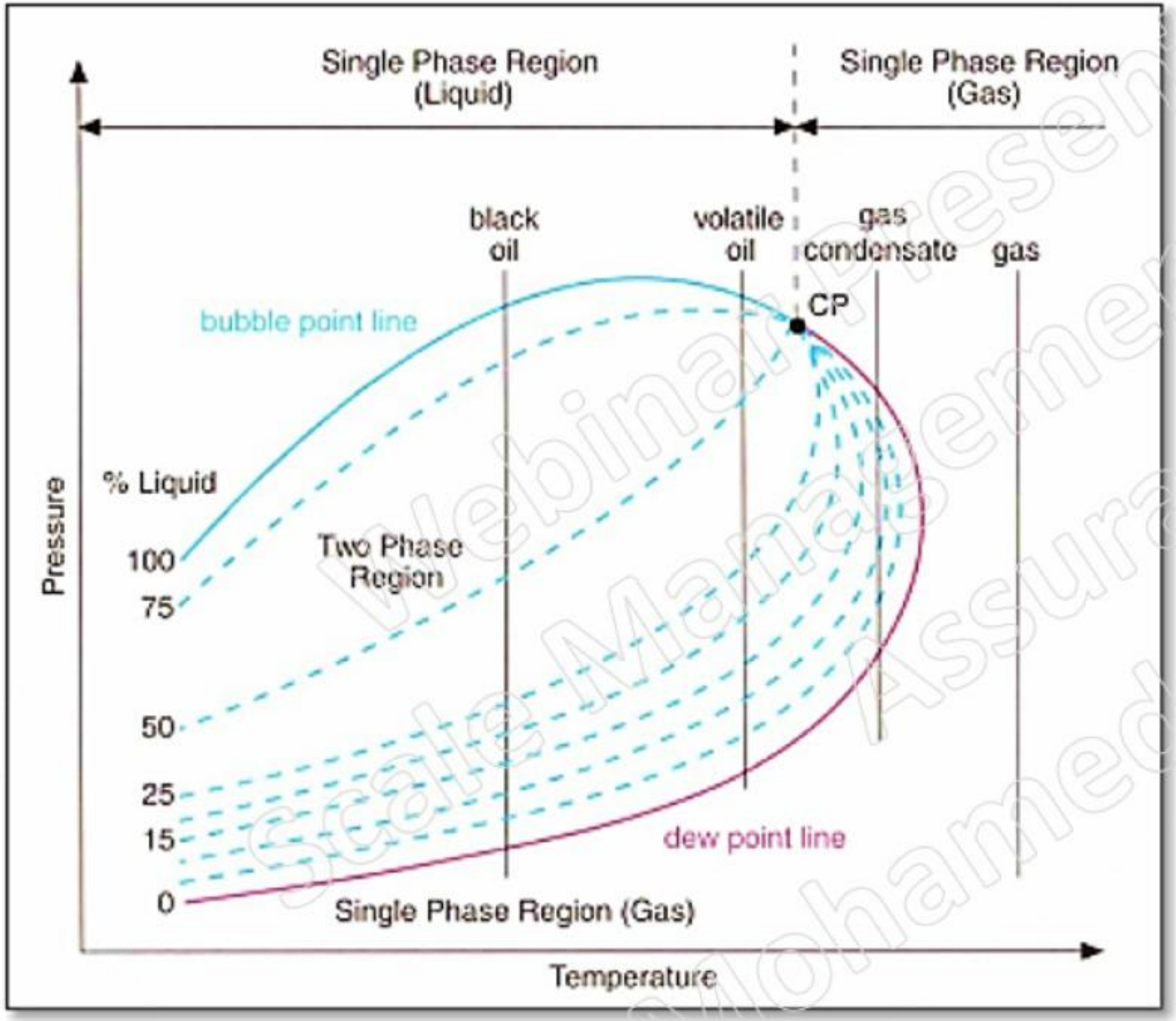
Fluid Flow

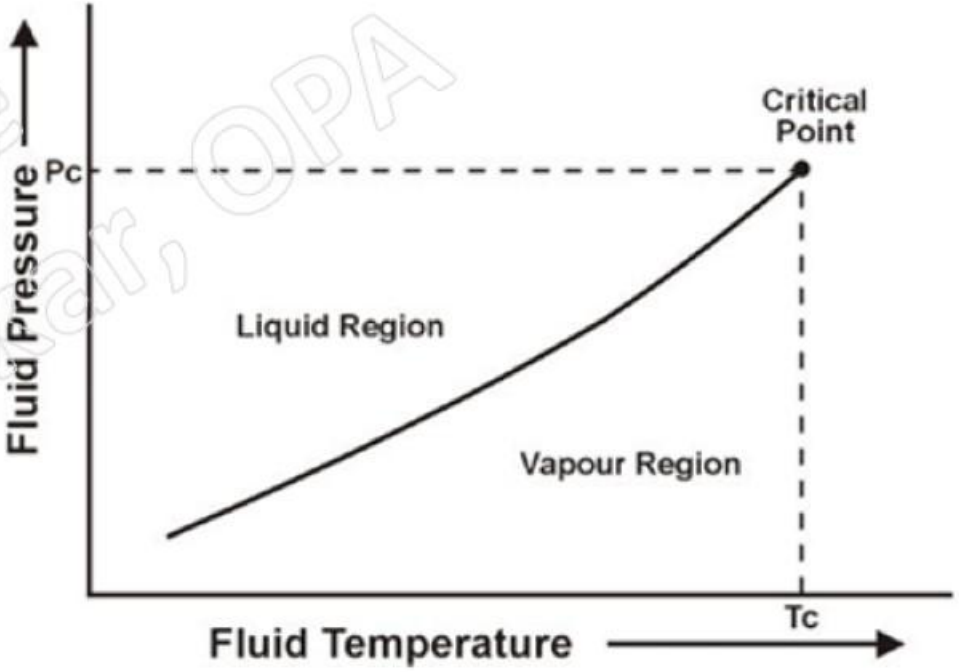

Wells
Impervious rock
Gas
Oil
Water
Reservoir


Dispersed oil
Dispersed water
Dispersed gas
Gas layer
Oil layer
Water layer

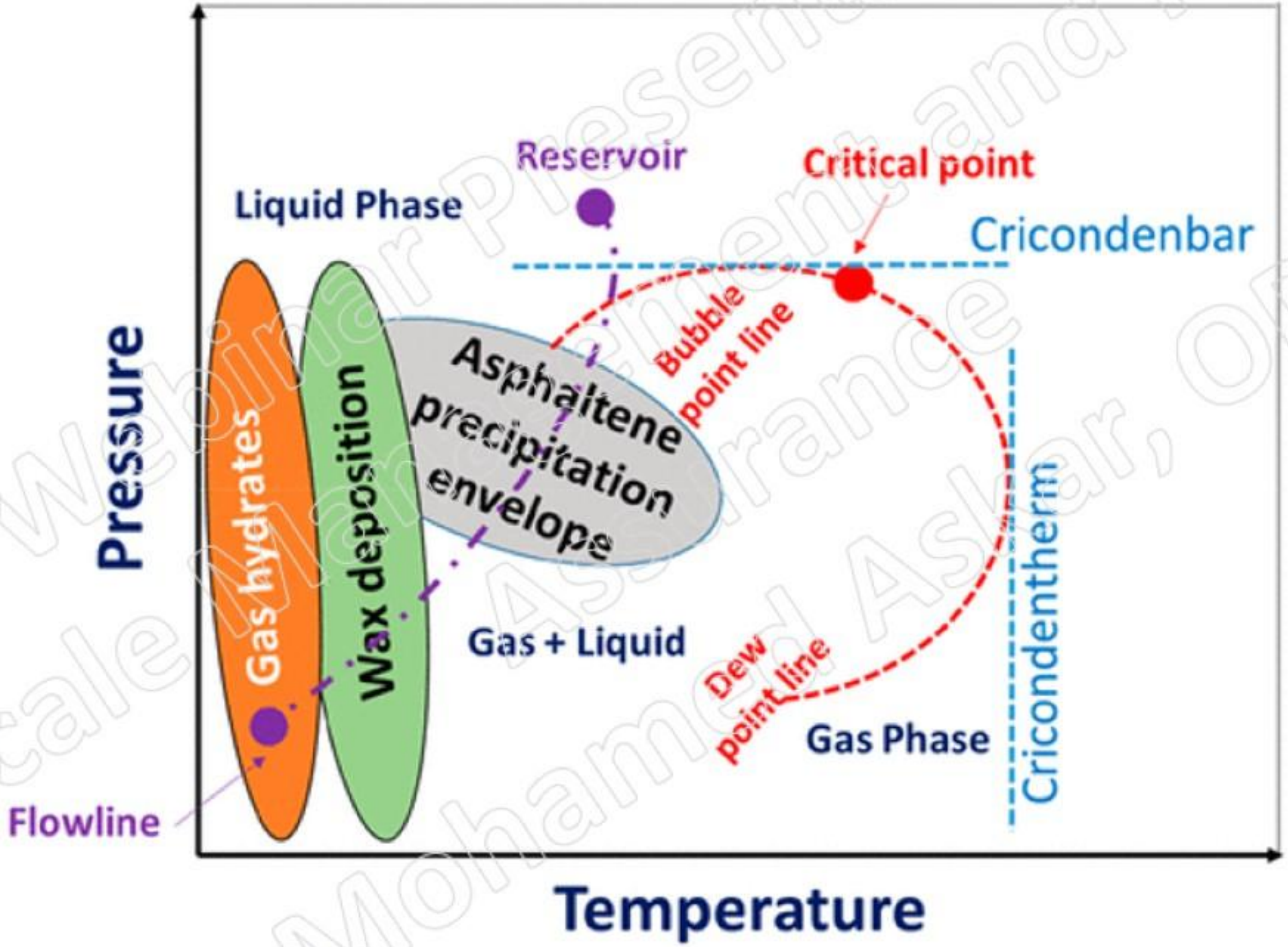

a)
Liquid
Vapour bubbles
Liquid Droplets
b)
Gas
Liquid
Gas
Liquid
Gas
c)
Liquid
Gas Bubbles
Gas
Liquid Droplets or Solid Particles

Typical P-T Diagram for Different Scenarios



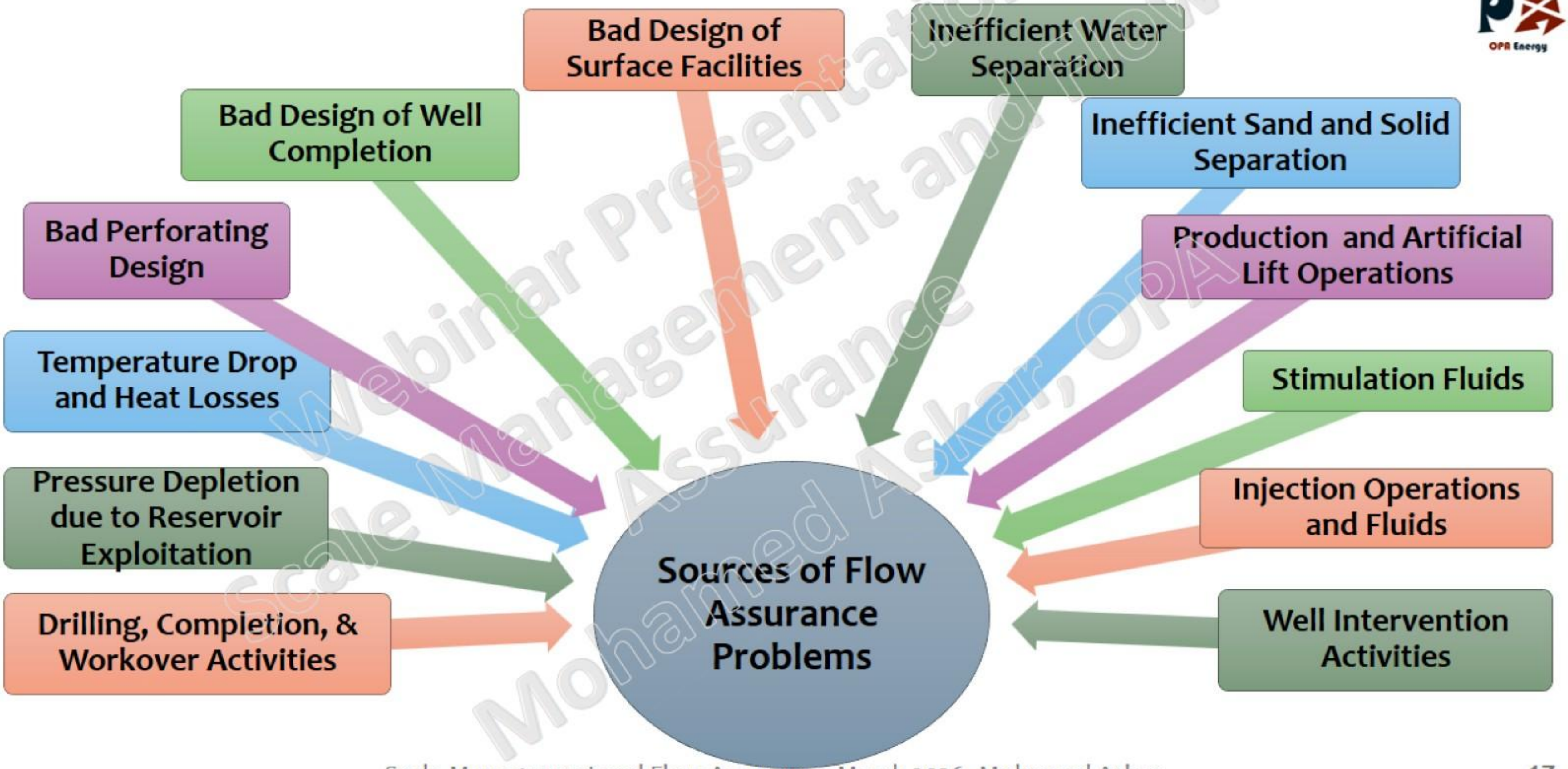


Fluid Phase Diagram WRT Pressure and Temperature



Current Holistic Scope of Flow Assurance

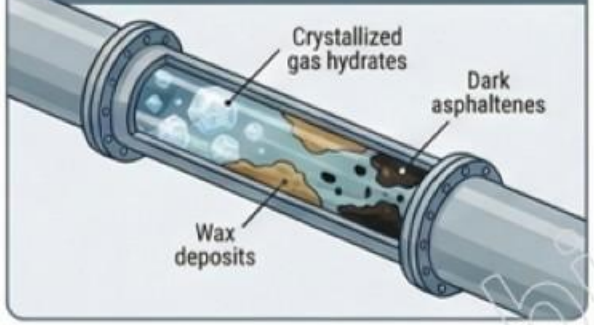
- Reservoir Fluids
  - Sampling
  - Lab Analysis
- Multiphase Flow
  - Rheology
  - Flow Modelling
  - Pressure Loss
  - Slugging and Liquid Surge
  - Diameter of Tubing & Flowlines
- Heat Transfer
  - Insulation
  - Heating
- Challenges and Problems
  - Flow Restrictions
    - Emulsion
    - Foaming
  - Blockages
    - Hydrates
    - Wax
    - Asphaltenes
    - Scale
    - Naphthenates
    - Sand
  - Integrity Loss
    - Corrosion
    - Erosion
    - Bacteria
    - Souring
  - System Operability
    - Normal Operation
    - Shutdown and Startup
    - Well Testing
    - Separation of Solids
    - Turndown and Ramp-up
    - Pigging
- Production Chemistry
- Material Science


Bad Design of Surface Facilities
Inefficient Water Separation
Bad Design of Well Completion
Inefficient Sand and Solid Separation
Bad Perforating Design
Production and Artificial Lift Operations
Temperature Drop and Heat Losses
Stimulation Fluids
Pressure Depletion due to Reservoir Exploitation
Injection Operations and Fluids
Drilling, Completion, & Workover Activities
Well Intervention Activities
Sources of Flow Assurance Problems

Benefits of Maintaining Flow Assurance

PREVENTION OF PIPELINE BLOCKAGES

Identifies and mitigates solids like gas hydrates, wax, and asphaltenes that obstruct flow.

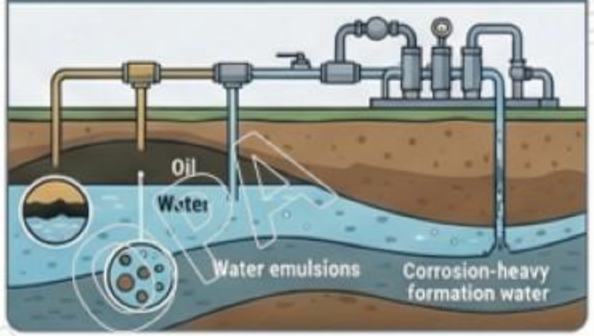


PROTECTION OF ECONOMIC VIABILITY

Reduces capital and operational expenditures by preventing costly downtime and hazardous repairs.

COMPLEX FLUID MANAGEMENT

Provides strategies to manage mature fields, water emulsions, and corrosion-heavy formation water.



Flow Assurance: The Foundation of Reliable Energy Production

ENHANCED OPERATIONAL SAFETY

Mitigates the high-risk, dangerous task of removing subsea pipeline plugs.

PRODUCTION OPTIMIZATION

Enables predictable production rates and higher efficiency through better system knowledge and control.

ENVIRONMENTAL RISK MITIGATION

Prevents off-spec production and environmental consequences resulting from process upsets.

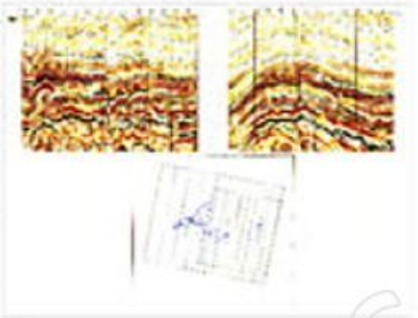
Workflow of Production Field and Wells

Exploration (5-10 years) | Production (10-30 years)

Discovery

Mapping of Reserve Location

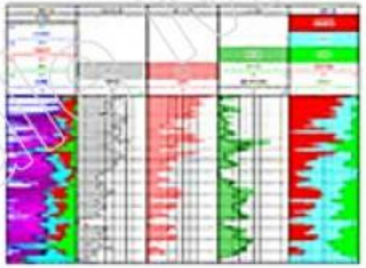
- Concession Agreement
- Geological and Seismic Studies
- Exploratory Wells
- Production Tests
- Oil Presence Confirmation



Appraisal

Reservoir Sizing and Simulator

- Appraisal/Delineation Wells.
- Reservoir Studies
- Reservoir Modelling
- Preliminary Development Plan
- Environmental Impact Analysis (EIA)
- Feasibility Studies



Development

Production Installations Design and Construction

Field Design:
- Wells location and design
- Surface network and facilities design
- Well placement design
- EIA and Economics risk assessment

Field Operation:
- Well Drilling Schedule
- Rig Fleet Size and Mix/Scheduling
- Flow Scheduling
- Offshore Support Vessels Scheduling

Field Construction:
- Procurements
- Facilities Fabrication
- Facilities Installation
- Well Construction
- Well Drilling
- Well Completion

Production

Oil and Gas Production

- Reservoir Management
- Well tests and inspection
- Production Optimization
- Workover Rig Scheduling
- Wells Interventions

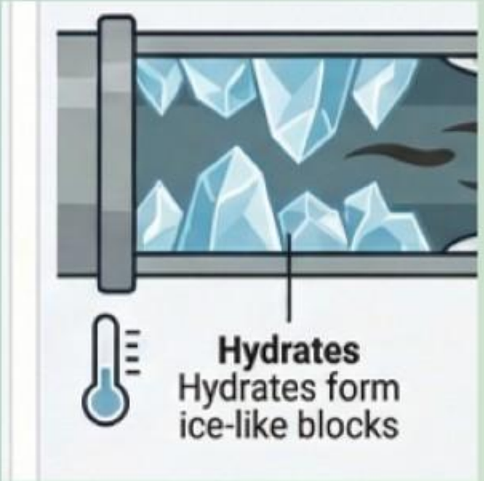
Abandonment

Explored Site Restauration

Well Plug & Abandonment:
- Rigs and offshore vessels
- Plant Removal

Environmental Restoration

Hydrate

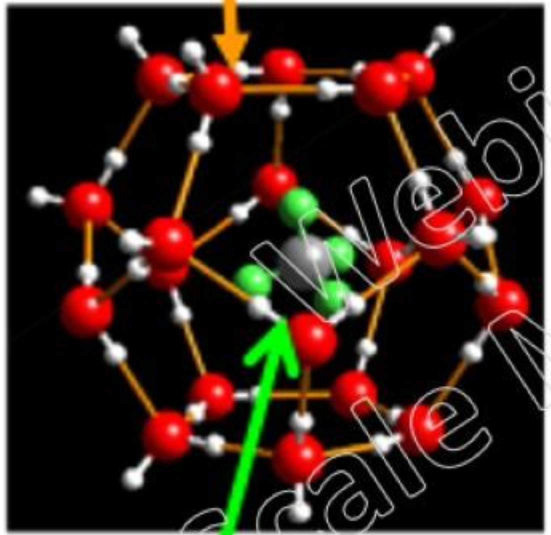


Hydrate Formation

- Hydrates are **ice-like structures** composed of **water and natural gas molecules.** Under favorable conditions of **high pressure and low temperatures**, water molecules form **cages**, which encapsulates as molecules inside a hydrogen-bonded solid lattice.
- The following conditions are necessary for the formation of hydrates:
  - Presence of free water
  - Presence of light natural gas molecules
  - Relatively high pressure
  - Relatively low temperature
  - Flow Regime; stratified flow and free gas promotes Deposition while oil flow hinders it.

Hydrate Structure

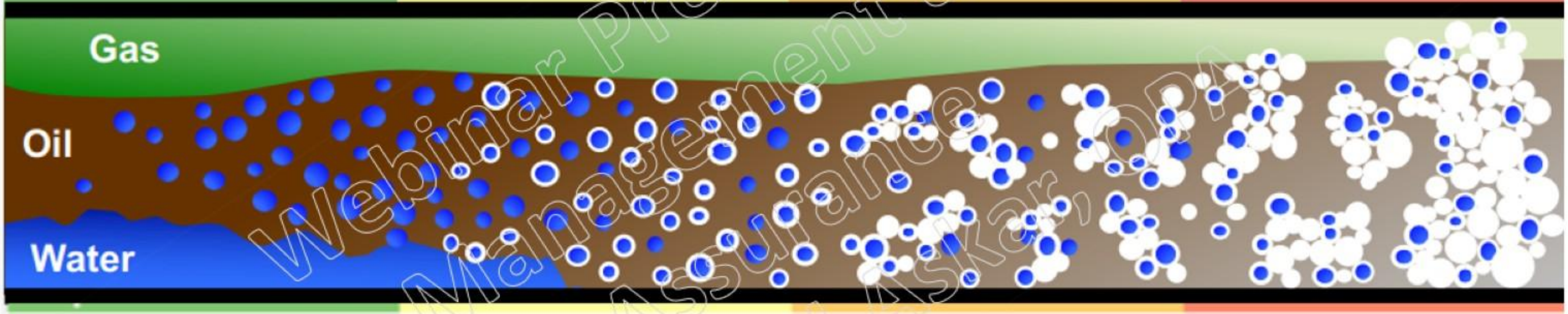
Water molecules



Methane molecule

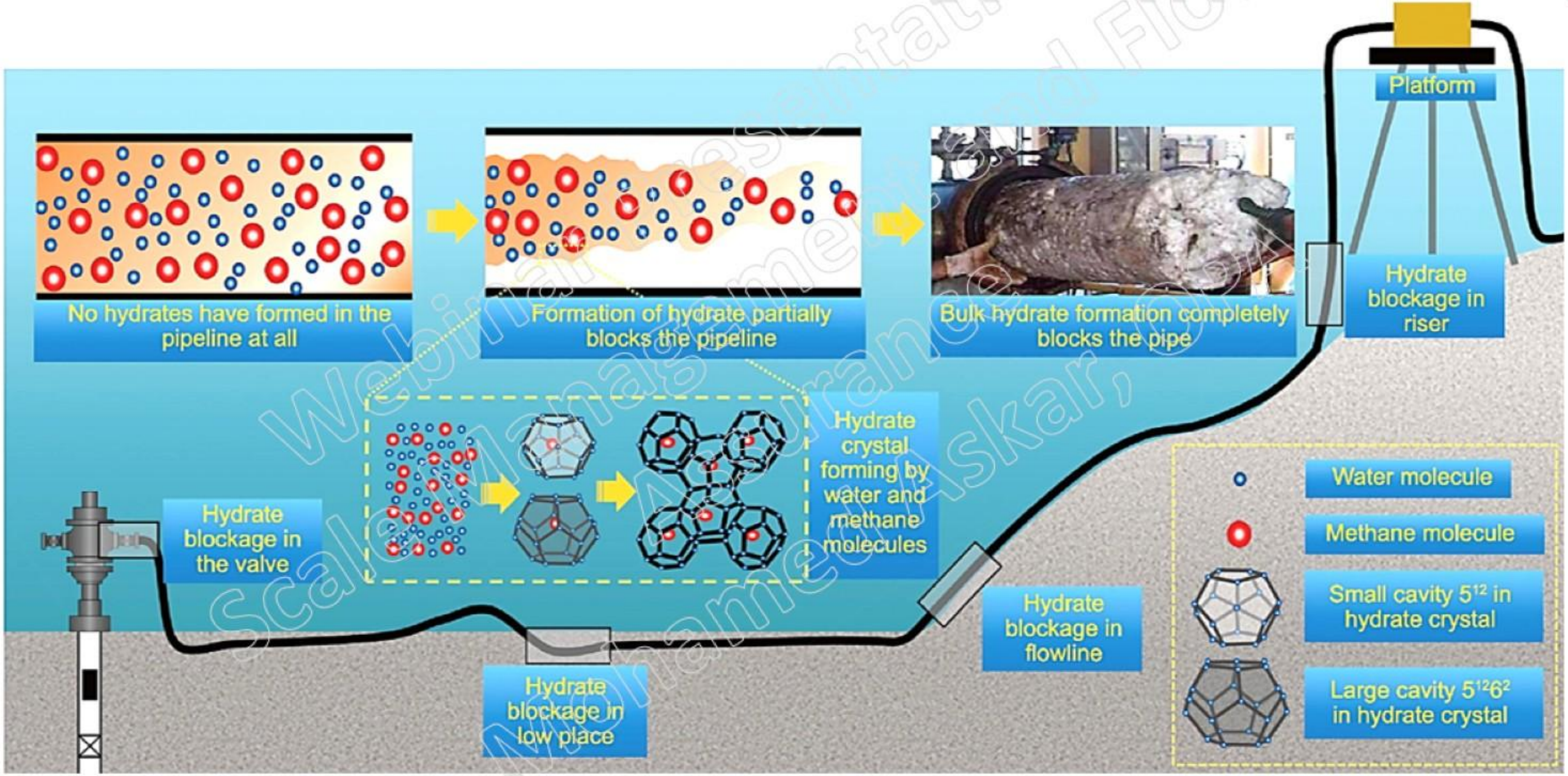
Hydrate Formation Steps

Water Entrainment	Hydrate Growth	Agglomeration	Plugging



Water Entrainment	Hydrate Growth	Agglomeration	Plugging
Surface area between water/hydrocarbon phases	Intrinsic kinetics or transport resistances	Particle aggregation via capillary attraction	Plugging from viscosity increase (Pressure drop increase)

Locations for Hydrate Formation and Blockage

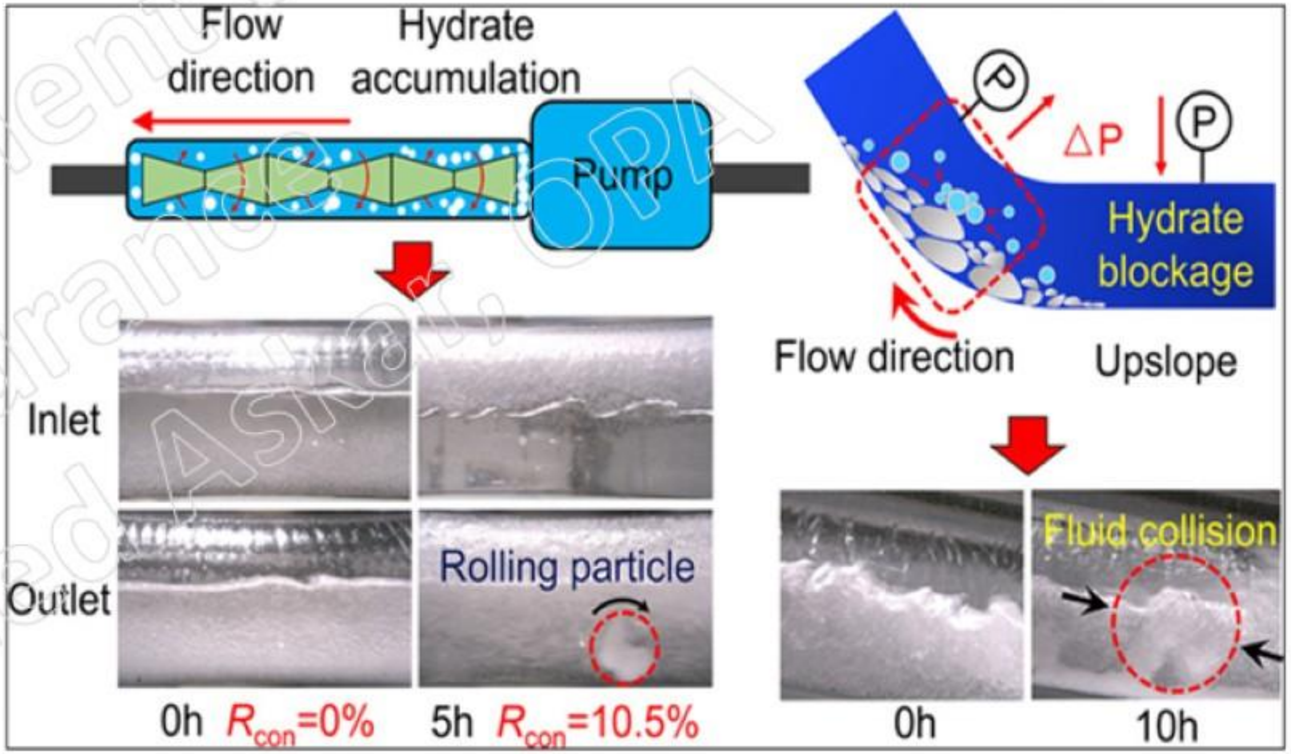


Locations for Hydrate Formation

- Occurrence of hydrate plug is usually **between wellhead and platform** (especially for **subsea wells and flowlines**)
- Any location where gas & water flow under cold conditions
- **Downstream of a choke** or other valve where there is a pressure drop (and subsequent **cooling** effect)
- In pipelines where gas flows over or bubbles through liquid pools.
- During **shut-in's and startup conditions** the flow and mixing regimes favors hydrate formation.
- During **well tests and drilling operations** there can be high gas velocities and water mixing allowing for hydrate generation.

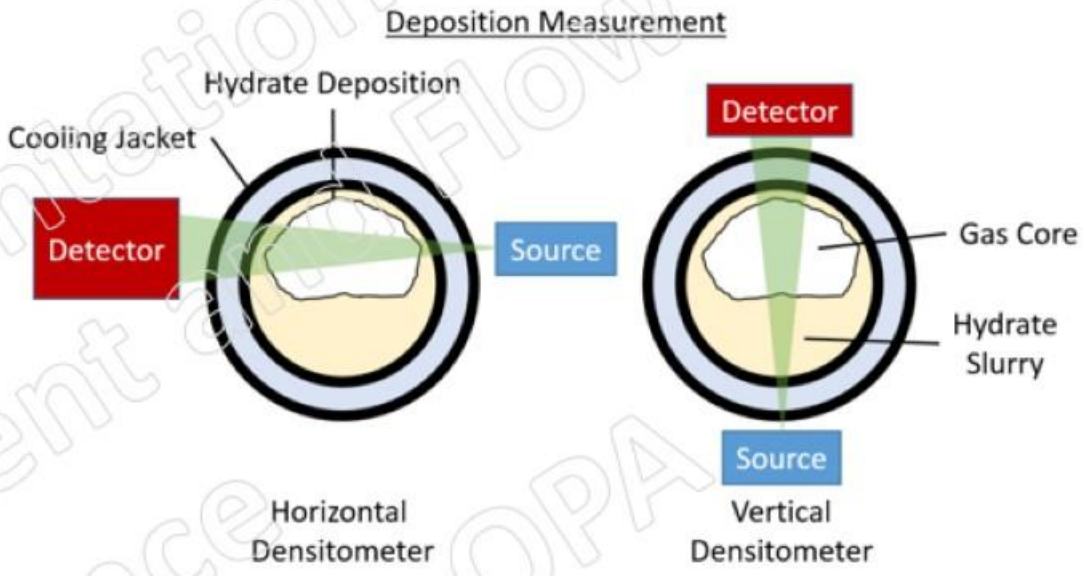
Risks of Hydrate Formations

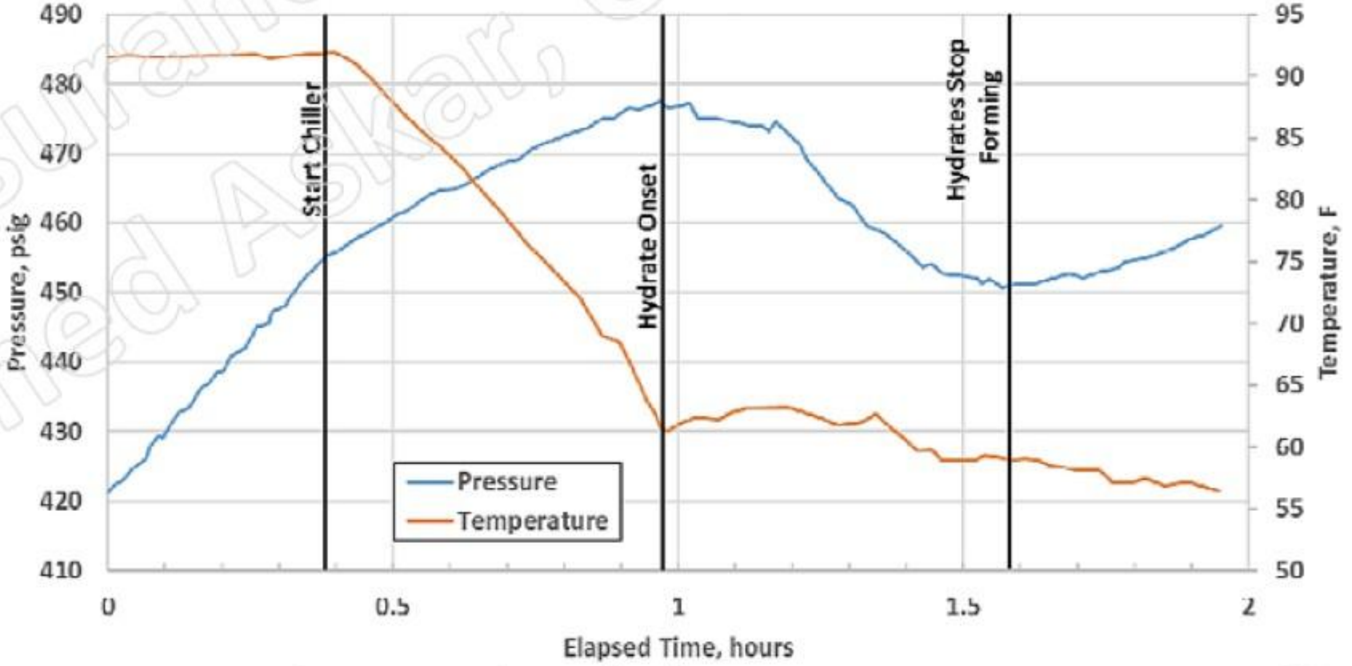
- Rapidity of Plug Formation Production Loss
- Time and resources required to mitigate plugs
- Production loss due to shut-ins
- Exacerbate other flow problems i.e. combination wax and hydrate plugs
- Safety Risk



Hydrate Detection Methods

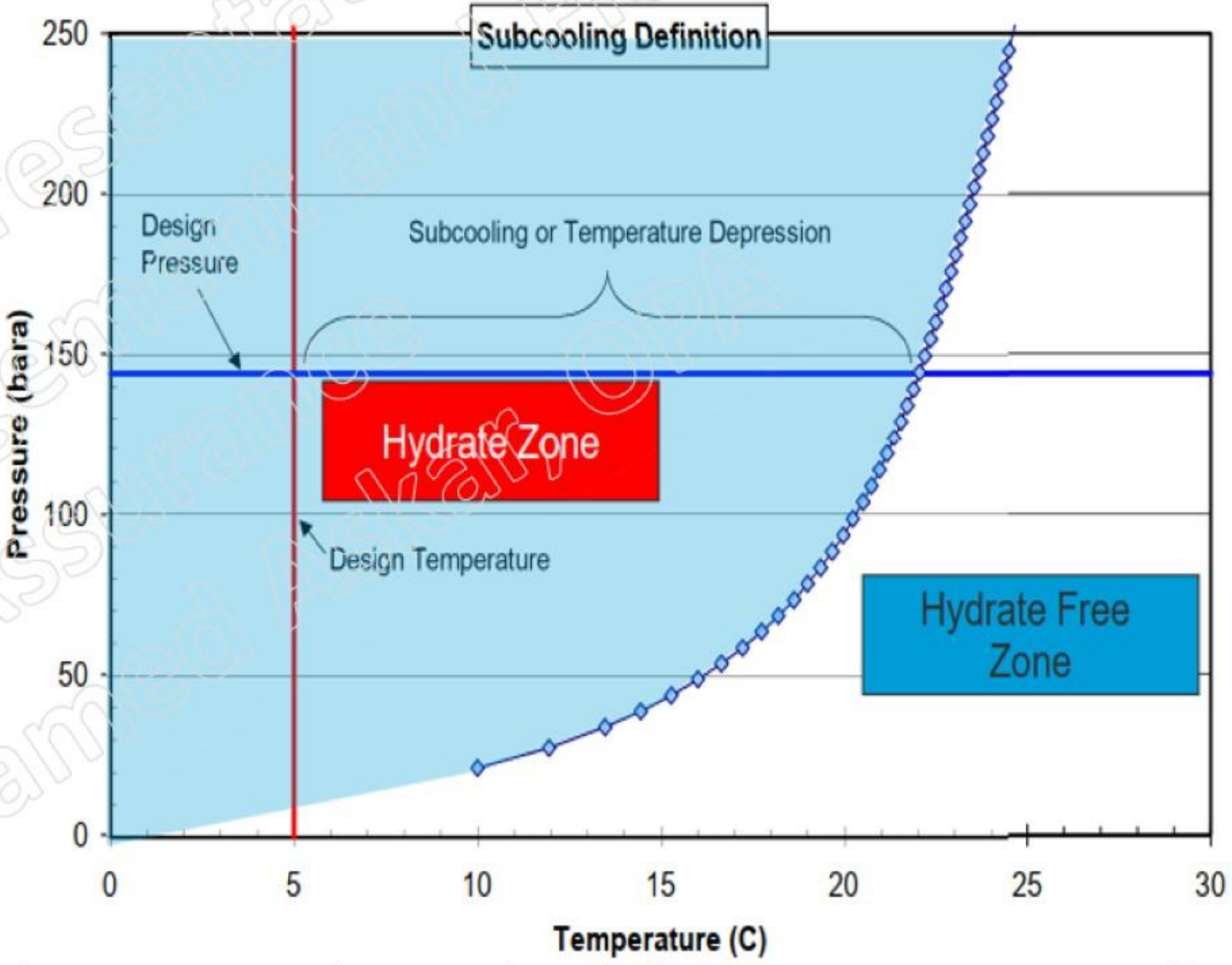
- Pressure and Temperature Measurements
- Acoustic Pulse Reflectometry
- Ultrasonic Detection
- Gamma Densitometer
- Electrical Probes
- Fiber-optic Sensing (DTS, DAS)
- Spectroscopy (NMR, Microwave)



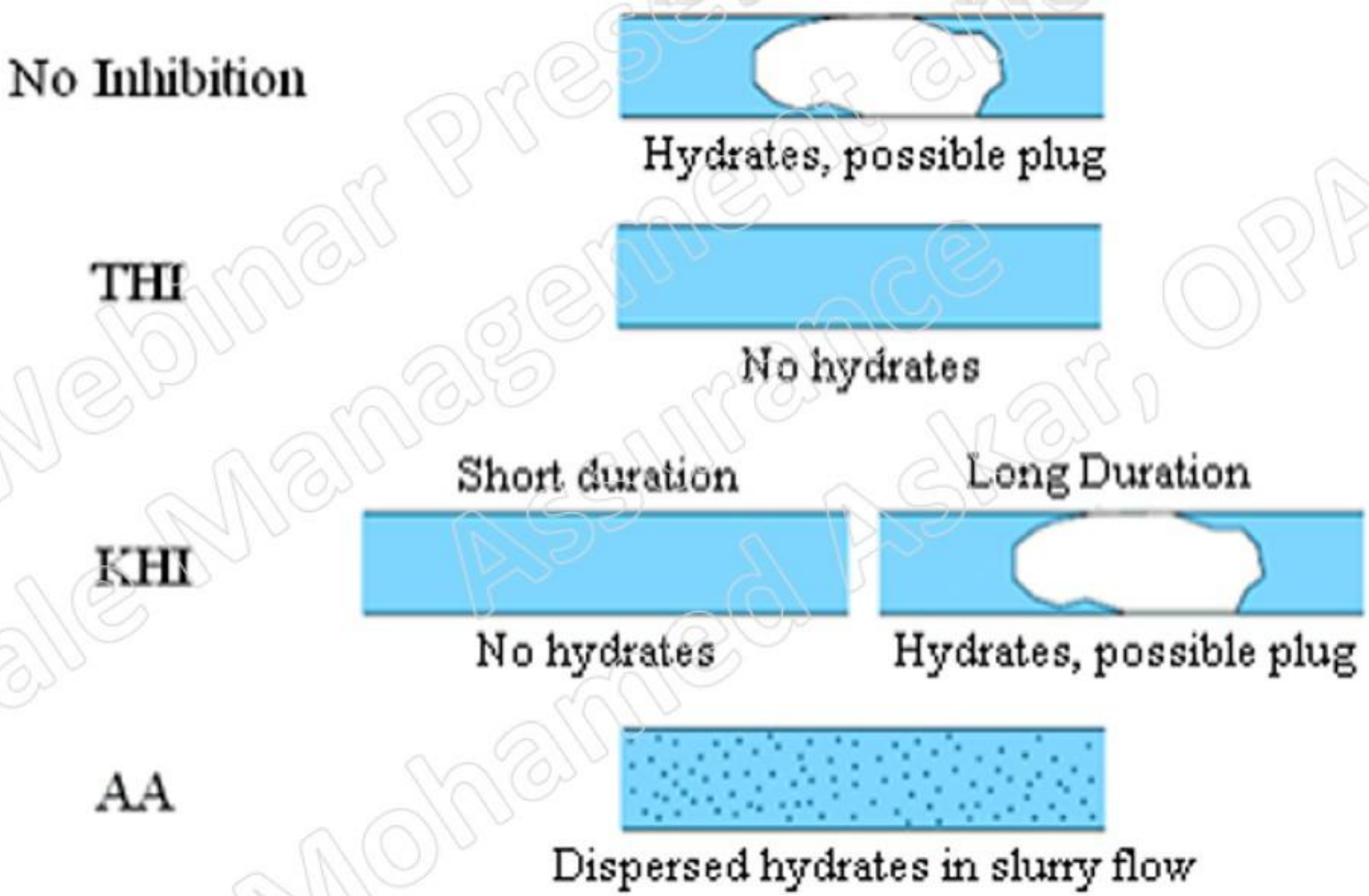


Hydrate Phase Equilibrium

Thermodynamic conditions favour hydrate formation once curve is crossed from hydrate free to hydrate zone

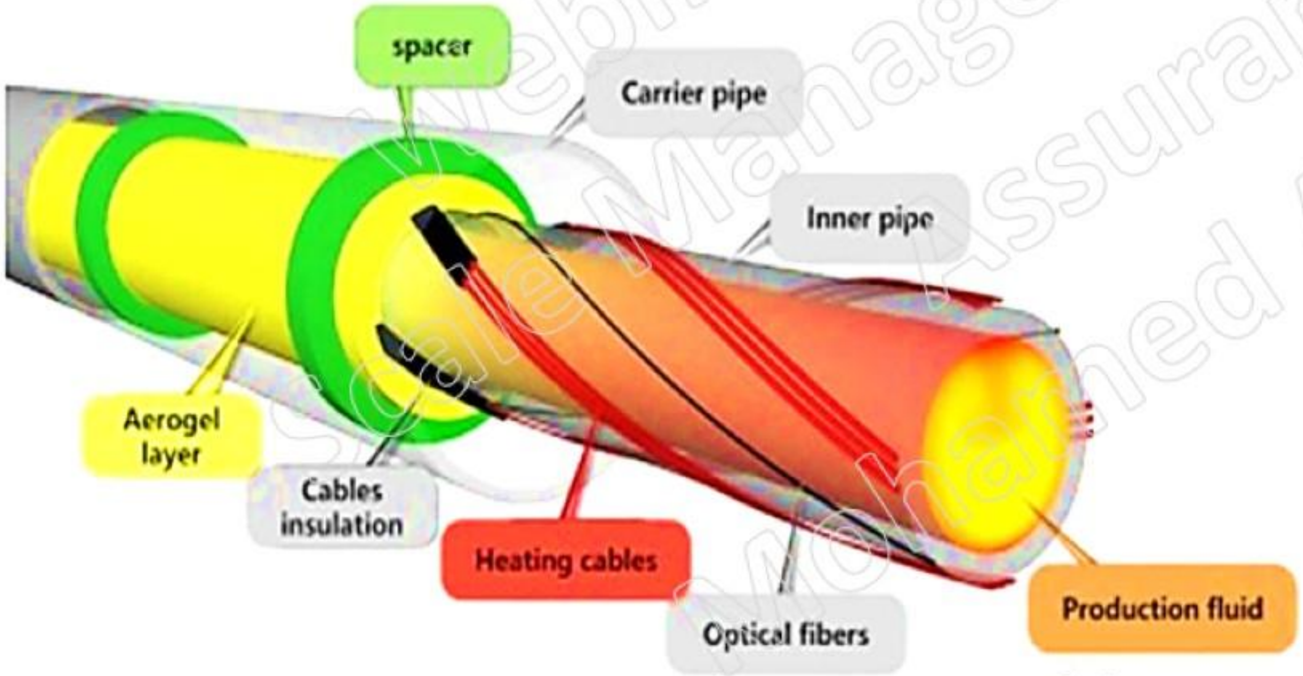


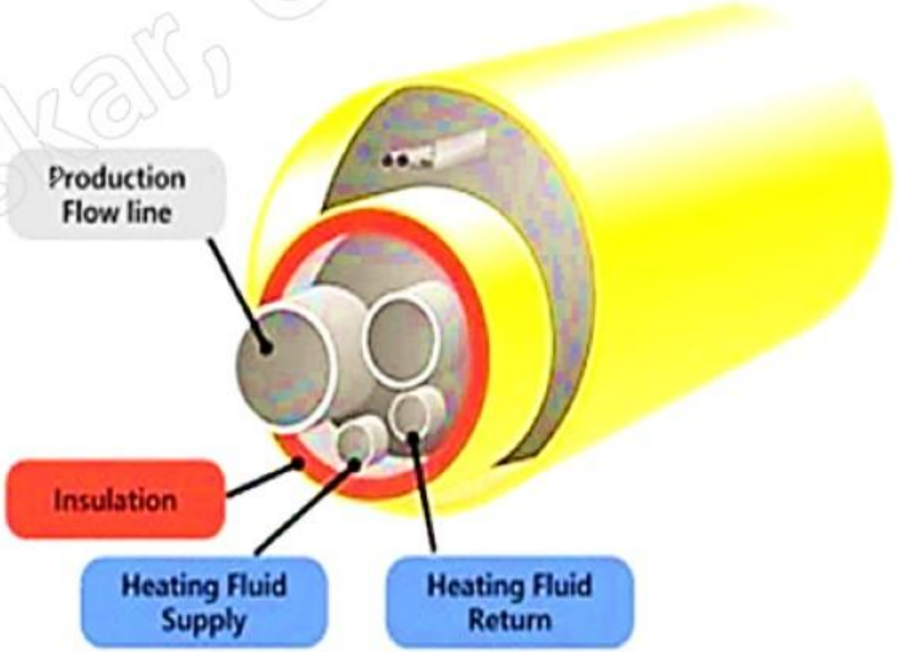
Transient Effects Of Chemical Hydrate Inhibitors



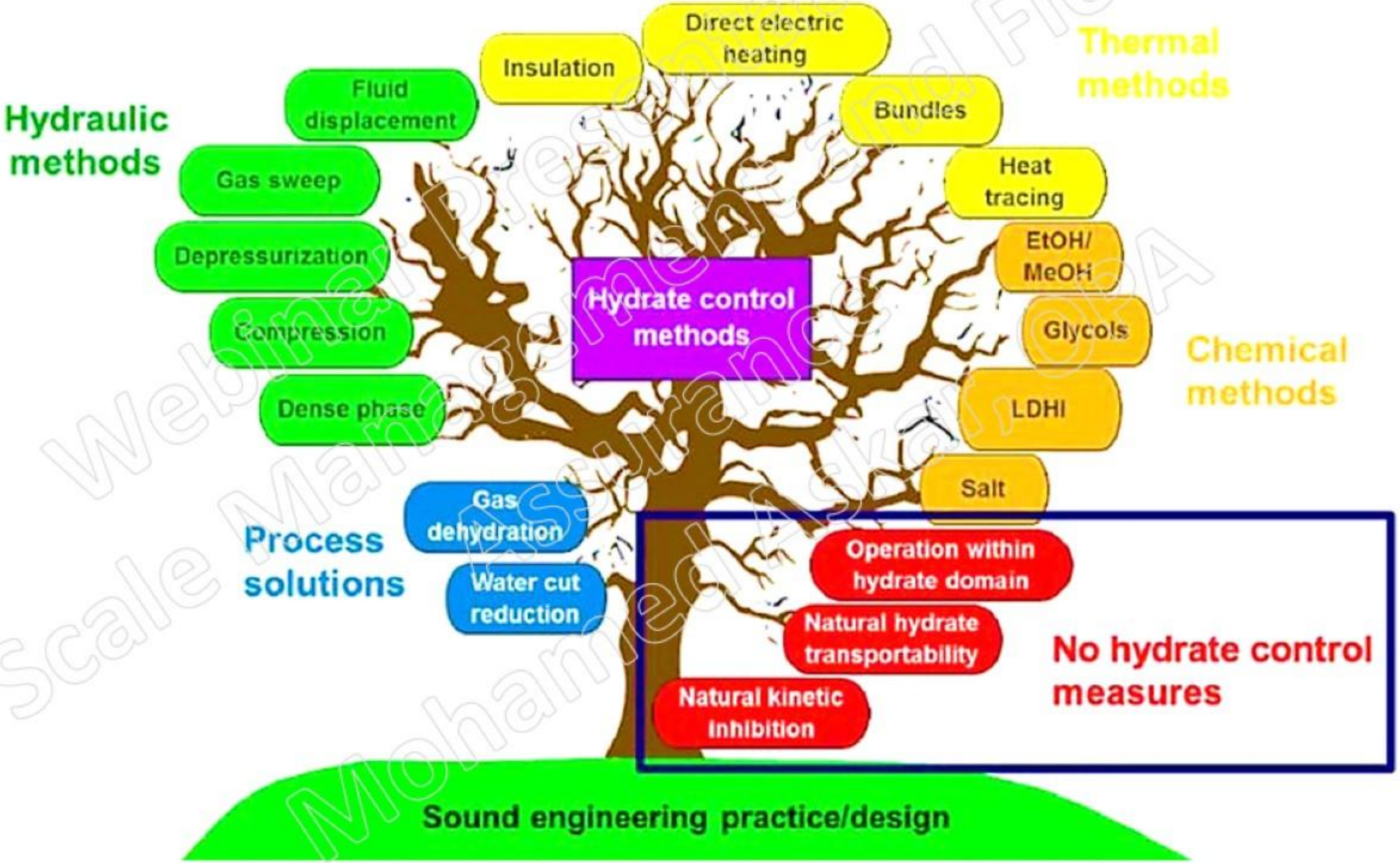
Hydrate Prevention by Active Heating

- Active heating for hydrate management in subsea pipelines can be achieved through two primary methods: electric heating and hot fluid circulation.
  - **Electric heating** involves using electrical resistance to **directly or indirectly heat the pipeline**
  - **Hot fluid circulation** involves **circulating a heated fluid** (like hot oil or glycol) through the pipeline to maintain or raise the temperature and prevent hydrate formation.

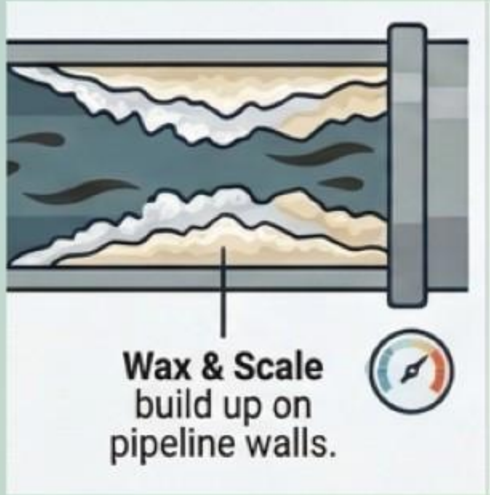




Hydrate Holistic Management

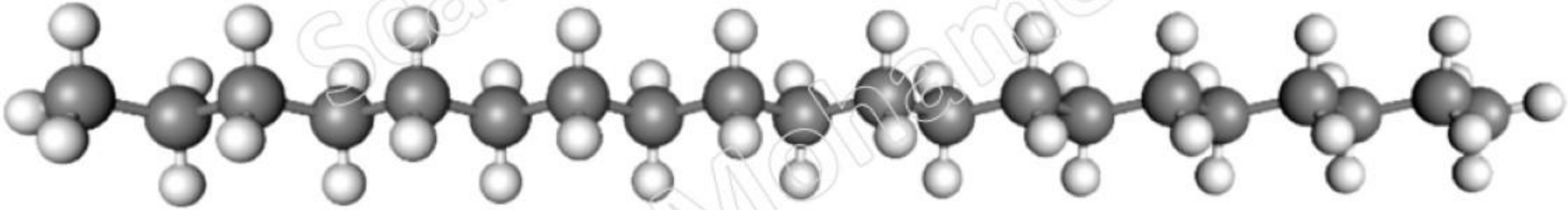


Paraffin



Definitions

- Waxes or Paraffines include wide range of **high molecular weight paraffins** (**alkanes or saturated hydrocarbons**) in crude oil.
- Wax deposition is an issue that arises whenever an oil composition containing appreciable wax content encounters flow, temperature, and pressure that are conducive for solids formation. Wax deposition can potentially occur **anywhere in the system** from the reservoir to the refinery.



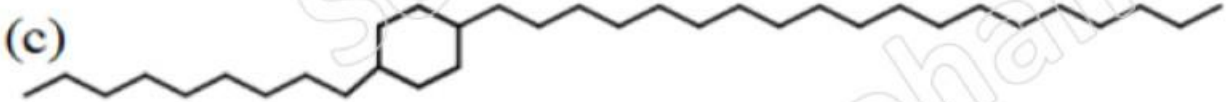
The Structure Of Main Paraffin Wax (a) straight, (b) branched, (c) cyclic

(a) 

n-paraffin

(b) 

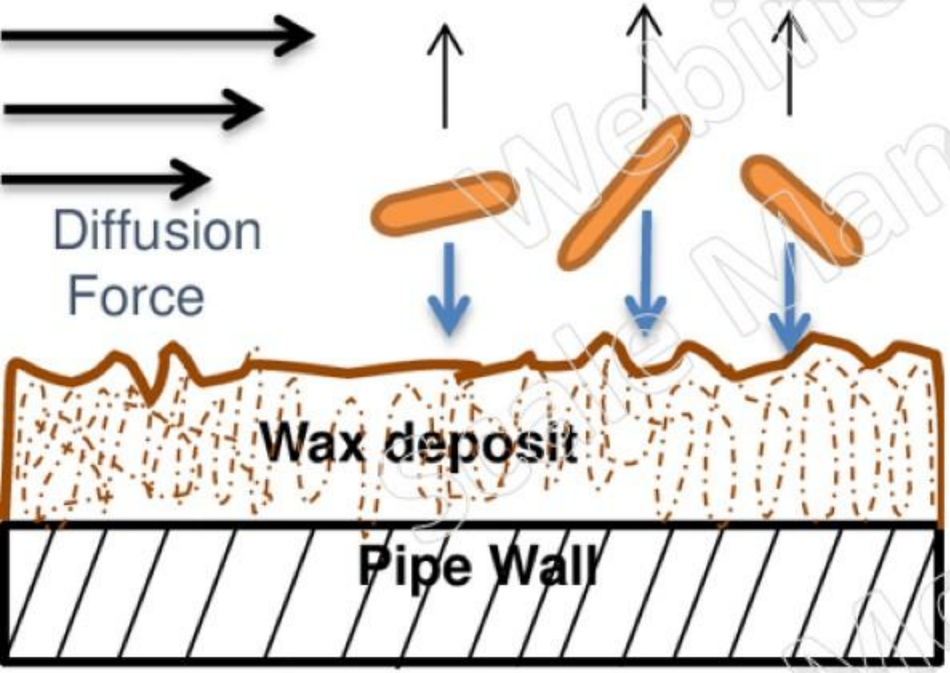
iso-paraffin

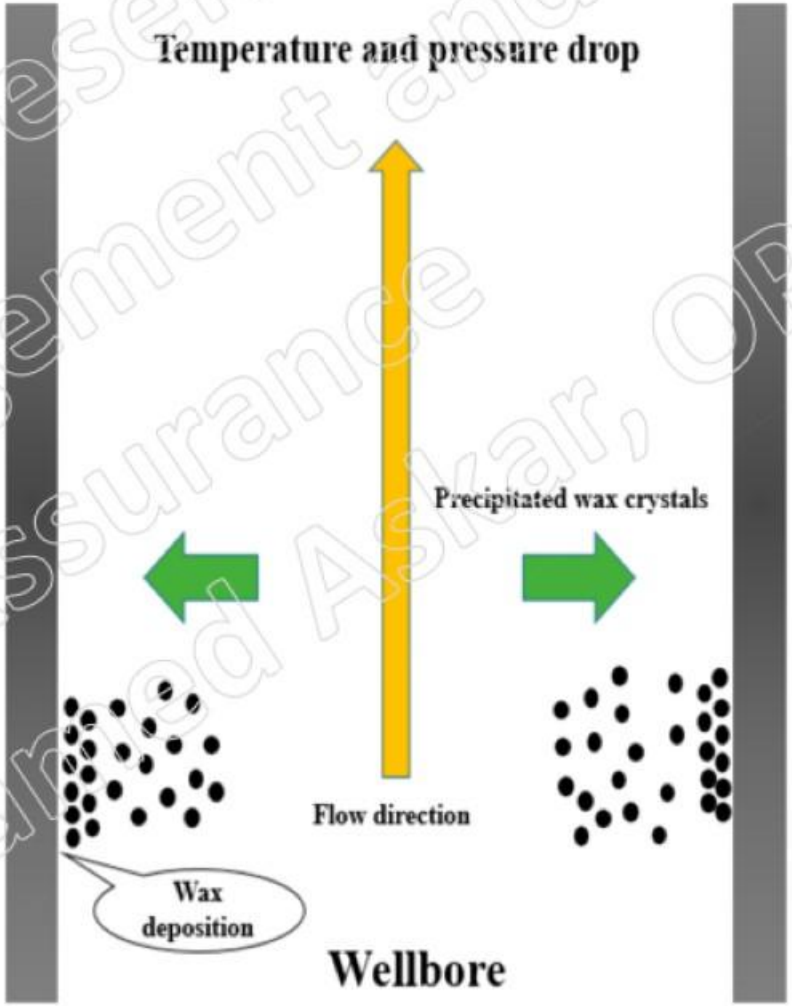
(c) 

cyclo-paraffin

Wax Plug from Pig Traps During Production Operation

Wax Deposition inside Production Wells



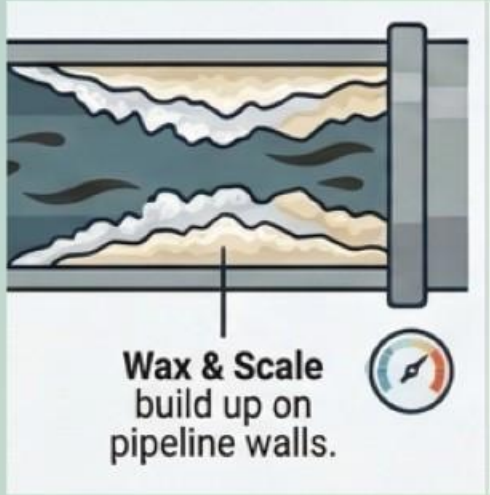


Wax Deposition Issues: Pipeline Blockage, Reduced Flow Capacity

Factors Governing Paraffin Deposition

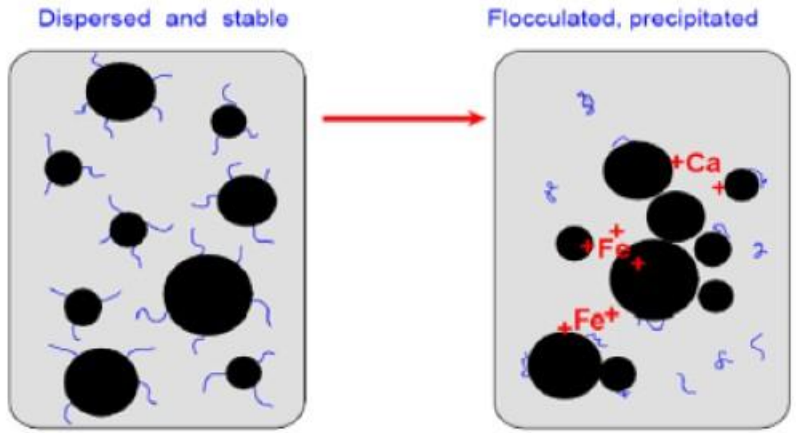
- Temperature (Relative to WAT and Pour Point)
- Pressure exerted on the solution
- Amount of gas in solution
- Presence of water
  - If **tubulars are water wet,** the **paraffin will not stick.**
  - Water also has a **higher heat** capacity and helps keep temperature up and paraffin in solution.
- **Surface roughness** (**Plastic coating** the pipe to provide a **smooth surface**)
- Paraffin Precipitation during **injecting cold fluids** (frac, acid, kill fluids,..)

Asphaltene



Asphaltene Stability in Crude Oil

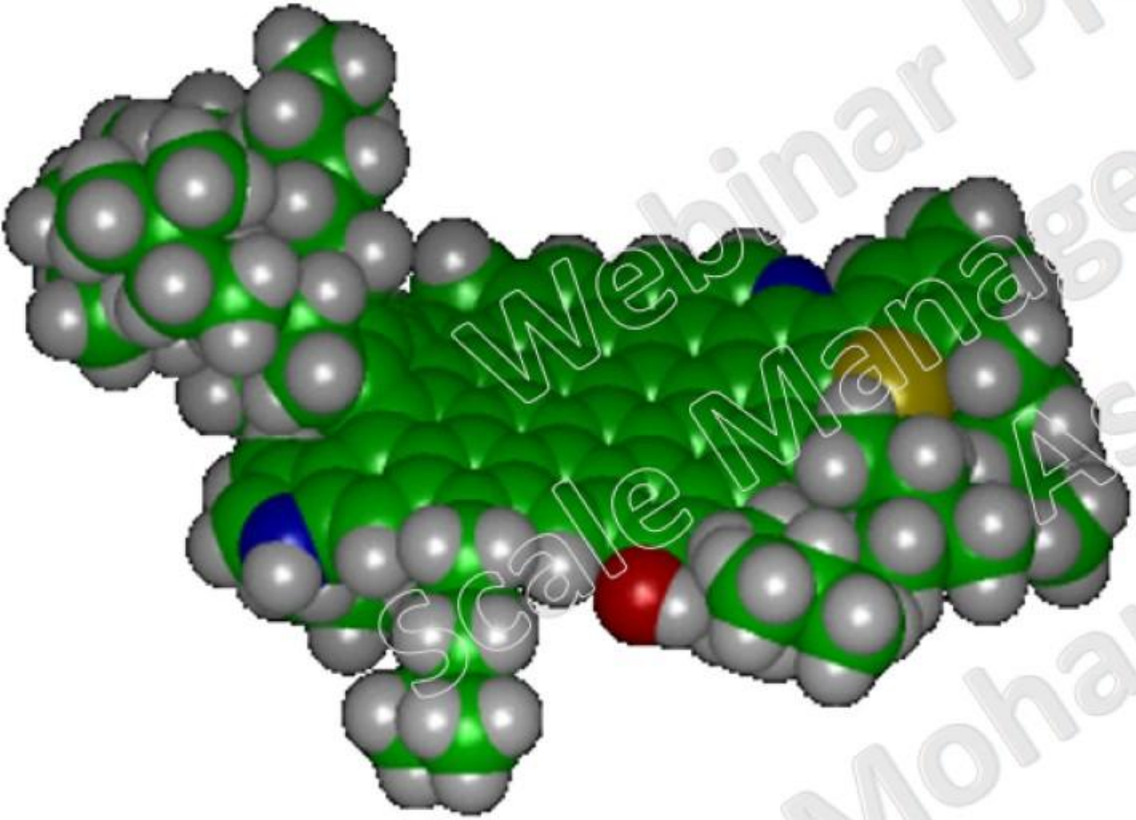
- **Asphaltenes are not soluble in crude.**
- They are **high-molecular-weight aromatic and naphthenic compounds** that are thought to be exist as a **colloidal suspension, dispersed and stabilized by maltene molecules in the oil.**
- This Colloidal state is **stabilized by the presence of resins in the crude oil**
- When these **resins are removed, the asphaltenes can flocculate**, creating particles large enough to cause formation damage.

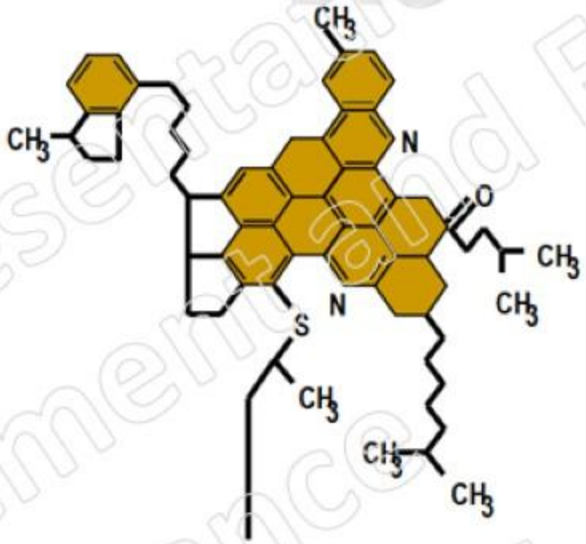


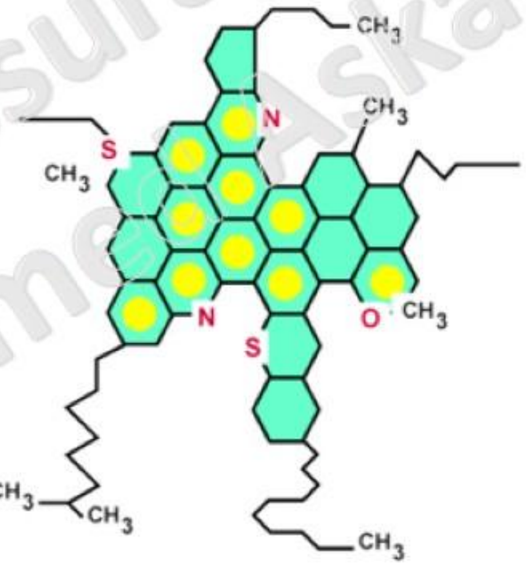
Asphaltene Deposition

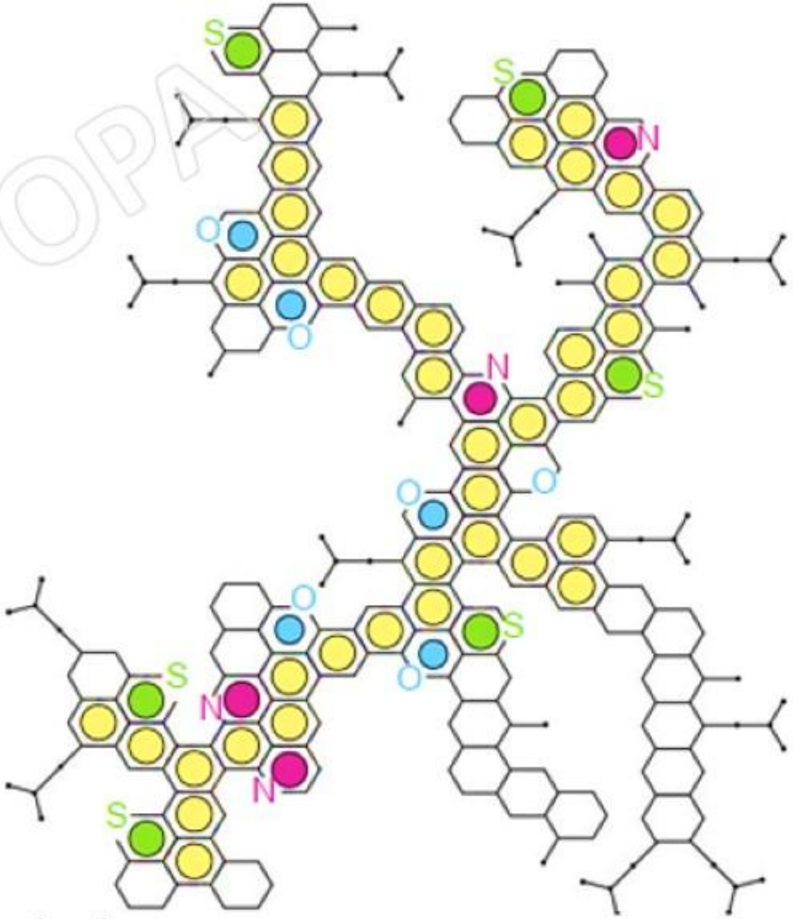
- Heavy molecules, highly heterogeneous.
- Difficult to predict, particularly deposition.
- Asphaltenes can deposit in formation, wellbore tubing, flowlines, and topsides.
- Asphaltenes can **cause emulsion problems**

Examples of an Asphaltene Molecule Structure

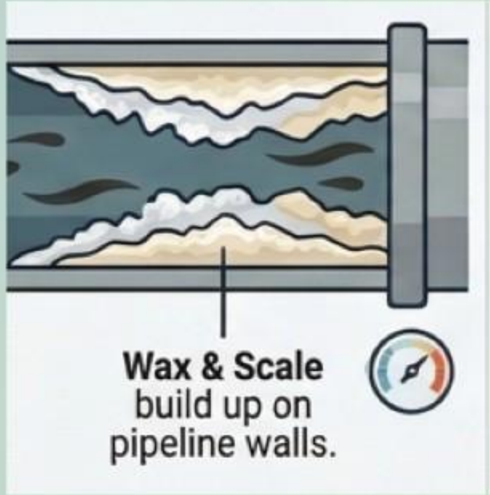




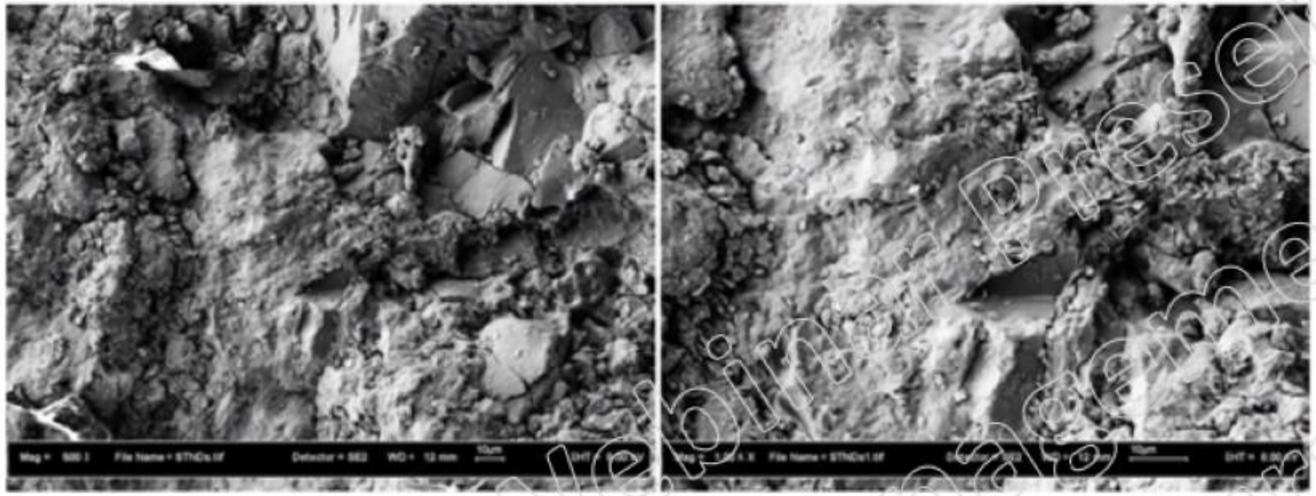




Mineral Scales

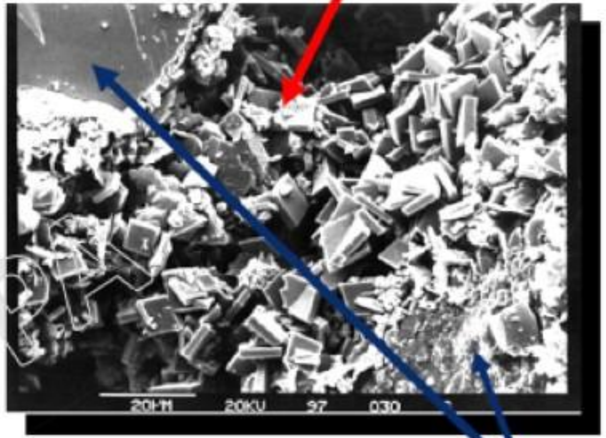


Water-formed Scale Deposits



SEM image of an unscaled sandstone cores

SEM image of $SrSO_4$ scales in sandstone cores

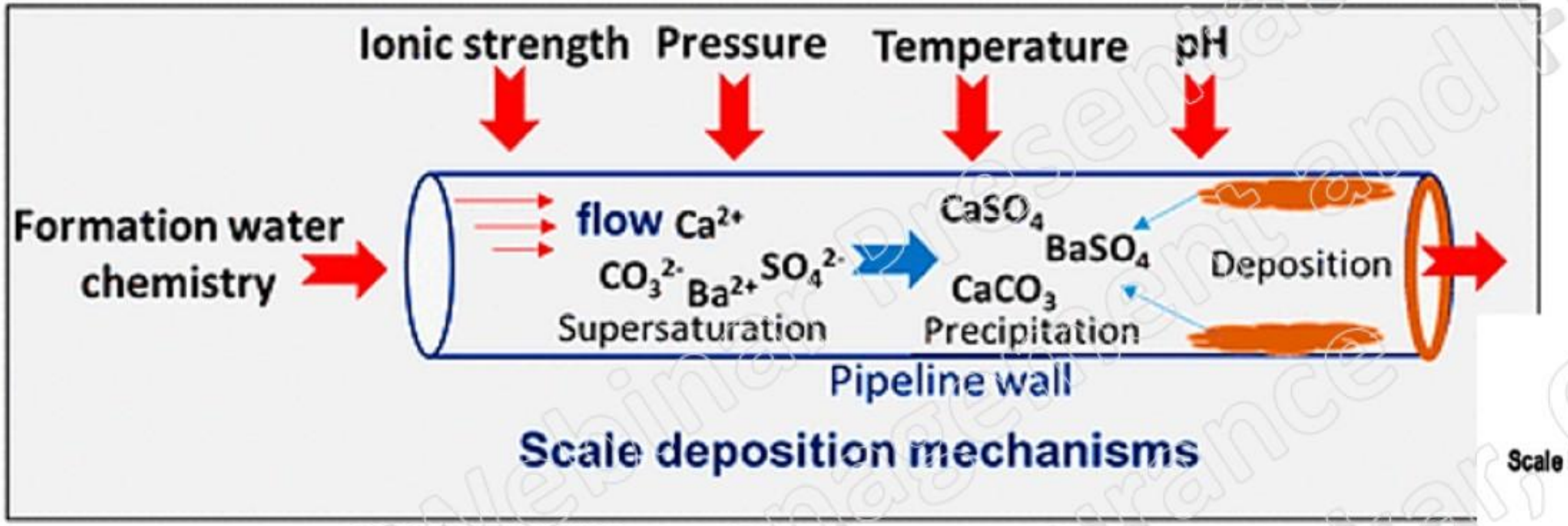


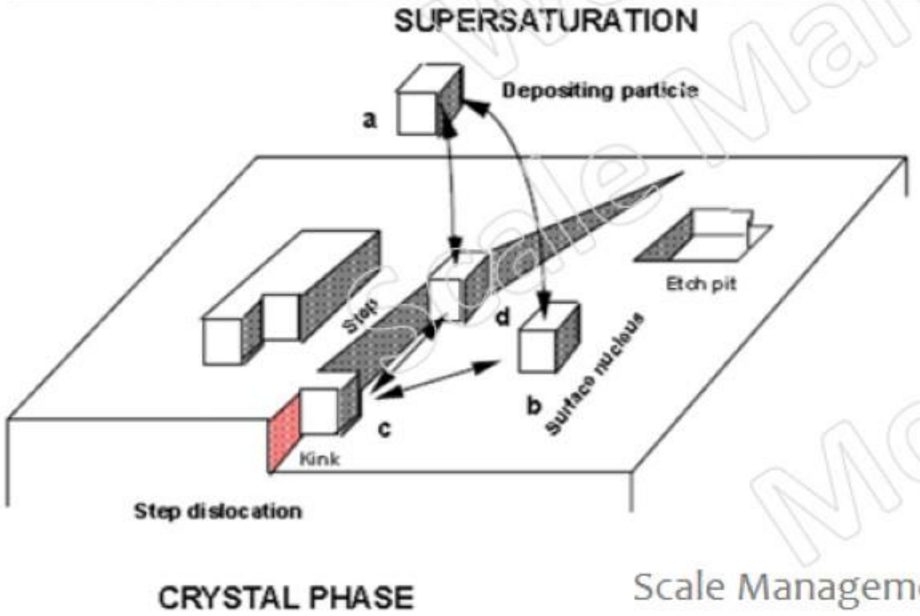
Types of Scale Minerals

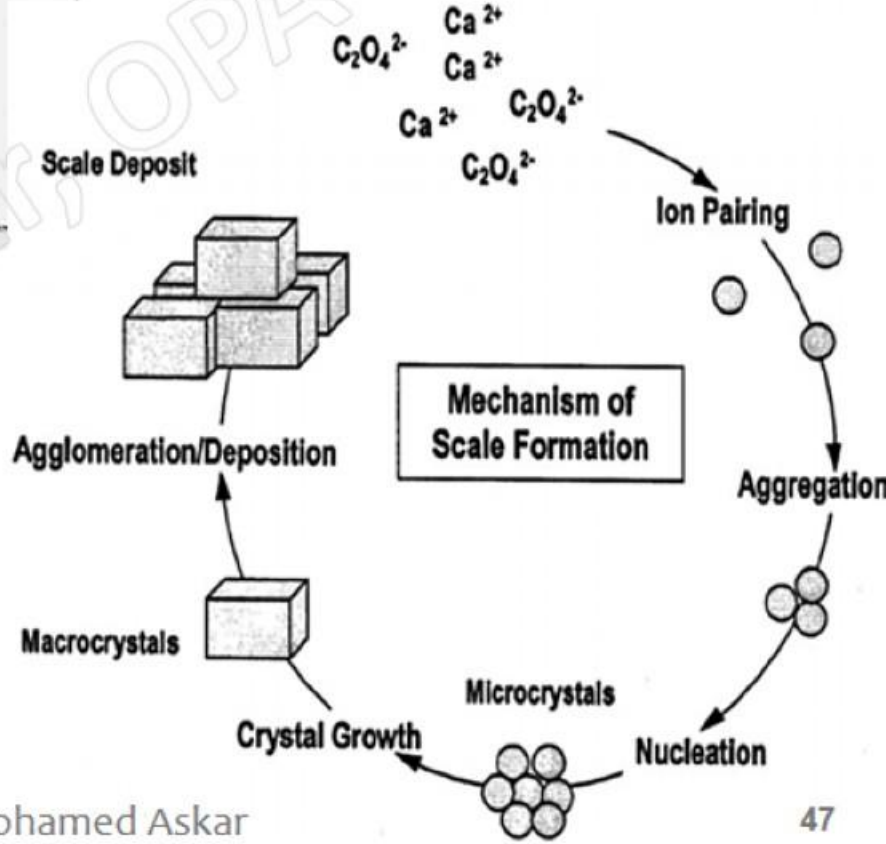
Category	Scale Type	Chemical Formula	Mineral Structure Form	Chemical Treatment
Water Soluble	Sodium Chloride	$NaCl$	Halite	Fresh Water
Acid Soluble	Calcium Carbonate	$CaCO_3$	Calcite, Aragonite	HCl Organic acids
	Iron Carbonate	$FeCO_3$	Siderite	HCl, THPS
	Iron Oxide	Fe_3O_4 and Fe_2O_3	Magnetite and Hematite	Acids Chelating Agents
	Iron Sulfide	FeS	Troilite (FeS) Pyrrhotite ($Fe_{1-x}S$) Mackinawite ($Fe_{1+x}S$) Pyrite and Marcasite (FeS_2)	Acids Chelating Agents Biocides e.g. THPS
	Zinc Sulfide	ZnS	Sphalerite	HCl
	Lead Sulfide	PbS	Galena	Oxidizing acids such as nitric acid
Acid Insoluble	Calcium Sulfate	$CaSO_4$ $CaSO_4 \cdot 2\ H_2O$ $CaSO_4 \cdot 0.5\ H_2O$	Anhydrite Gypsum Basanite (Hemihydrate)	Chelating Agents
	Strontium Sulfate	$SrSO_4$	Celestite	
	Barium Sulfate	$BaSO_4$	Barite	

Scale Depositions

Scale Precipitation and Deposition







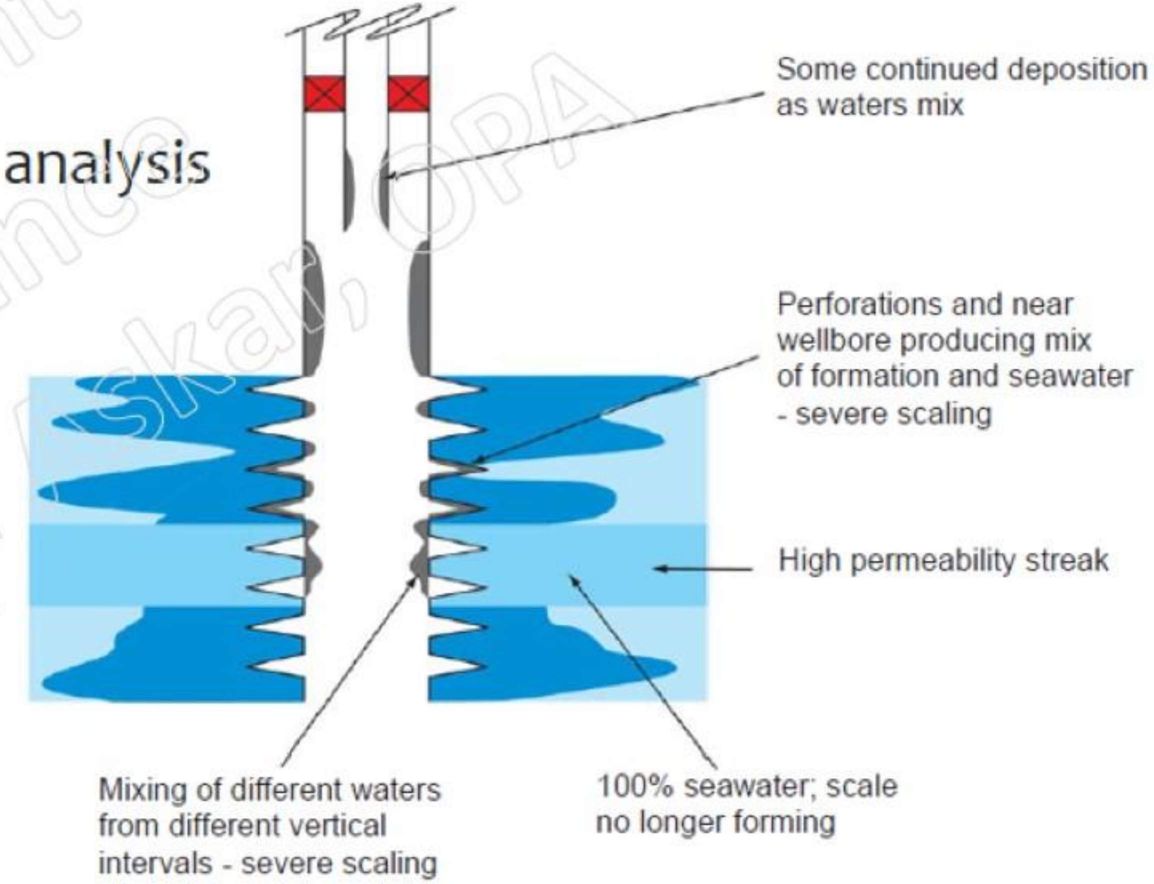
Causes of Scale Deposition

- Usually a precipitate from a **brine that becomes saturated** with a material due to a change in the flowing fluid conditions within a well.
- Scales Precipitate out of solution in response to:

1. **Changes in conditions (P, T, pH, TDS, Gas stripping**, etc.).
   - Form in the system of the well, in the perforations/near wellbore formation.
2. **Mixing of incompatible fluids.**
   - The ionic species in solution in the water in a reservoir are initially in chemical equilibrium with formation mineral.
   - For reservoirs with high bicarbonate values, using completion fluids with high calcium content e.g. $CaCl_2$ will promote more scale deposition.

Scale Monitoring and Surveillance

- Well productivity (PI) decrease, production rate drop
- Water chemistry change
  – Drop in Ba^{2+}, Ca^{2+}, Sr^{2+} and SO_4^{2-} noted in water analysis
- Injection water breakthrough
- P_{wf} decrease WRT bubble point pressure
- Residual scale inhibitor concentration versus MIC

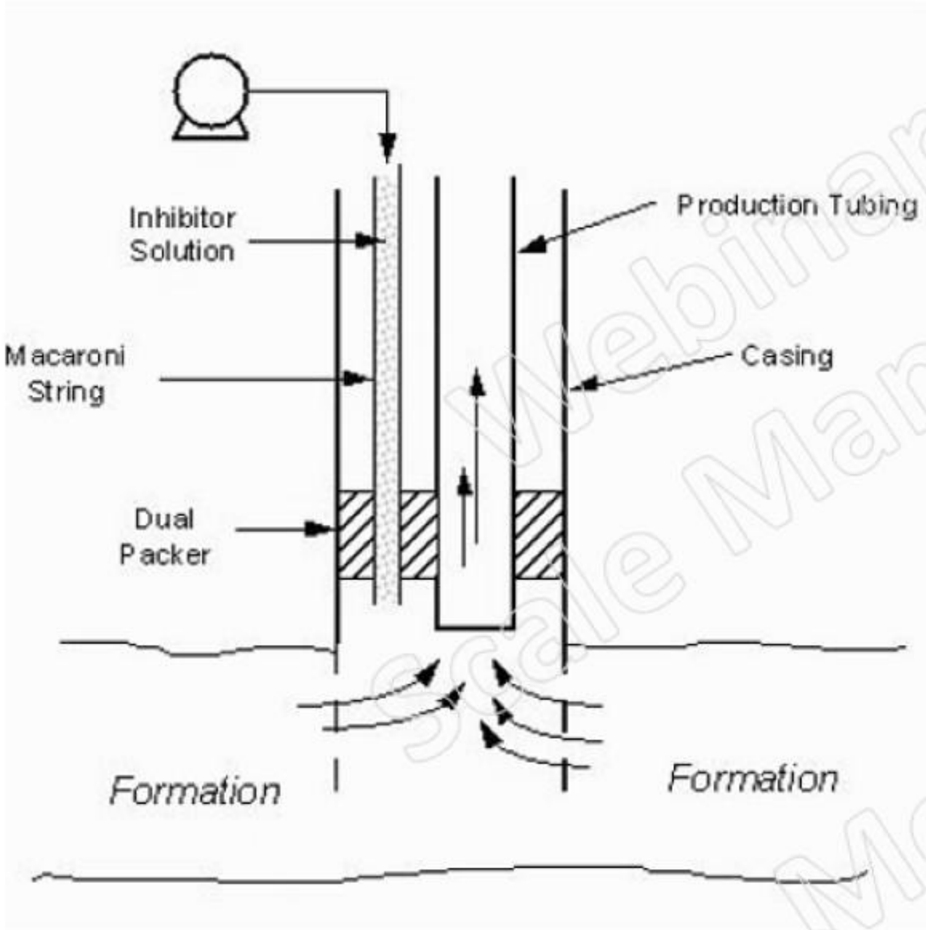


Scale Monitoring and Surveillance

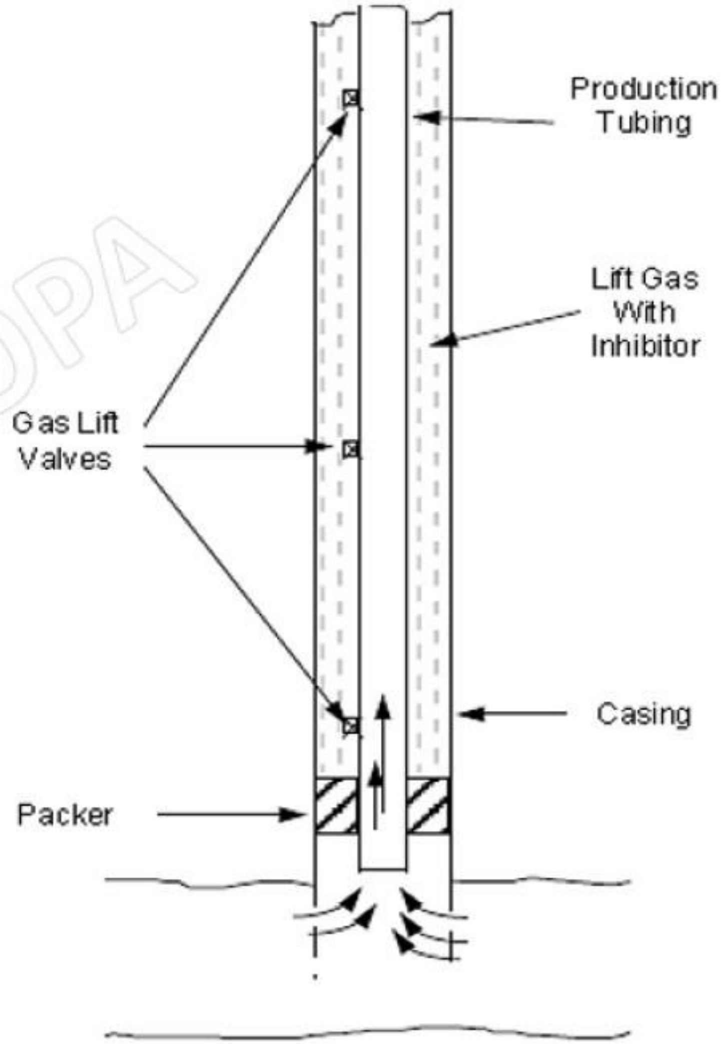
- Scale coupons or scale collection during gauging and pigging
- Observing total suspended solids (TSS)
  - increase in ratio
  - Identify type; active, modified, or transported
- Detection Sensors
- Develop a risk matrix of scale : filter paper coverage/solid vs water volume/rates
- Surface scale deposition causes throttling effect, pressure drop and temperature change

Downhole Scale Inhibitor Injection

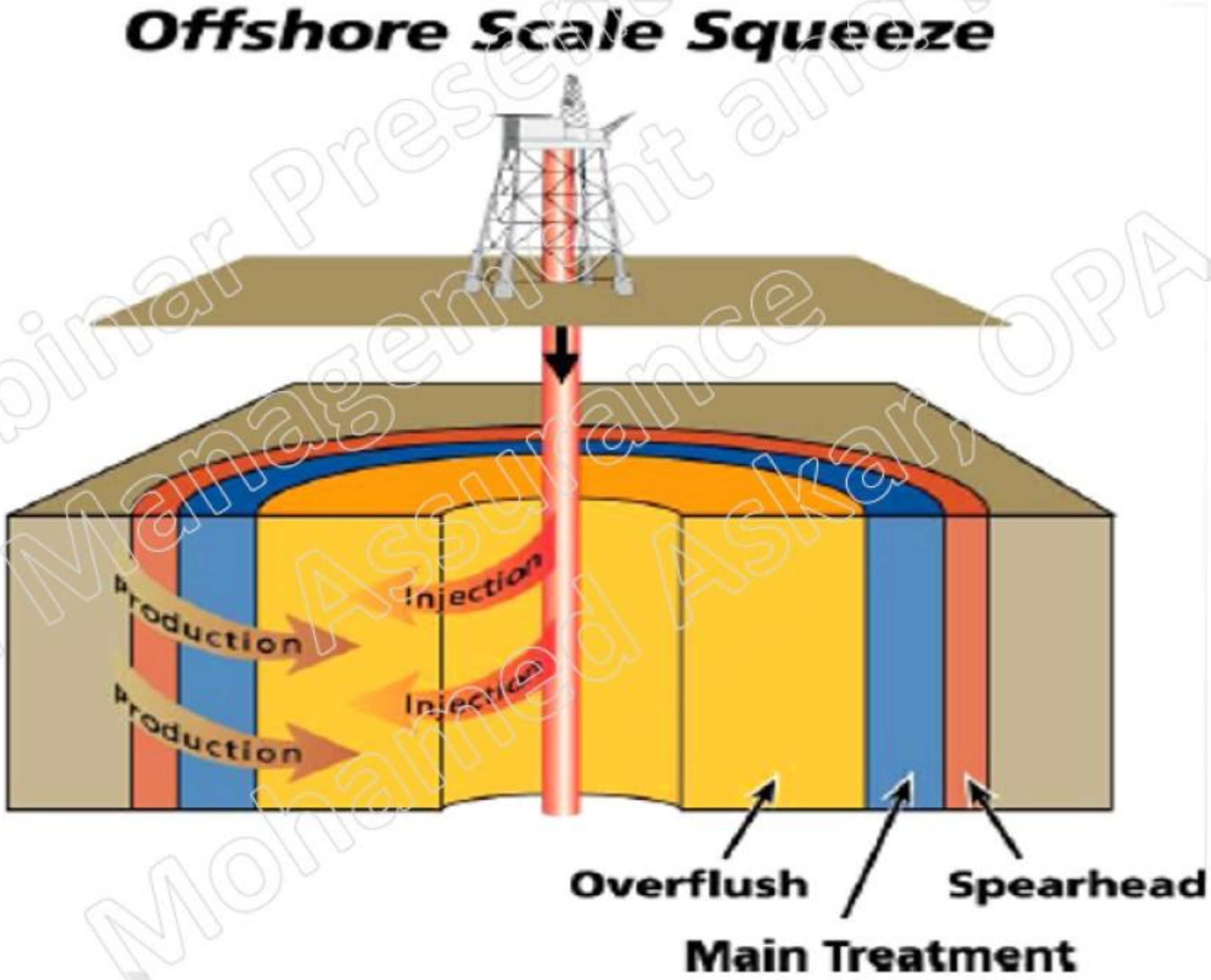
Macaroni String injection



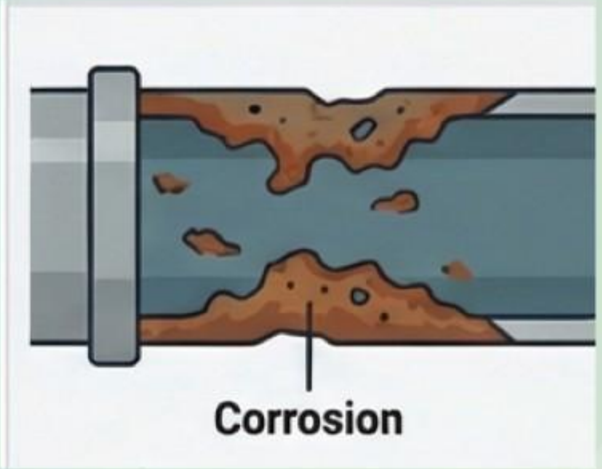
Injection into Gas Lift



Scale Inhibitor Deploying by Squeezing



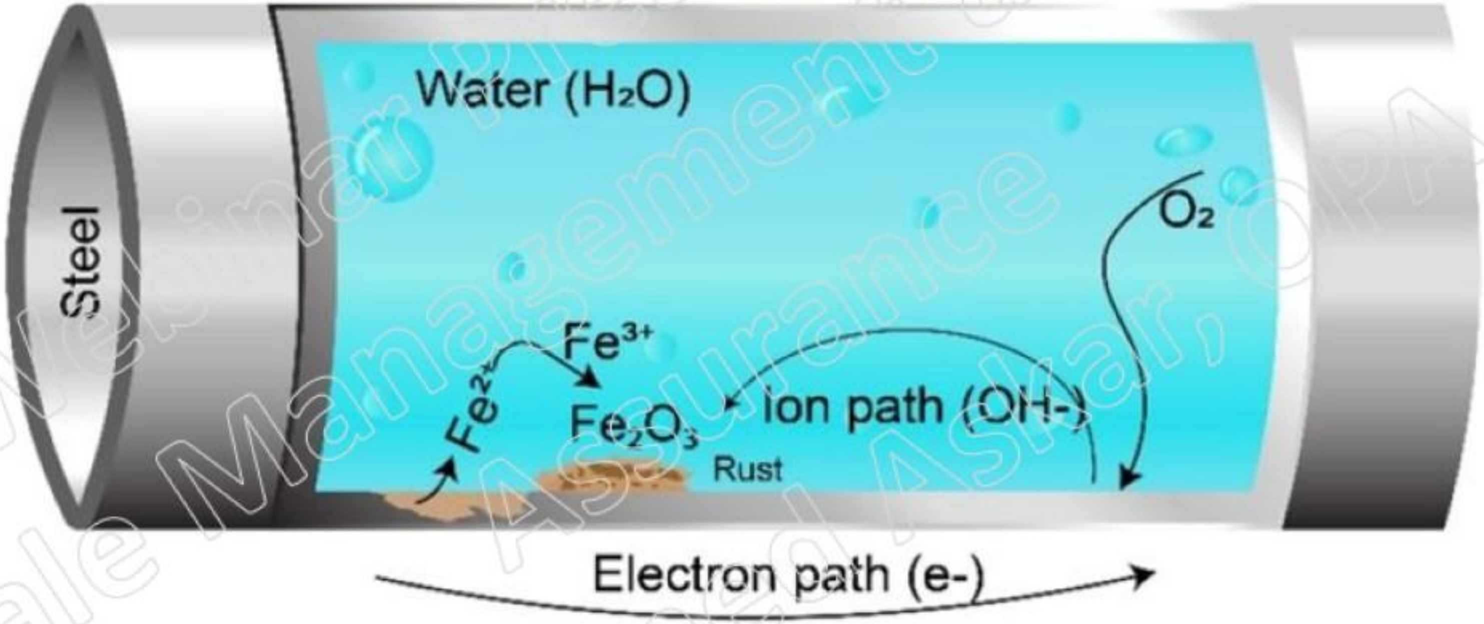
Corrosion



Corrosion Definition

- The spontaneous **oxidation of metal** is termed as corrosion, that is, Corrosion is the **deterioration or destruction of metals and alloys** in the presence of an environment by **chemical or electrochemical means.**
- The medium in which the metal undergoes corrosion is termed as **corrosive or aggressive medium.**
- Corrosion products formed are chemical compounds containing the metal in the oxidized form with the exception of gold and platinum, all other metals corrode and transform themselves into substances similar to the mineral ores from which they are extracted

Corrosion Definition and Reactions



Anodic Area (+)
Where metal dissolves

$Fe \rightarrow Fe^{2+} + 2e^{2-}$

Cathodic Area (-)
Electron conduction

$O_2 + 4H^{+} + 4e^{-} \rightarrow 2H_2O$

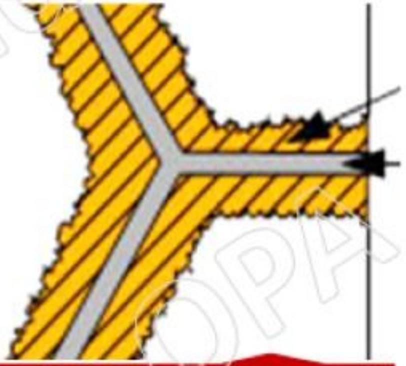
$O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-}$

Corrosion Mechanisms and Types


Uniform Corrosion


Pitting Corrosion


Crevice Corrosion


Intergranular Corrosion


Galvanic Corrosion


Erosion Corrosion


Selective Leaching


Stress-corrosion Cracking

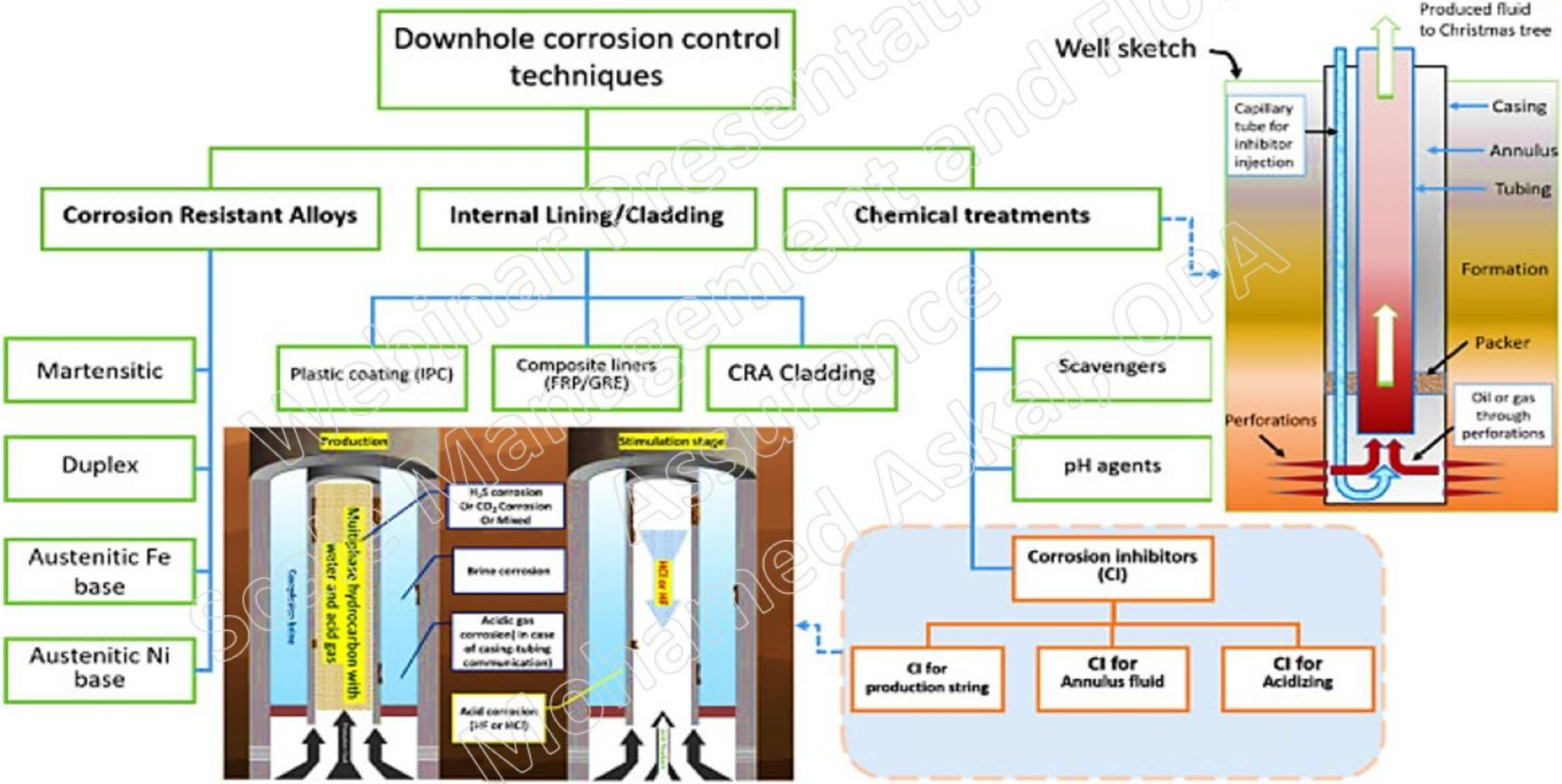

Cavitation Corrosion


Hydrogen Embrittlement

Fighting and Prevention of Corrosion

- Engineering Design
- Usage of Corrosion-resistant Alloys (CRA)
- Deployment of Protective Coatings
- Good Cementing Around Casing Strings
- Using inhibited Completions Fluids with Inhibitors
- Cathodic Protection
- Workover Option for
  - Changing corroded Tubulars
  - Tie-back liners

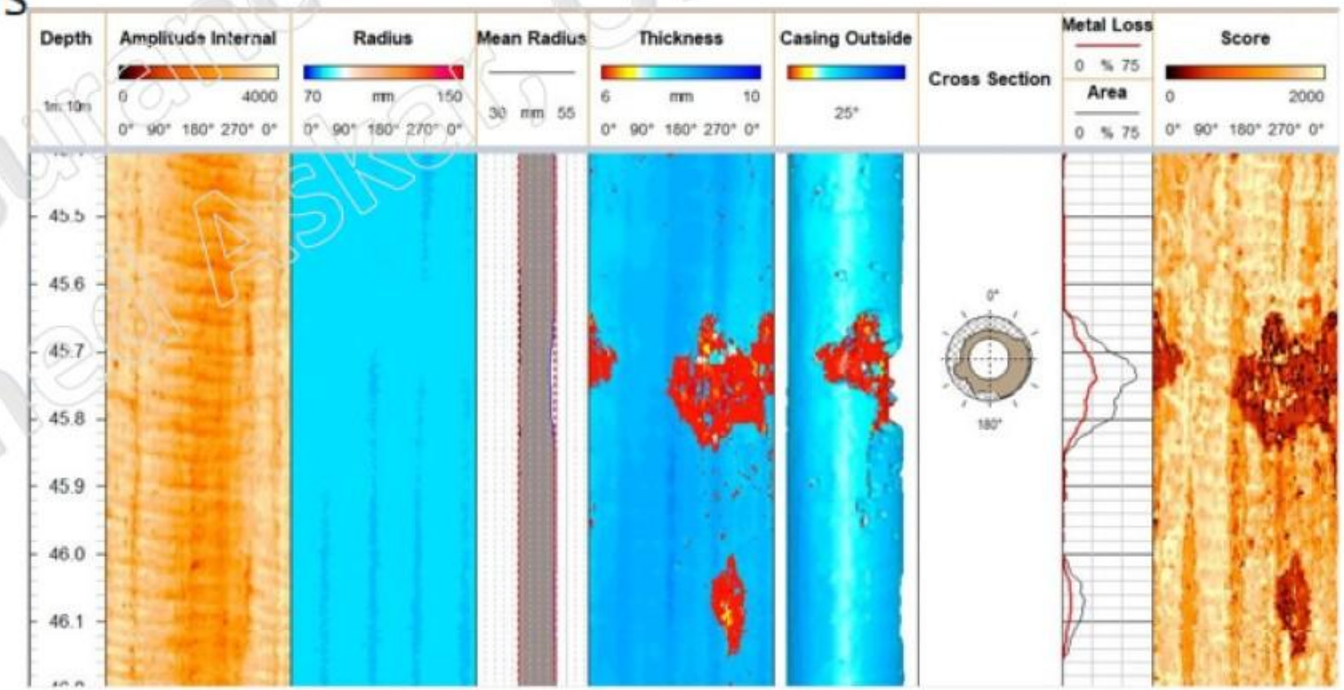
Downhole Corrosion Control Techniques



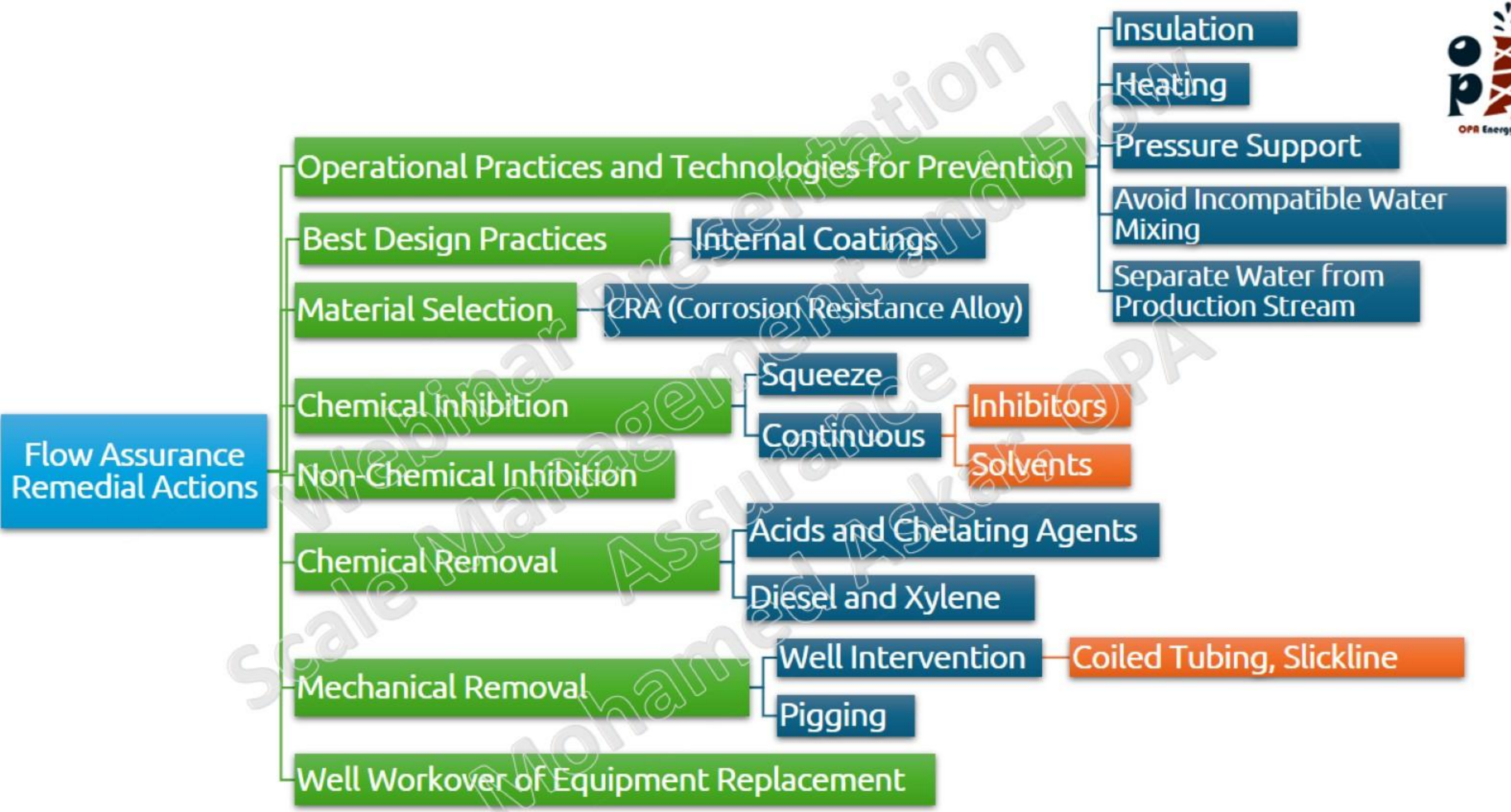
Corrosion Surface Monitoring

Corrosion Downhole Logging Tools for Tubing and Casing

- Mechanical Multi-finger caliper (MFC) Tools
- Ultrasonic Imaging (USI) Tools
- Electromagnetic (EM) Thickness Tools
- Magnetic Thickness Detection (MTD) Tools
- Noise Leak Detection Logging
- Fiber Optic Technology (DTS and DAS)
- Camera Recording



Flow Assurance Remedial Actions


Flow Assurance Remedial Actions
Operational Practices and Technologies for Prevention
Insulation
Heating
Pressure Support
Avoid Incompatible Water Mixing
Separate Water from Production Stream
Best Design Practices
Internal Coatings
Material Selection
CRA (Corrosion Resistance Alloy)
Chemical Inhibition
Squeeze
Continuous
Inhibitors
Solvents
Non-Chemical Inhibition
Chemical Removal
Acids and Chelating Agents
Diesel and Xylene
Mechanical Removal
Well Intervention
Coiled Tubing, Slickline
Pigging
Well Workover of Equipment Replacement

Thank You for Your Time

Mohamed Askar
Petroleum Engineer Trainer and PhD Candidate

Webinar Assessment

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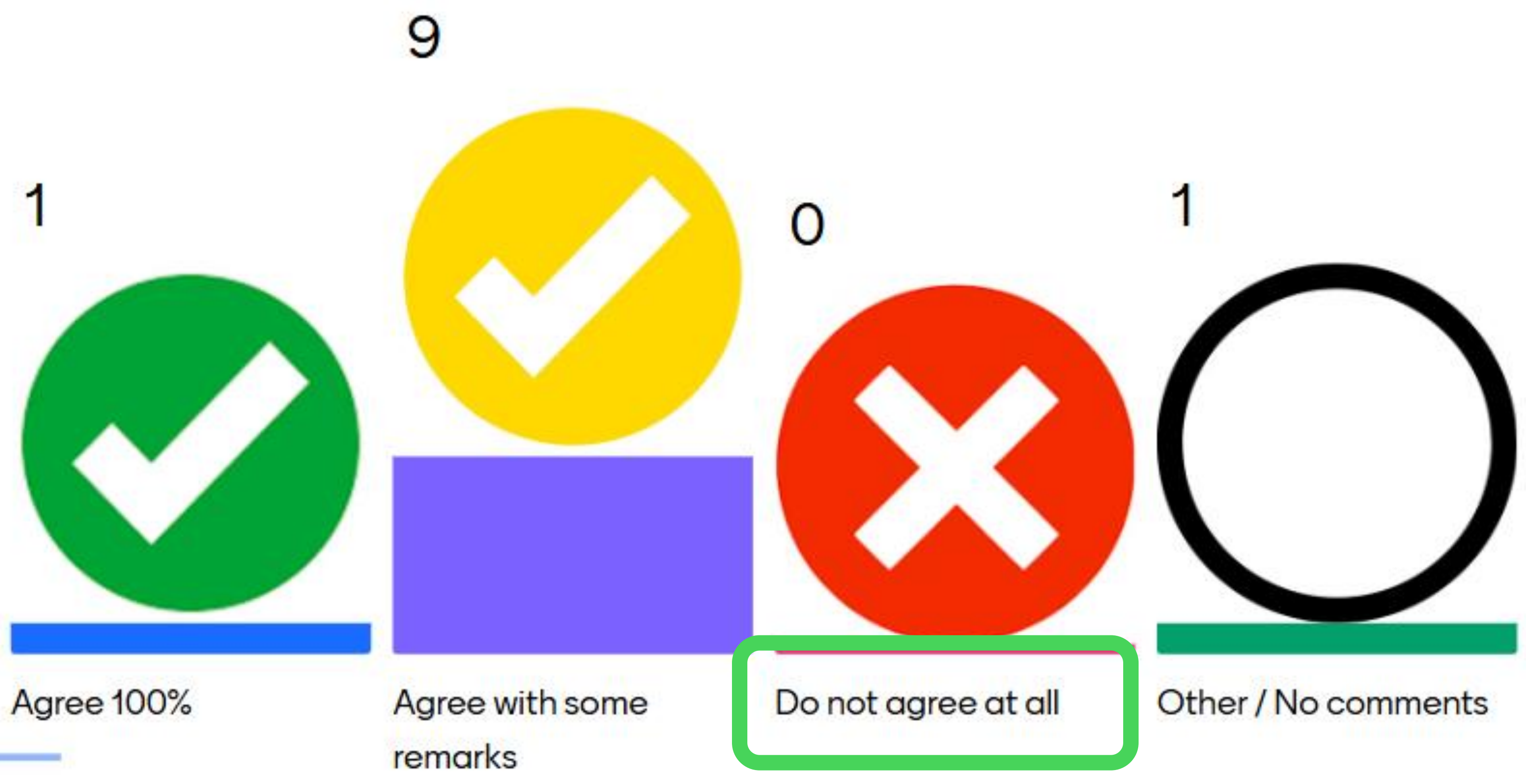
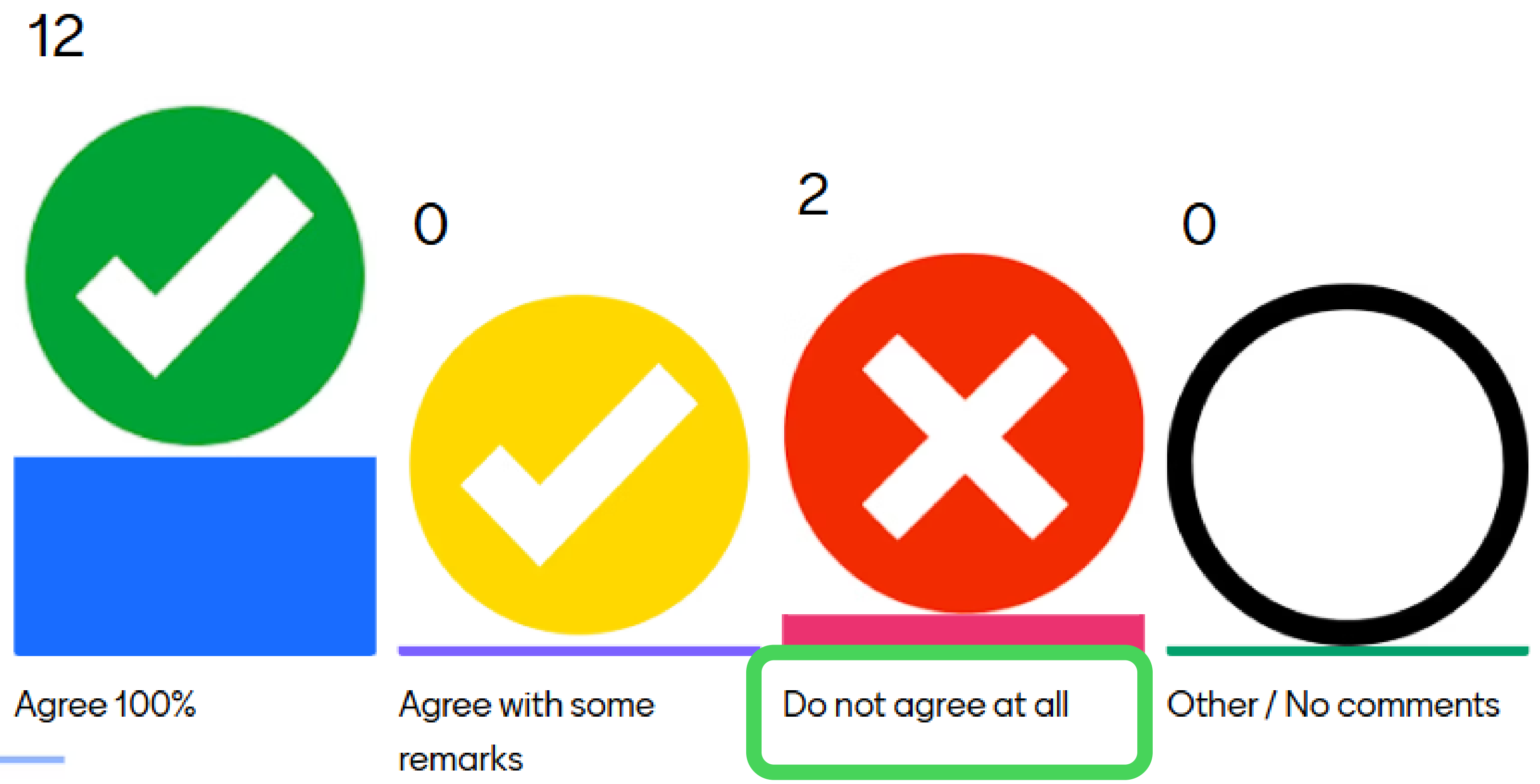
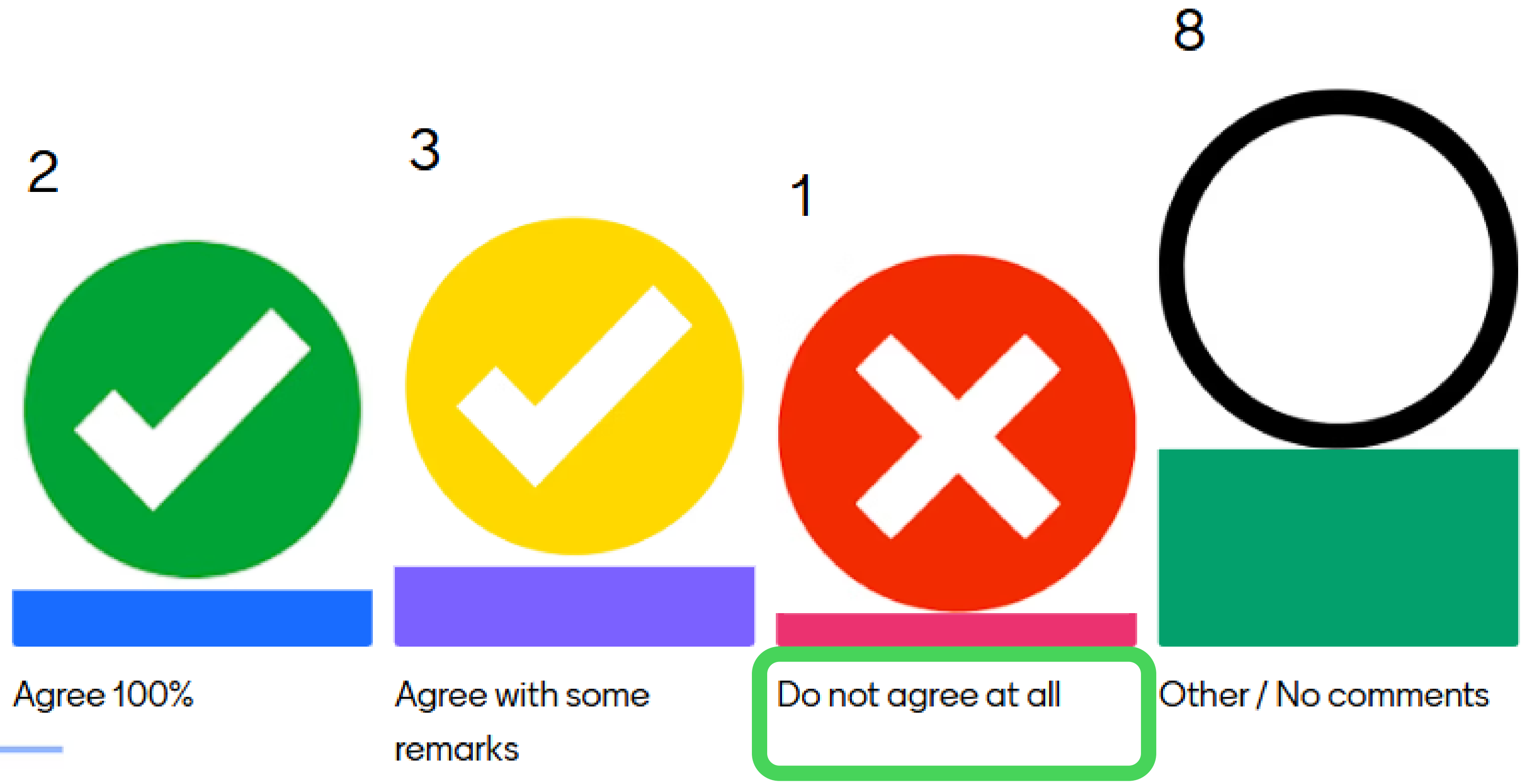
1. Hydrate plugs need water, hydrocarbon gas, and low pressure to form and restrict pipeline.



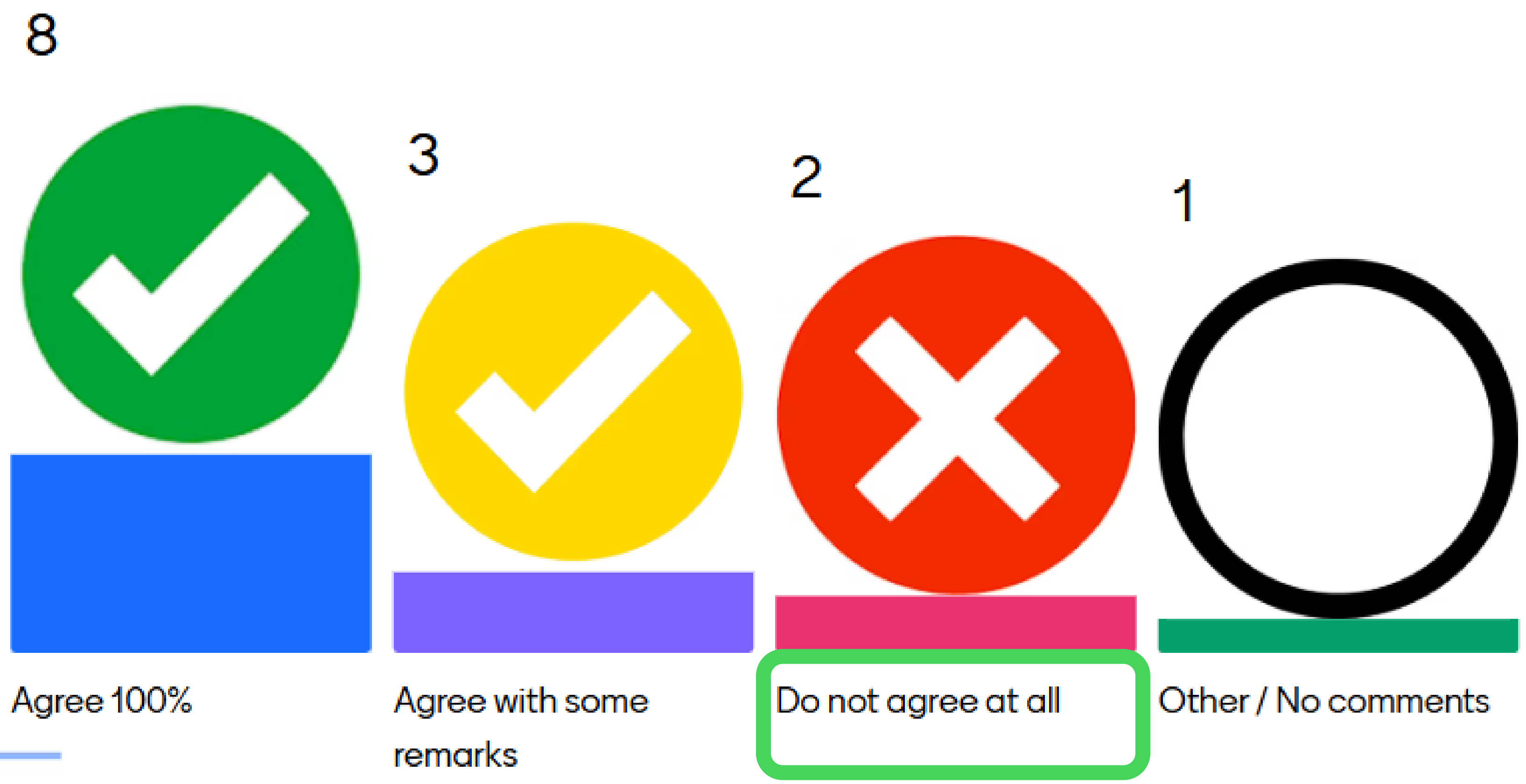
2. Asphaltene is a heavy soluble hydrocarbon compound.



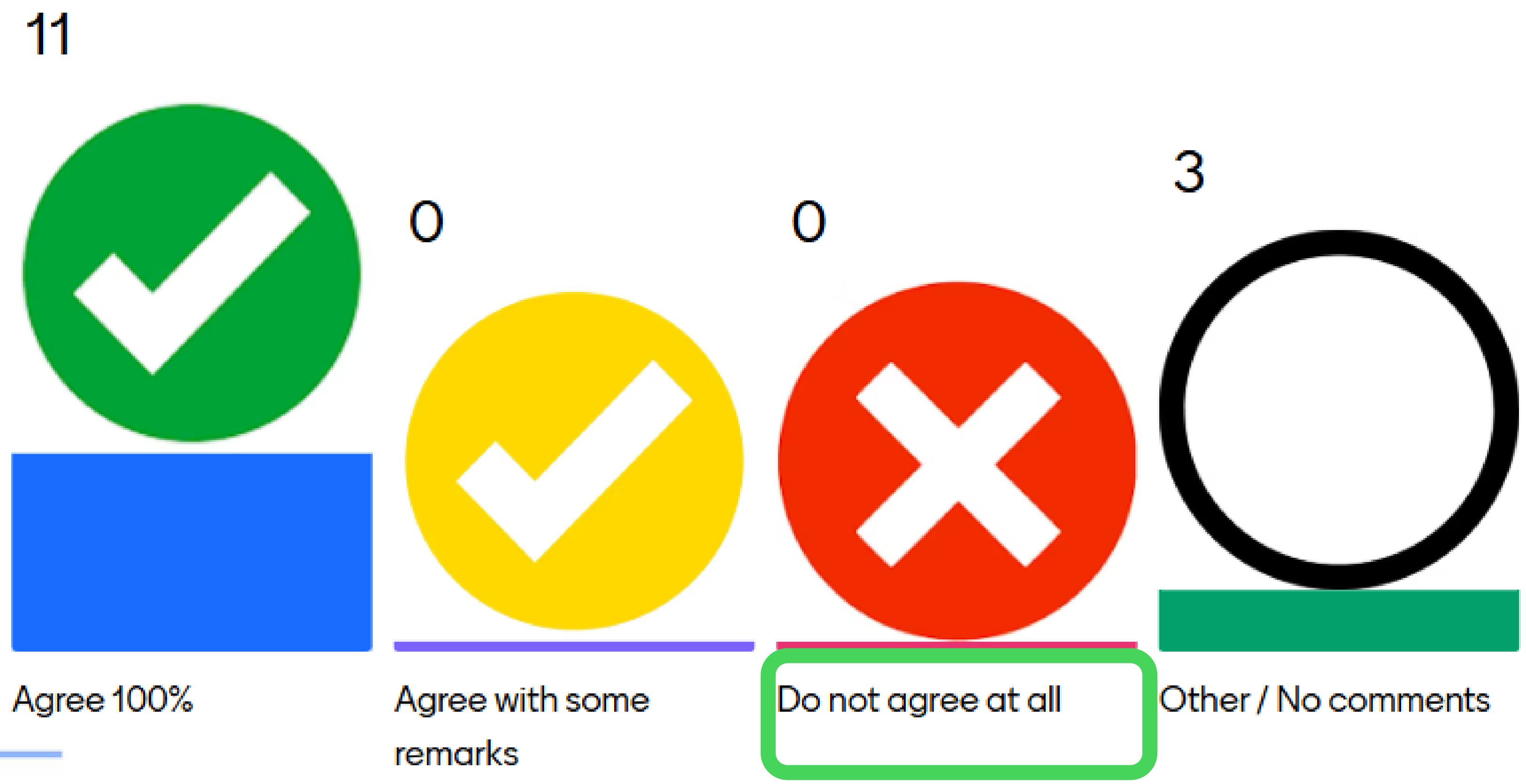
3. Paraffin dispersant works by depressing the wax appearance temperature (WAT).



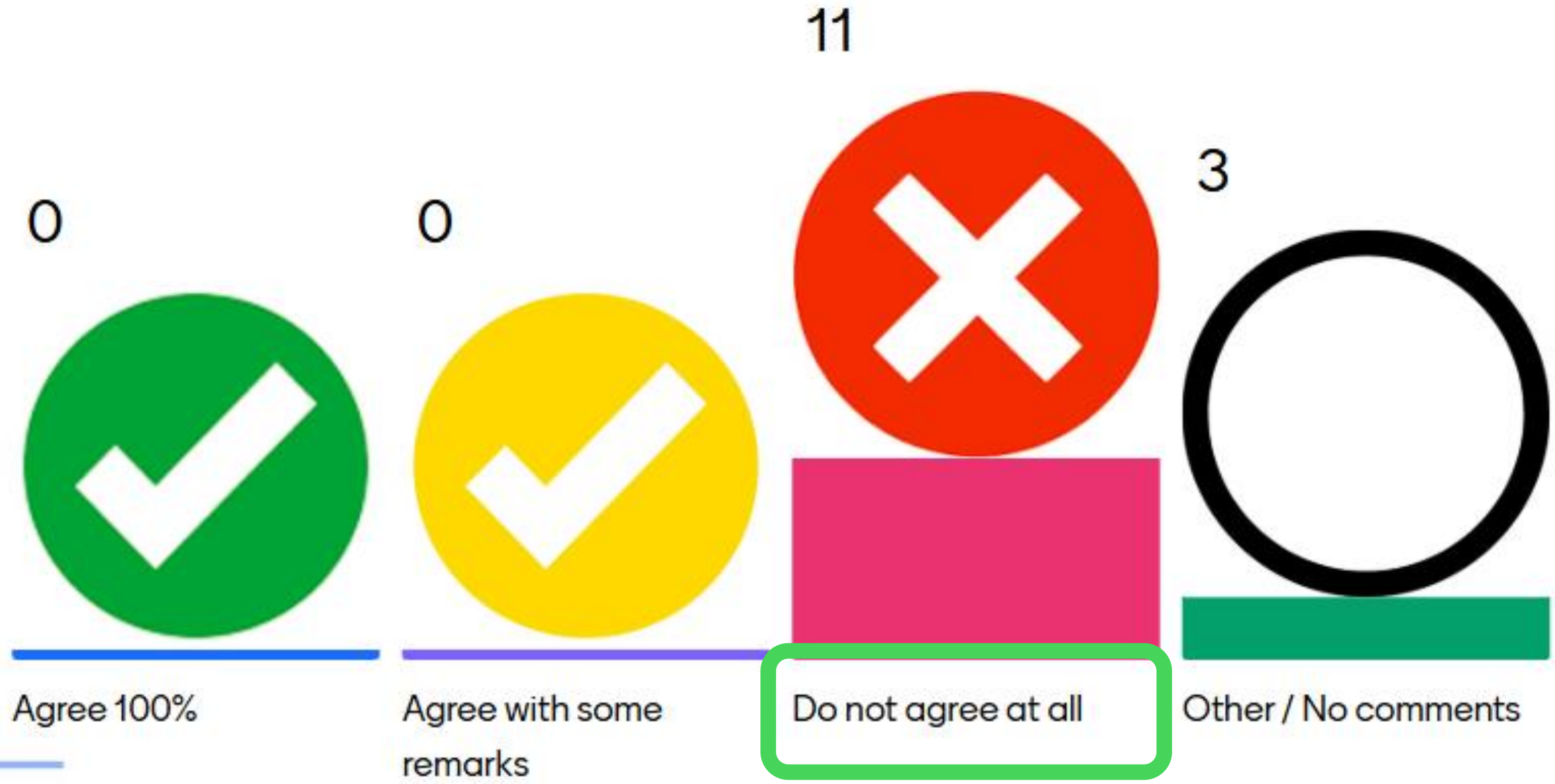
4. Wet insulation for the pipeline should be placed between two pipes for efficient thermal management.



5. Carbonate scales will deposit when temperature decreases.



6. Scale deposition affinity is not affected by the application of any hydrate chemical inhibitor.



7. Gas lift completions promote emulsion formation and scale deposition problems.

8. Smart or intelligent PIGs can inspect the pipeline wall thickness for corrosion monitoring purposes.