TOTAL
COMMITTED TO BETTER ENERGY

FLOW ASSURANCE IN FUTURE DEEPWATER DEVELOPMENTS

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With support of Thierry PALERMO, Luc RIVIERE and Clément BOIREAU

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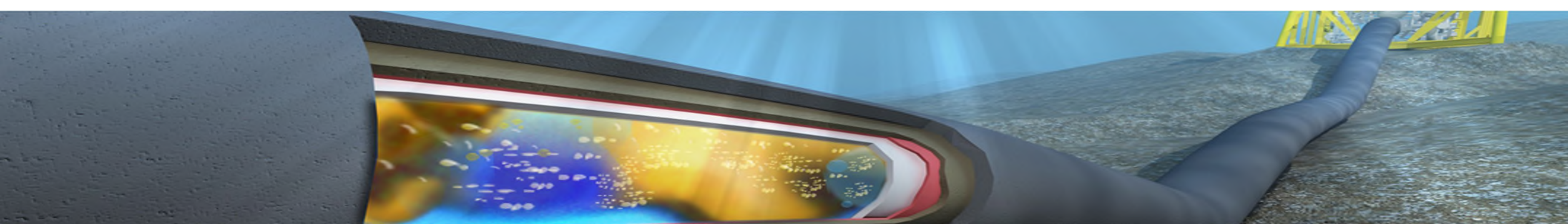


FLOW ASSURANCE CONVENTIONAL STRATEGIES

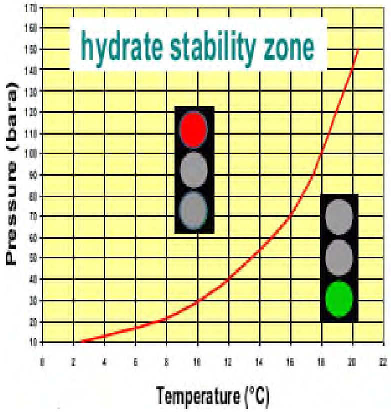
- Pipelines design – simulation

  LedaFlow® and/or OLGA© + …

  - Hydrates: CMSHyk, Leda, Pro II modified, in-house models
  - Wax: MWP, TUWAX, …, and In-House
- HYDRATES Management: conservative

  The 'Hydrate Curve' generally considered as a red line that must not be crossed

  - Oil fields
    - Insulation
    - Preservation (with diesel or dead oil)
      - + flushing of jumpers with MeOH
      - + MeOH injection in the restart
    - Separation + boosting
  - Gas fields
    - Continuous injection of the THI (MeOH, MEG)



- WAX Management : costly + high uncertainty
  - Pigging @ frequency simulation+ operations
  - Heating
  - Inhibitors (at a limited extent)

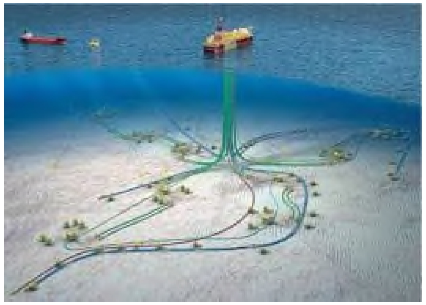
BUT UNDER NEW MARKET CONDITIONS….

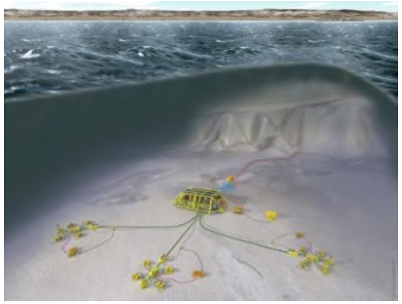
- Low gas & oil price environment
  - *Around 50 US$ / barrel anticipated for a long term*
- Development of marginal Deep Offshore fields
  - *No economically viable*
  - *Development costs must be reduced*
- Perspectives
  - *'Low cost' architecture based on:*
    - *Long subsea tie-backs (no stand-alone platform)*
    - *Innovative subsea technologies and processing*
    - *<u>Change in our Flow Assurance and production management strategies</u>*

TOTAL in DW:

Top 3 operators for operated production and # of wells

More than 50 % of conventional exploration for TOTAL





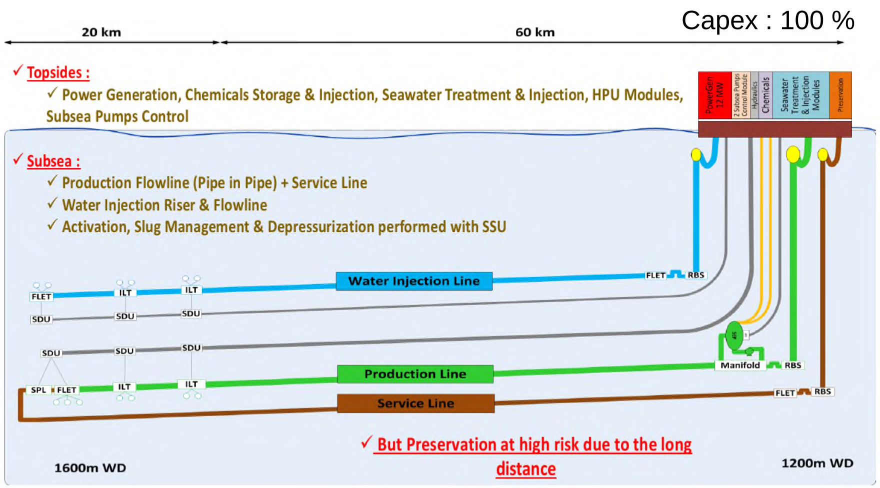
HYDRATES

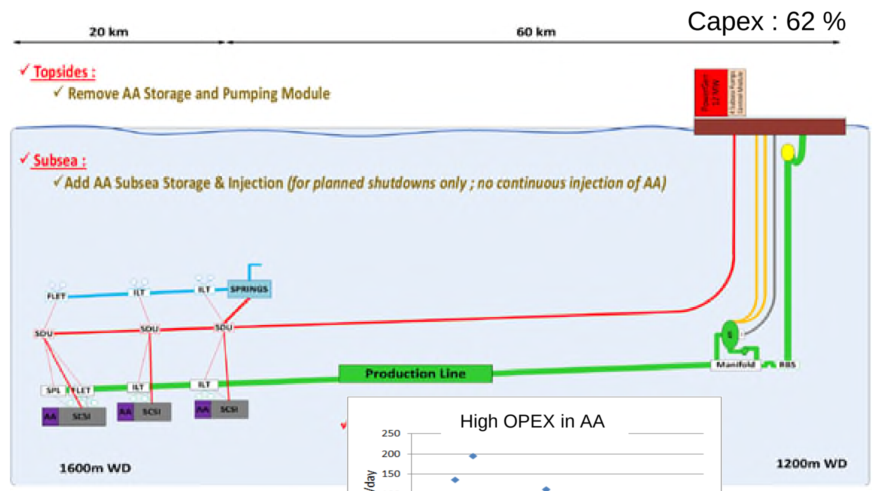
Opportunities To Change The Economy In DW Developments

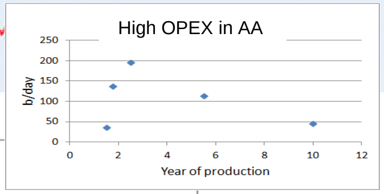
LONG TIE-BACK FIELD SCENARIO

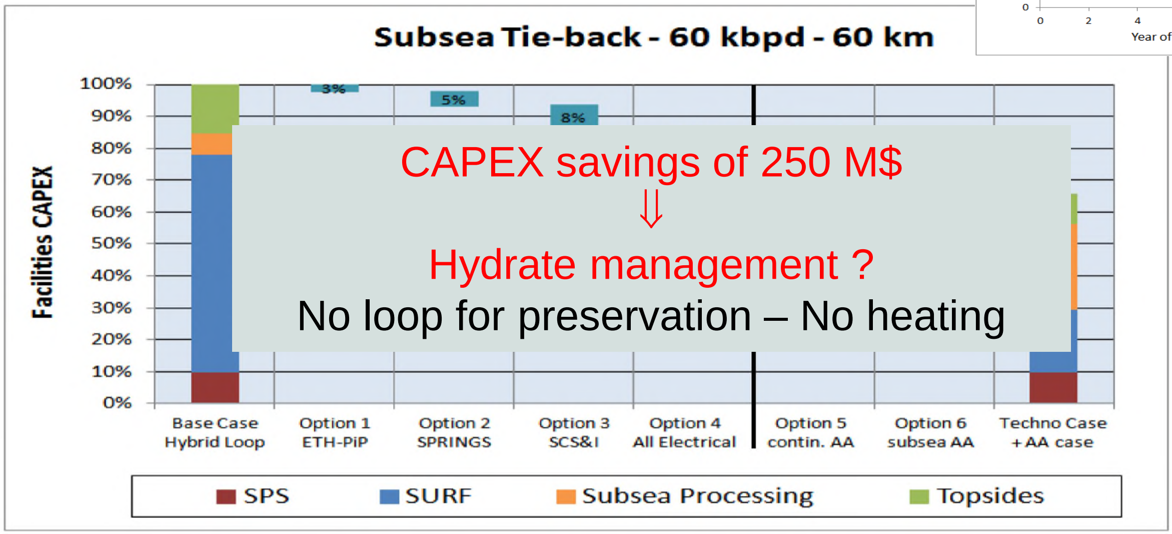
OIL FIELD LONG TIE-BACK – CASE OF STUDY

60 kbopd; 1600 WD; 60 km SS tie-back



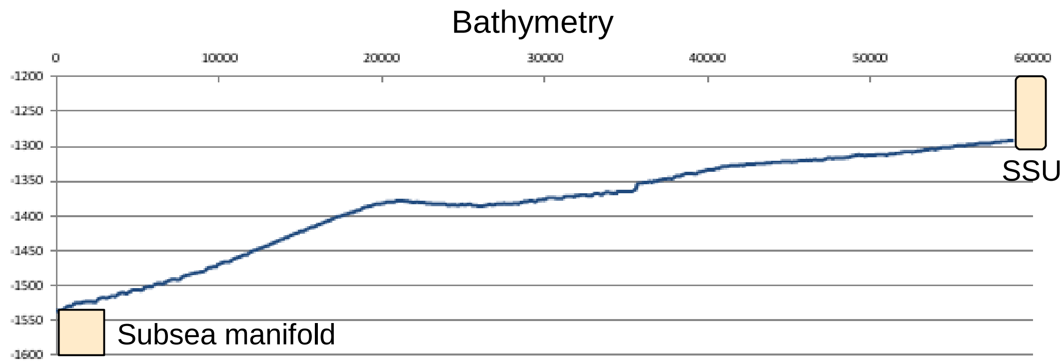


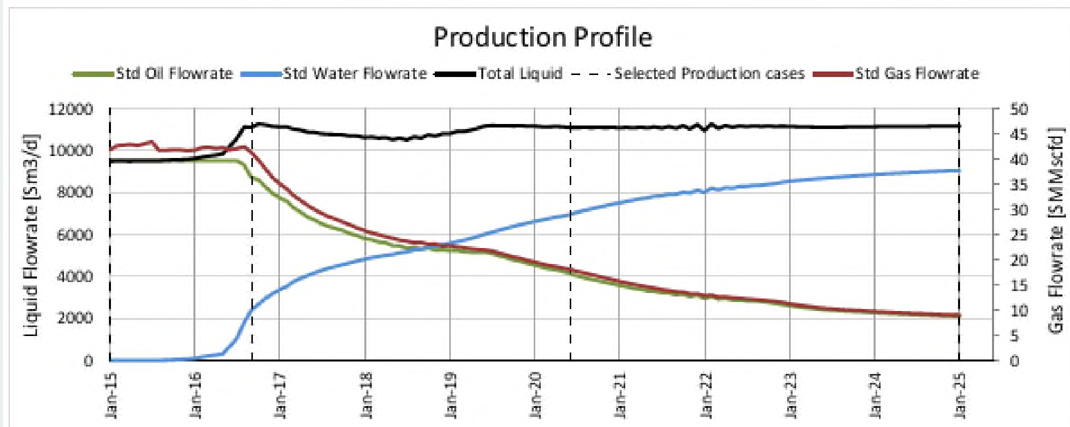




HYDRATE MANAGEMENT

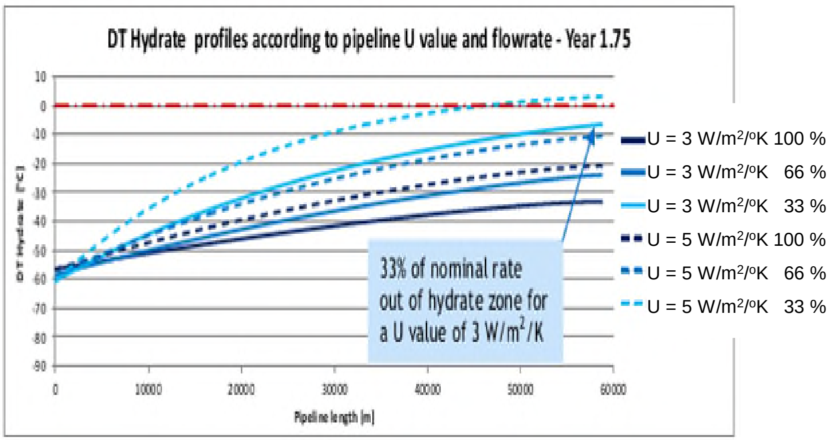
- Flow conditions investigated with LedaFlow simulator
- Conditions
  - 60 km long - 14 in. pipeline : from manifold to SSU
  - U_Value = 3 W/m²/K; T_{ext} = 4°C
  - T_{in} = 76 °C → 99 °C along the field life
  - P at the SSU = 30 bara
  - GOR = 120 – 135 Sm^3/Sm^3
    - (670 – 760 scf/sb)
  - WC = 0 → 80 %





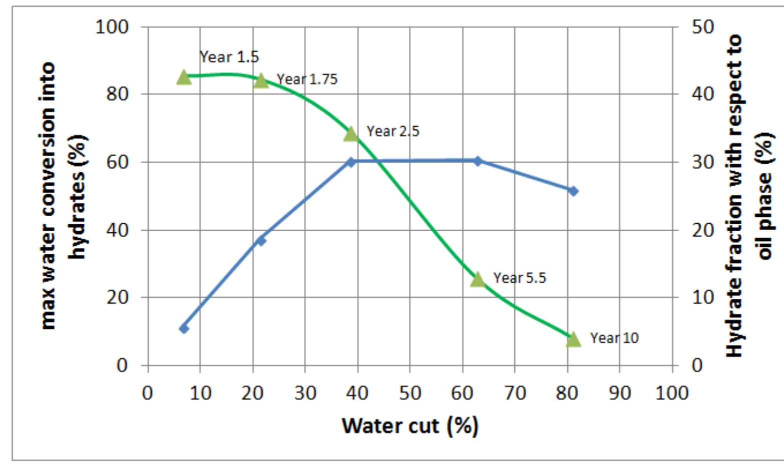
HYDRATE MANAGEMENT

- Production outside th HydZ
  - Always out of HZ, even at 33% of downturn



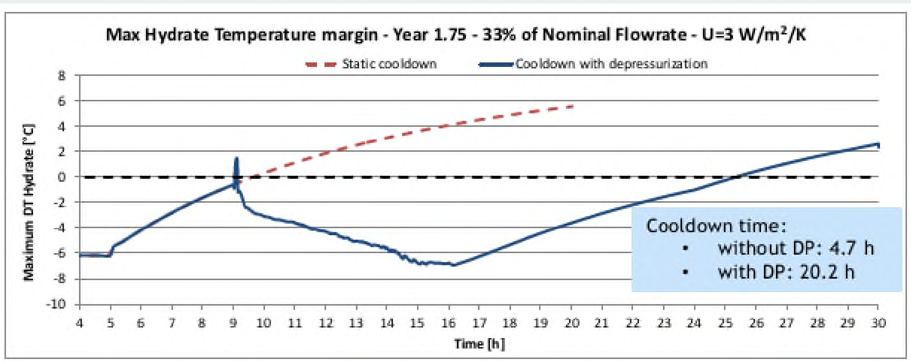
- Shut down / Restart phases
  - Quantity of hydrates limited by the GOR and salt

→Batch injection of AA-LDHI prior to shut down is feasible



- Unplanned Shut downShut down ?

Low probability for NTT > 20 hr → risk-reward to manage



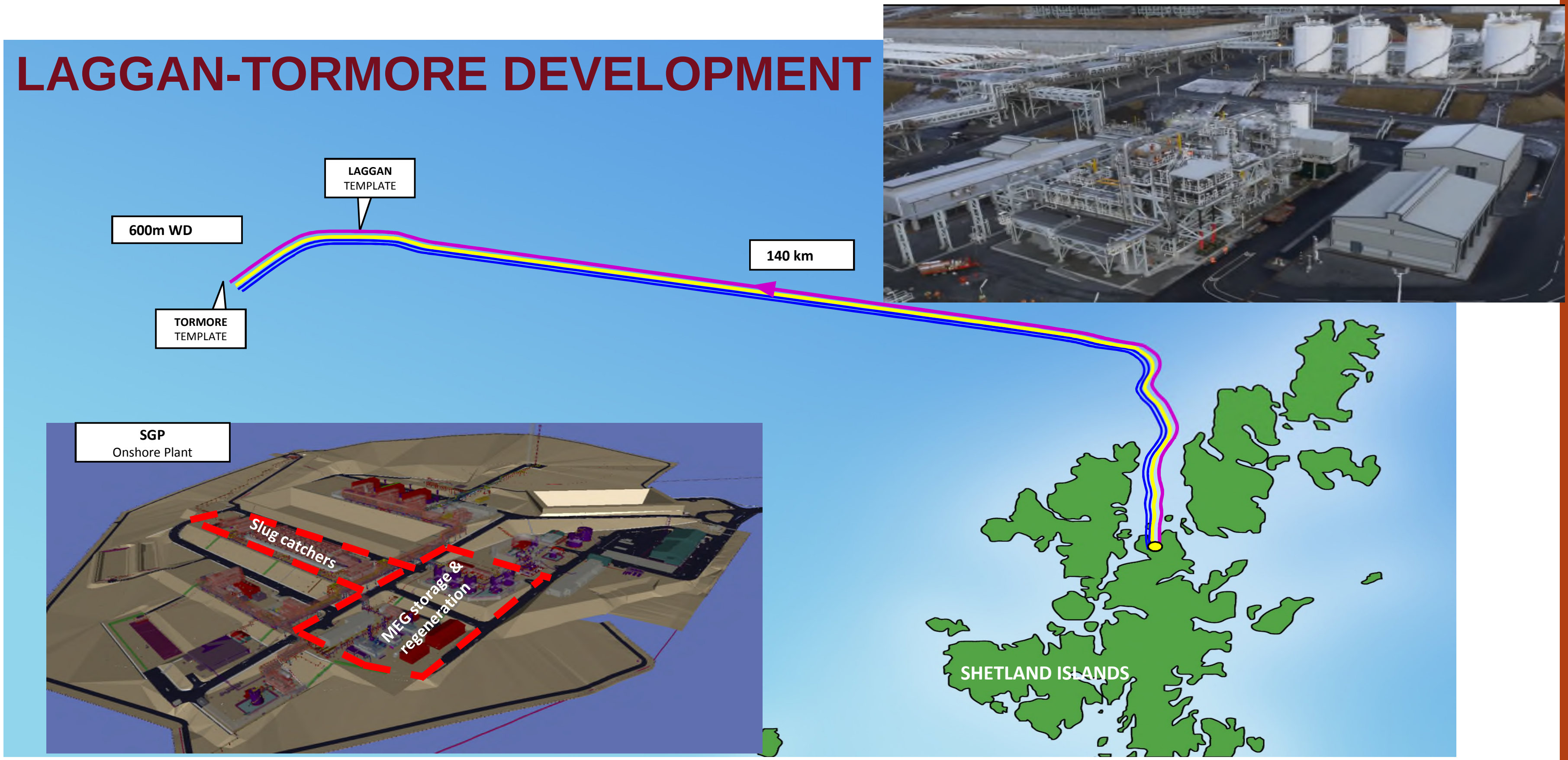
HYDRATES

Opportunities To Change The Economy In DW Developments

GAS CONDENSATE FIELD SCENARIO

OIL FIELD LONG TIE-BACK – CASE OF STUDY

500 MMscfd; 600 WD; 140 km Subsea to Shore



- Is it possible to reduce the development costs to make them profitable in a 50 \$/bbl environment ?
- Example of Laggan-Tormore – West of Shetlands – to Shetlands Gas Plant (SGP)

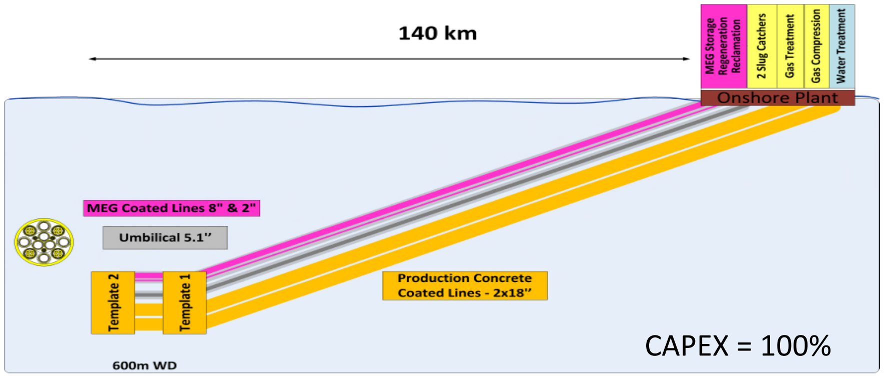
TOTAL

OIL FIELD LONG TIE-BACK – CASE OF STUDY

500 MMscfd; 600 WD; 140 km Subsea to Shore

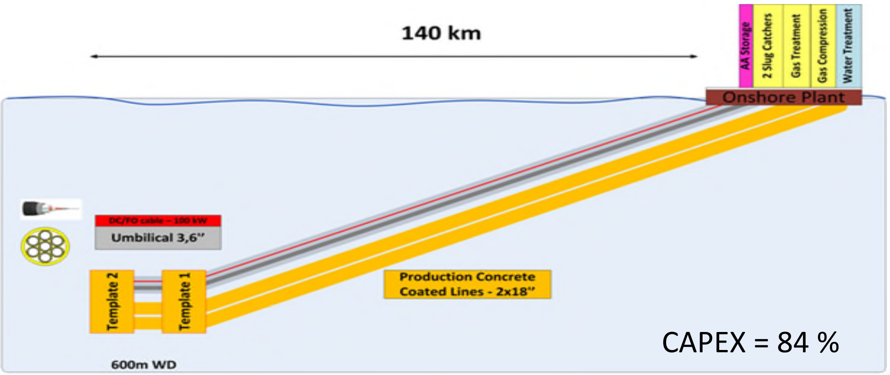
BASE CASE : As Built

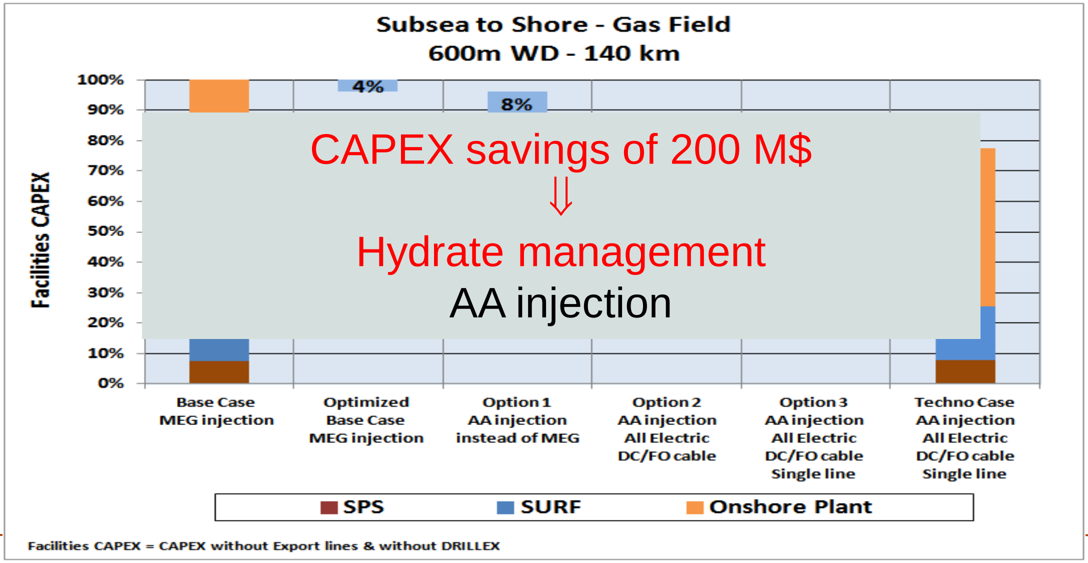
MEG continuous injection
2 production lines for pigging & turndown
Umbilical for chemicals & well control



OPTION 1 : AA Injection

Replace continuous MEG injection by continuous AA-LDHI injection
Remove 8'' MEG line & MEG onshore storage & regeneration
AA injected through umbilical





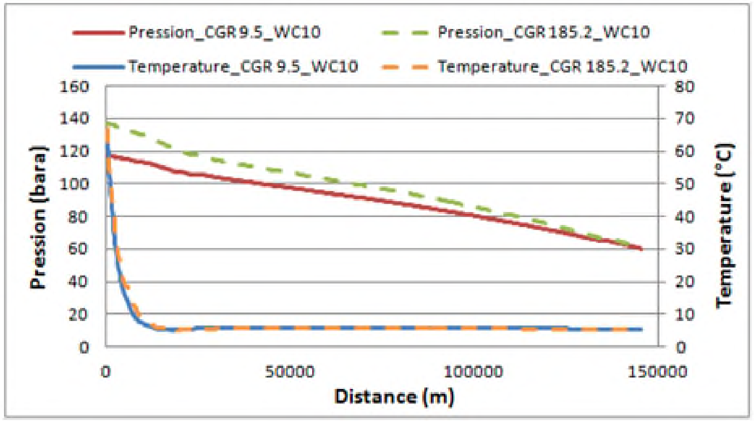
HOW TO MANAGE HYDRATES? A GENERIC CASE STUDY

Water cut

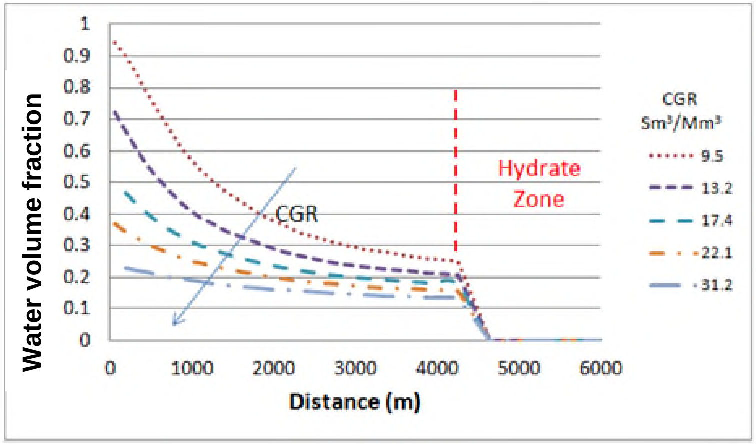
Hydrates volume fraction: Max Hydrate volume fraction around 50 %

Transportability : Condensate as carrier fluid must be sufficient to enable hydrates transport

- Volume flow rate of water and condensate vary along the line



- No significant difference in P – T conditions depending on the CGR
- The maximum hydrate volume fraction (~ local water fraction at the inlet of the hydrate zone) is below 30 vol% for CGR > 10 Sm^3/SMm^3
- Transport of the hydrate slurry with AA-LDHI should be feasible for most of gas condensate fields
  - As far as the water phase is mainly composed of condense water



HYDRATE MANAGEMENT

- The use of a wet insulated line work on a 'Do Nothing' strategy
  - no prevention method will be deployed in oil fields
- LDHI-AA Injection in gas field as a primary strategy
- A risk analysis of blockage occurrence has to be carried out
  - Consideration of natural kinetic and natural properties of oils
  - Localization of the different phases during the shut down and restart
    - Local volume fraction of water, oil and gas phases in the pipeline
  - Consideration of full life of gas field and the real hydrates volume and fraction that will need to be transported

R&D TO IMPROVE HYDRATES RISK MANAGEMENT STRAT

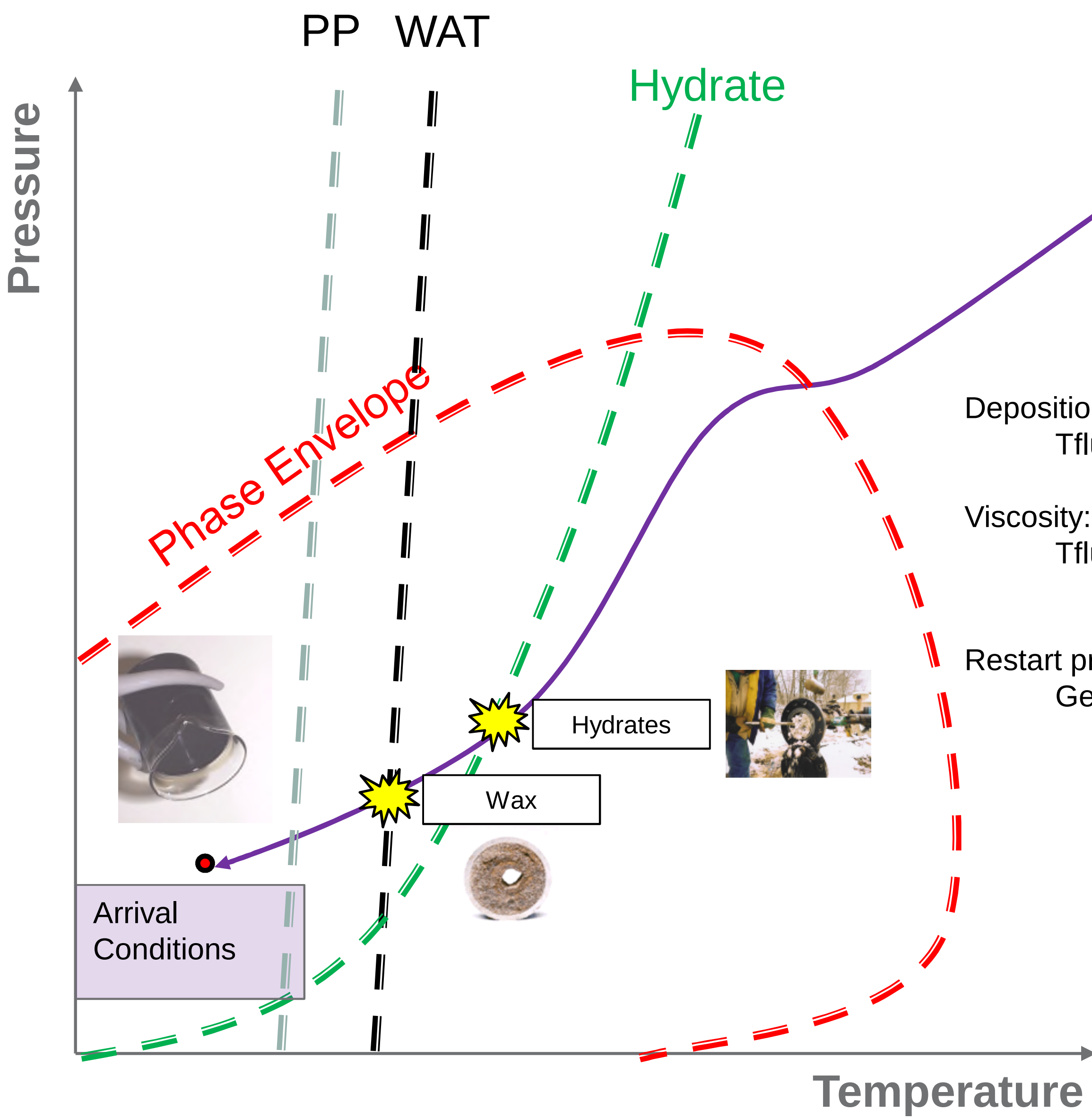
- Hydrates modeling
  - Hydrates formation is key to estimate all properties: rheology, inversion
    - Kinetic models → reduce uncertainty, validation of models
  - Rheology models improvements and validation
  - Base on fully disperse systems : water in oil or oil in water
    - Partial disperse system not well understood
- LDHI –AA
  - Selection – compatibility with oils, water and other additives
  - Concentration, fully or partially dosed systems & alternatives to consider AA + THI
  - Stability – performance in terms as a function of SS condition, consumption
- Accurate, safe and low cost mitigation methods must be developed
- Hydrates monitoring technologies must be developed

WHY AA-LDHI IS NOT YET WIDELY USED ?

- HSE issues
  - Toxicity is often said to act as a brake on business extension.
- Efficiency in ice zone
  - Due to gas expansion associated with pressure drop the temperature might fall down below 0 °C.
- Top of line deposition is sometime reported as a concern
  - Such an issue should be fixed by periodic batch injections of THI
- Better understanding of performance:
  - Selection – compatibility with oils, water and other additives
  - Concentration, fully or partially dosed systems & alternatives to consider AA + THI
  - Stability – performance in terms as a function of SS condition, consumption

WAX
Improving Wax Deposition Model

WAX-RELATED ISSUES



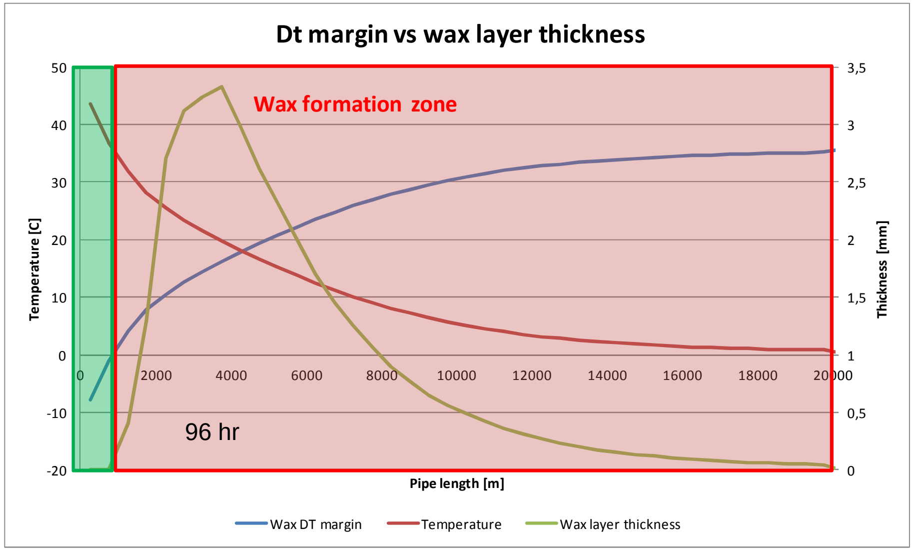
Deposition
Tfluid > Twall and Twall < WAT

Viscosity:Non-Newtonian behaviour
Tfluid < WAT

Restart pressure
Gelation of waxy oil during shut-down

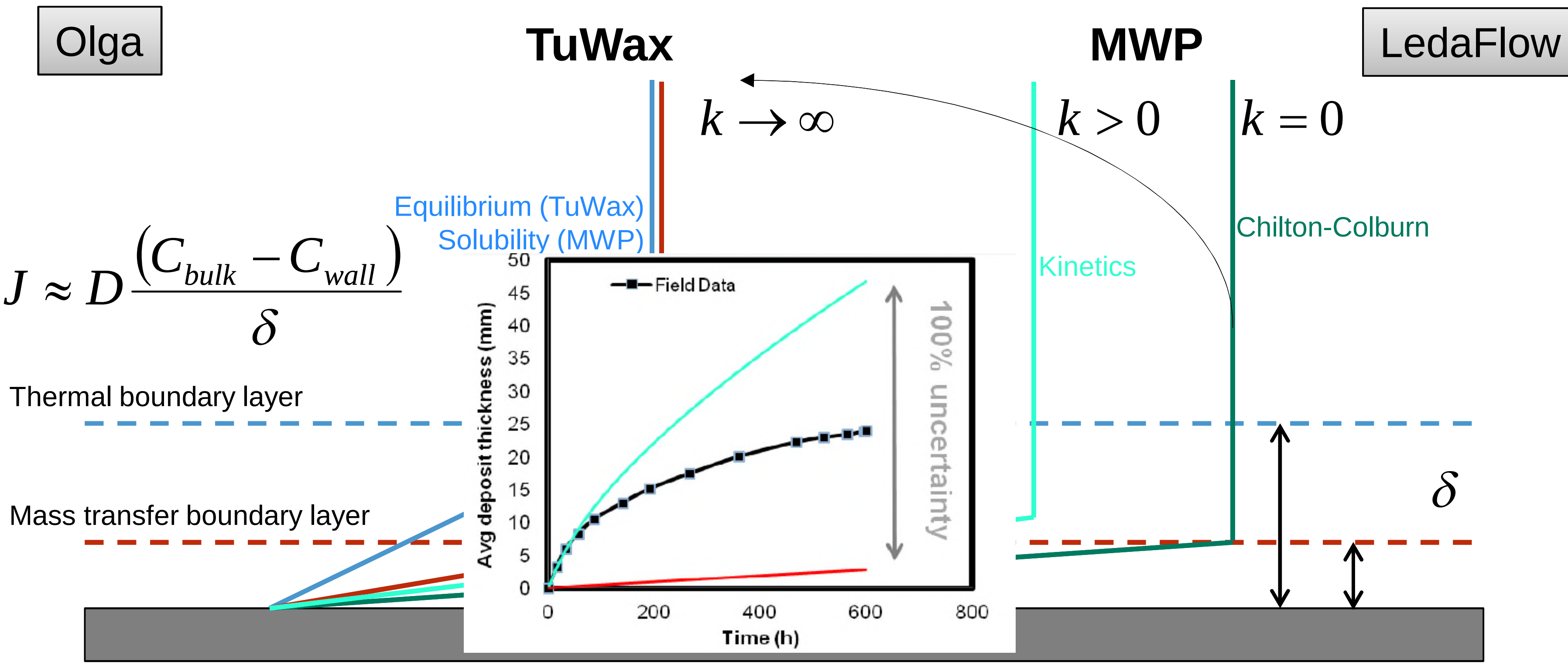
WAX DEPOSITION MODELING MUST ASSIST DESIGN

- Simulate Long flow lines with no heating/insulating
- Estimate pigging frequency
  - Today: Field experience + criteria of deposit thickness reaching 2mm
  - Optimization based on field observations
- Existing wax deposition model
  - LEDA-Wax, OLGA-Wax,, PVTSim DepoWax,
  - TUWax(University of Tulsa), FloWax (Infochem), MWP (University of Michigan)



ISSUES IN DEPOSITION MODELING

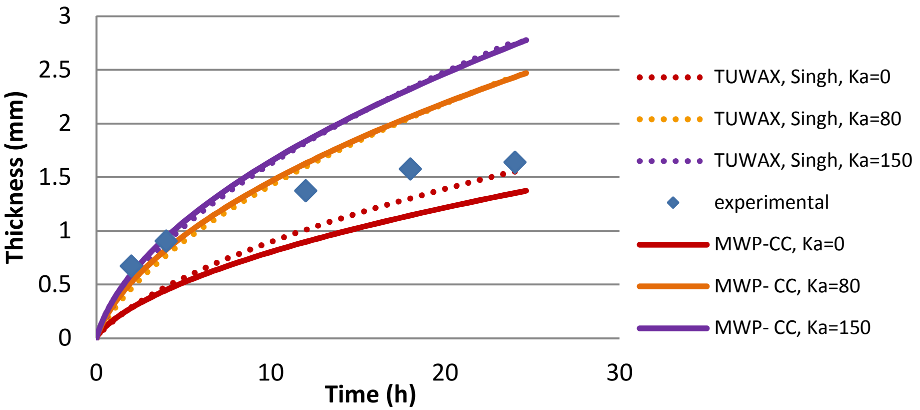
- In turbulent flow: what model – what BL to account for?

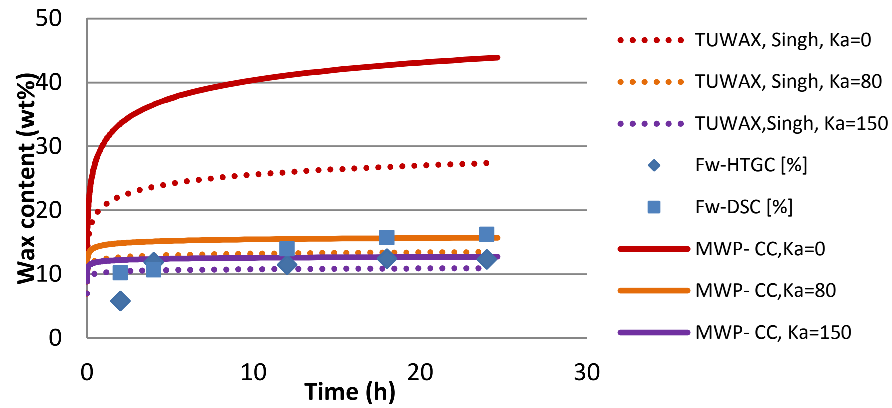


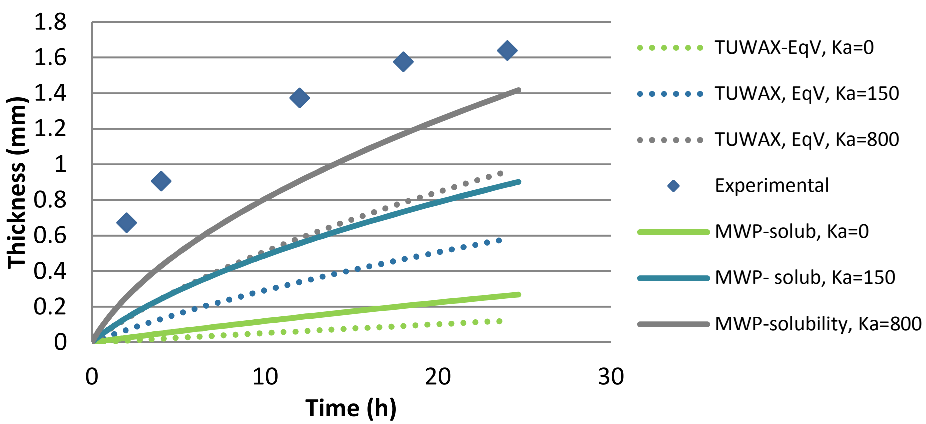
$$J_{Chilton-Colburn} > J_{FMT} \to 10 \times J_{Equilibrium}$$

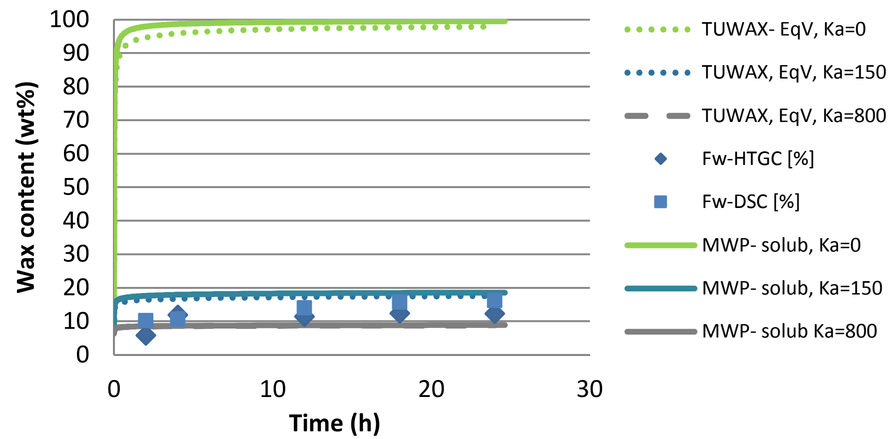
Results simulation, Comparison TUWAX and MWP

Turbulent regime : Re =12643, WAT = 42 °C







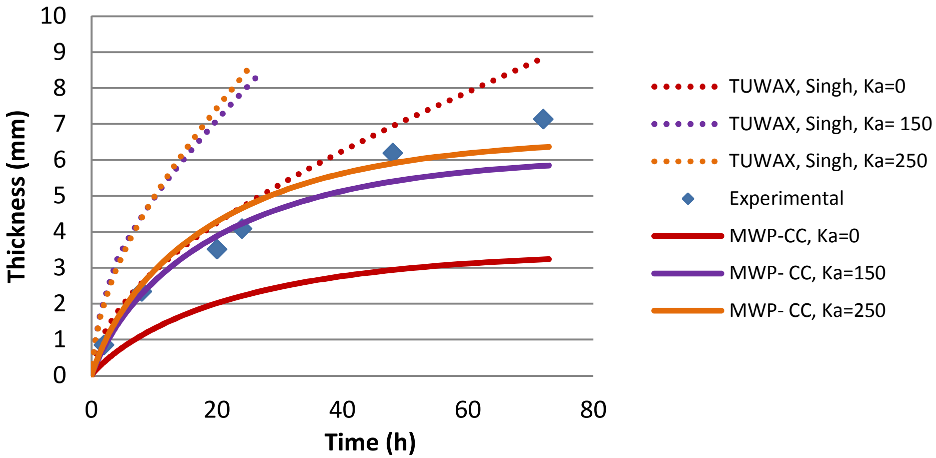


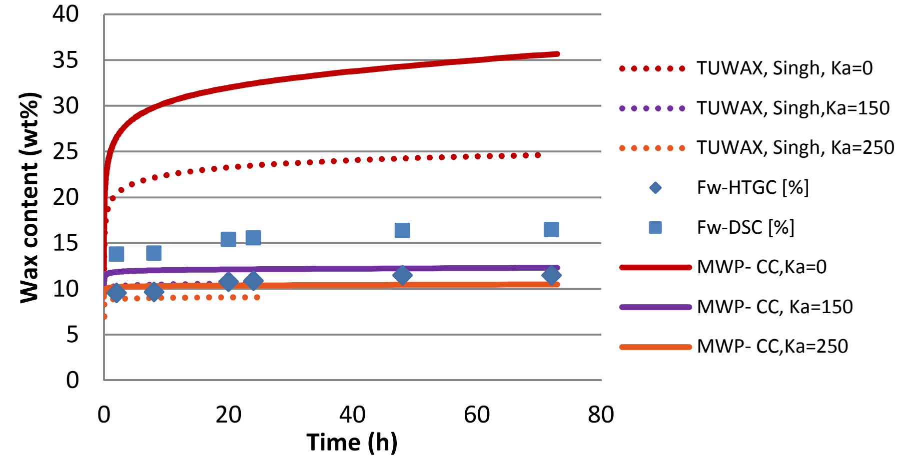
Chilton-Colburn ≈ Singh

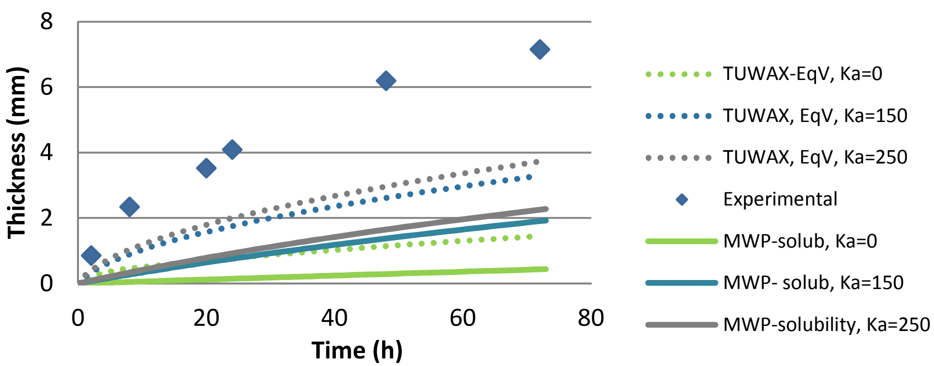
Solubility MWP > Equilibrium TUWAX

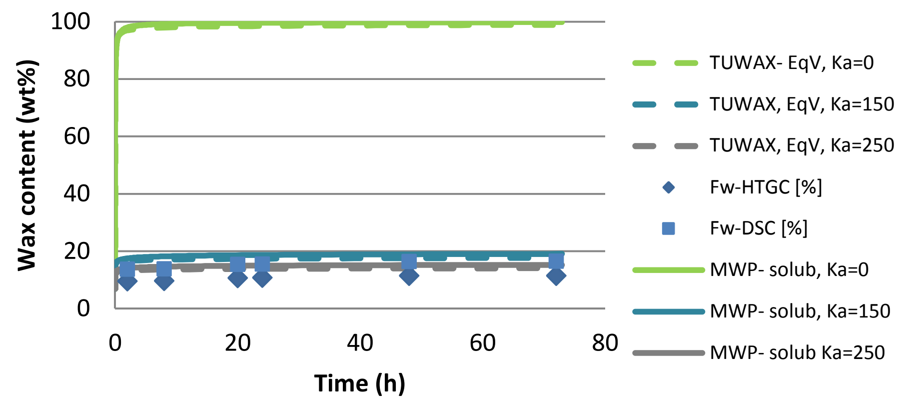
Results simulation, Comparison TUWAX and MWP

Laminar regime : Re =1064, WAT = 40 °C





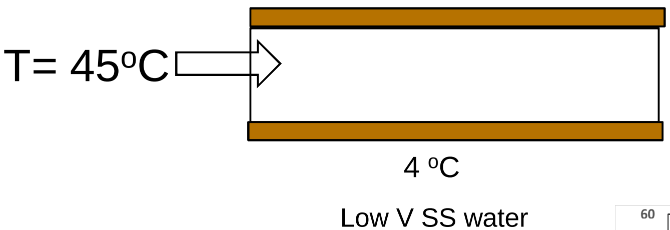


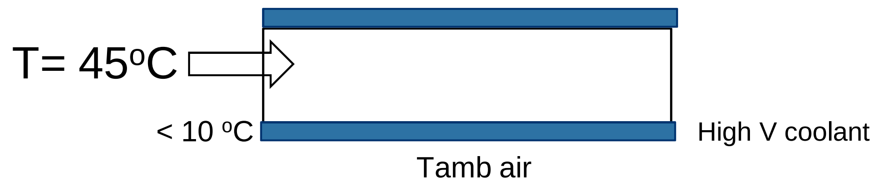


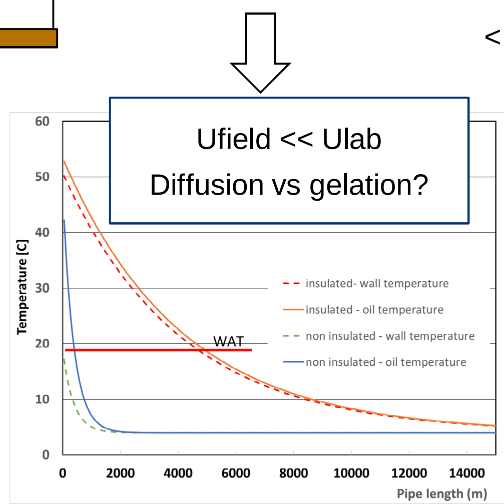
Simulations do not capture the experimental deposition

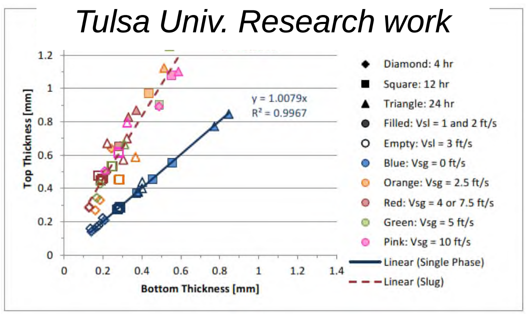
MODELS VALIDATION

- Experimental flow loops vs real scale pipelines
  - Thermal driven force

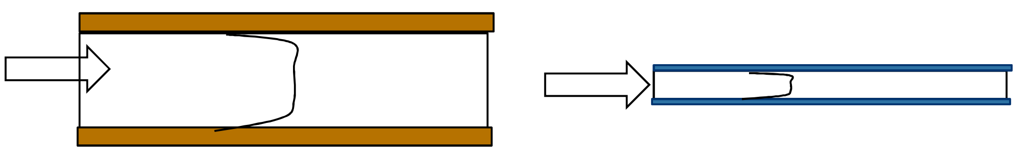








  - Scale-up

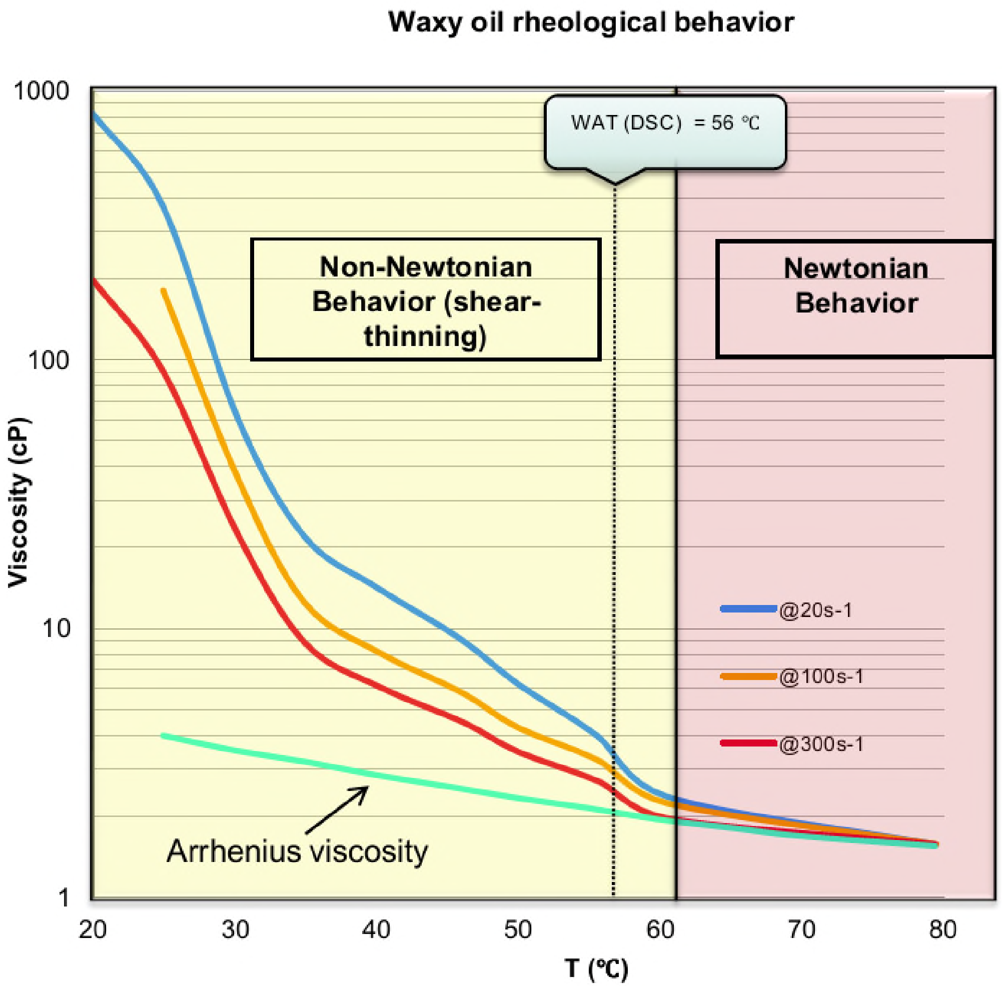


Re(lab) < Re (field)

Characteristic time and distances,

topography, Single vs Multiphase flow

IDENTIFIED DEFICIENCY: VISCOSITY DEFINITION



Hydrodynamics

Axial velocity | Turbulence

$$y^+ = \frac{y}{\nu}\sqrt{\frac{\tau_w}{\rho}} = \left(1-\frac{r}{R}\right)\frac{Re}{2}\sqrt{\frac{f}{8}}$$

$$\mathrm{Re} = \frac{\text{inertial forces}}{\text{viscous forces}} = \frac{\rho v L}{\mu}$$

Mass Diffusion

$$D_{\mathrm{wax}} = A_{\mathrm{HM}}\frac{T^{1.47}\mu_{\mathrm{B}}^{\gamma}}{V_{\mathrm{A}}^{0.71}}, \quad \gamma = \frac{10.2}{V_{\mathrm{A}}} - 0.791$$

University Of Michigan Collaboration
M Zheng work at TOTAL as PhD student internship
(OTC paper 26914 –MS. 2016)

NEW MODEL DESCRIPTION

COMPARISON BETWEEN SIMULATION RESULTS AND THE CONCEPTUAL DRAWING

Newtonian fluid:

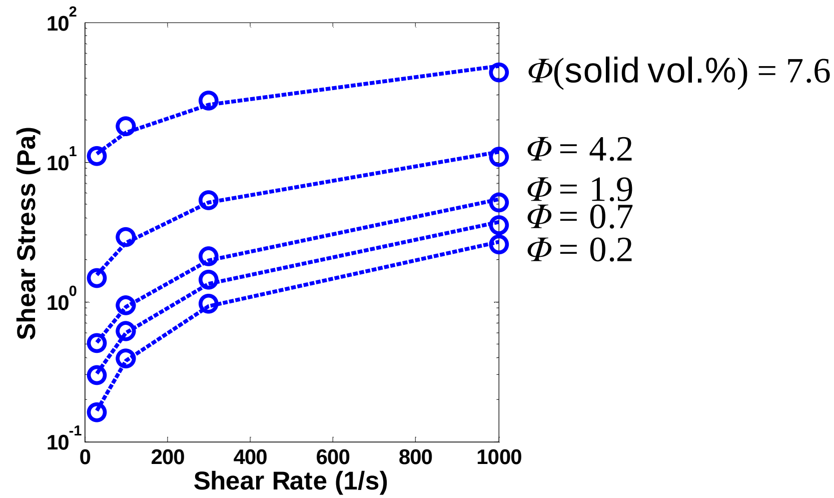
$$\tau = \mu\dot{\gamma} \qquad\qquad \mu = \frac{\tau}{\dot{\gamma}}$$

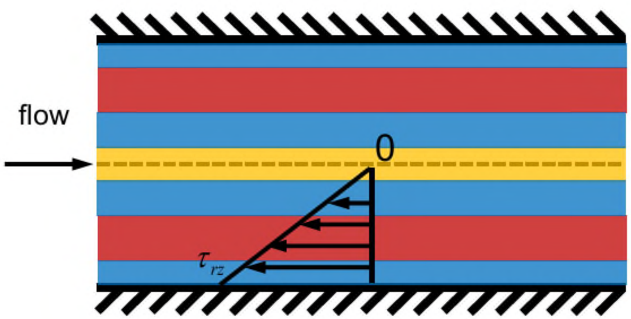
Non-Newtonian fluid (Herschel-Bulkley):

Plasticity

$$\tau = \tau_y + K\dot{\gamma}^n \qquad \mu = \frac{\tau}{\dot{\gamma}} = \frac{\tau}{\left(\dfrac{\tau - \tau_y}{K}\right)^{1/n}}$$

Shear thinning





un-yielded (plug)

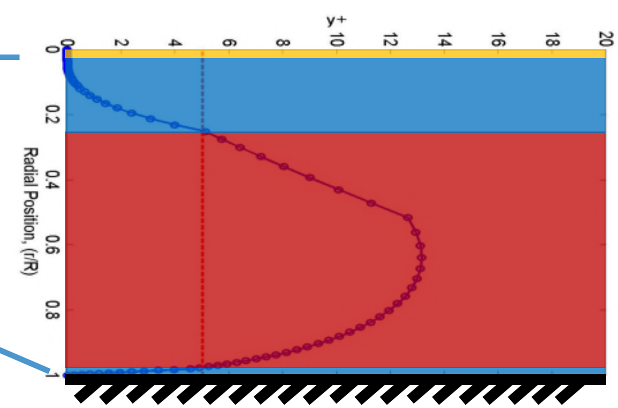
laminar

turbulent

$$\tau_w = \frac{1}{2}\frac{dp}{dz}\frac{R}{L}$$

$$\tau_{rz} = \tau_w \frac{r}{R}$$

Simulation result



ADJUSTMENT IN INITIALLY GUESSED PRESSURE DROP TO MATCH SPECIFIED FLOW RATE

- Shear rate profile can be generated with an initial guess of the pressure drop
  - Numerical integration to calculate velocity profile and flow rate

Guess a pressure drop and $\tau(r)$,a linear function of radial position

Near-wall laminar layer

$$\dot{\gamma} = \frac{\mathrm{d}v_z(r)}{\mathrm{d}r} = \left(\frac{\tau - \tau_y}{K}\right)^{1/n}$$

Turbulent layer

$$\dot{\gamma} = \frac{\mathrm{d}v_z(r)}{\mathrm{d}r} \sim \sqrt{\frac{\tau}{\rho}}\frac{1}{y}$$

Near-plug laminar layer

$$\dot{\gamma} = \left(\frac{\tau - \tau_y}{K}\right)^{1/n}$$

Within the un-yielded layer

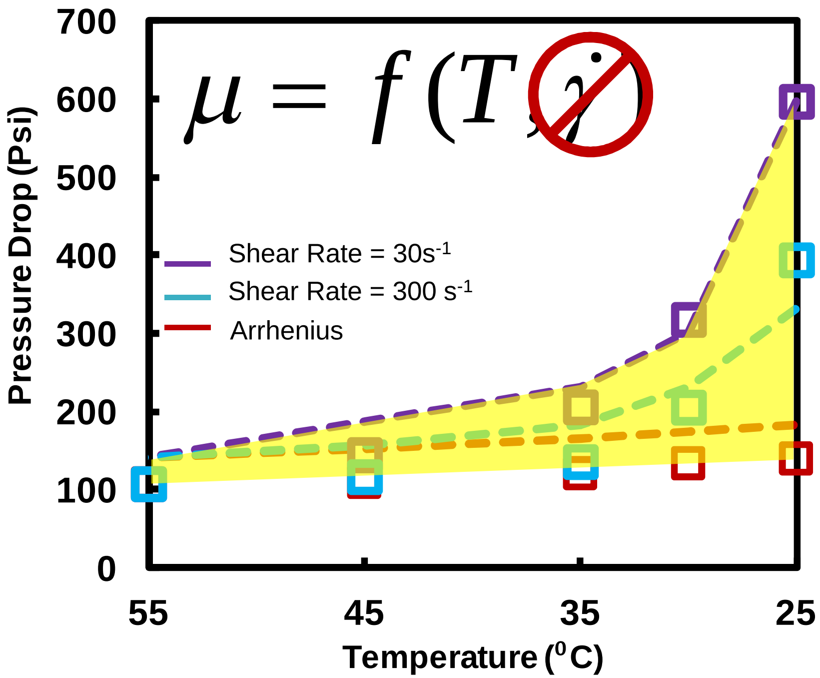
$$\dot{\gamma} = 0$$

$$\dot{\gamma}(r) \rightarrow v_z(r)$$

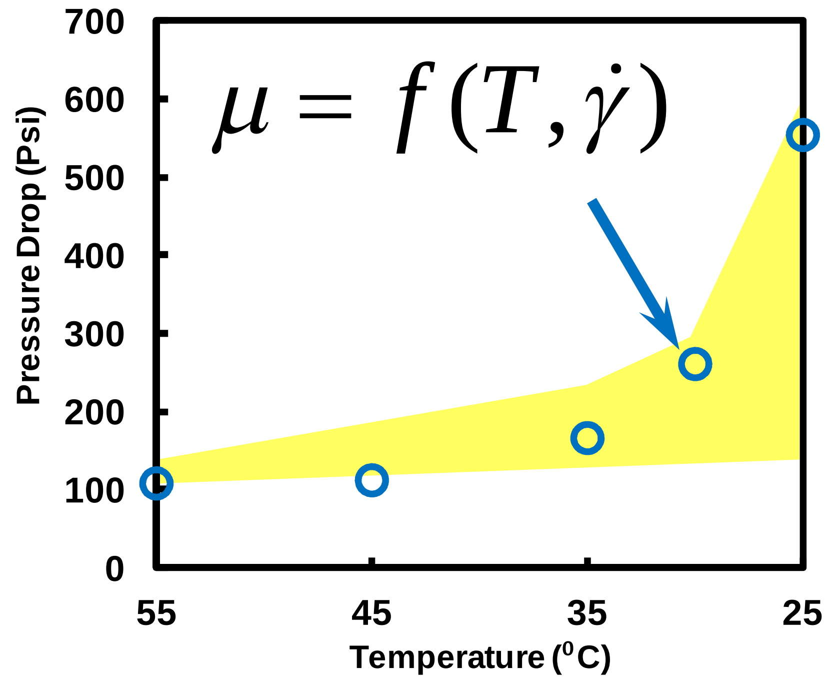
Adjust $\tau(r)$, if calculated flow rate ≠ specified flow rate

COMPARISON WITH PREDICTIONS CONSIDERING NON-NEWTONIAN CHARACTERISTICS (ISOTHERMAL CALC)

Without considering non-Newtonian fluid characteristics (friction factor)

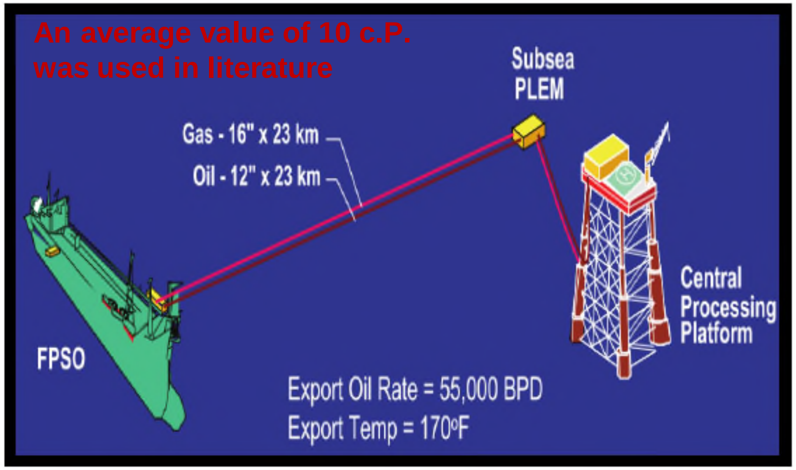


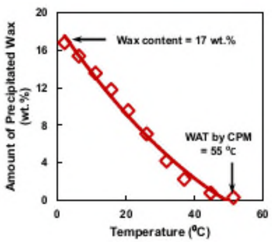
Considering non-Newtonian fluid characteristics

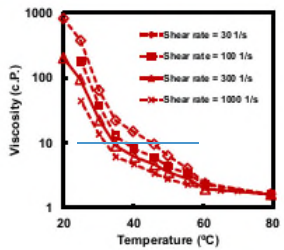


- Pressure drop predictions vary with the viscosity curve used
- Uncertainty in pressure drop prediction increases as temperature decreases
- Can obtain reliable pressure drop predictions with non-Newtonian fluid characteristics

BENCHMARKING WITH FIELD OBSERVATION







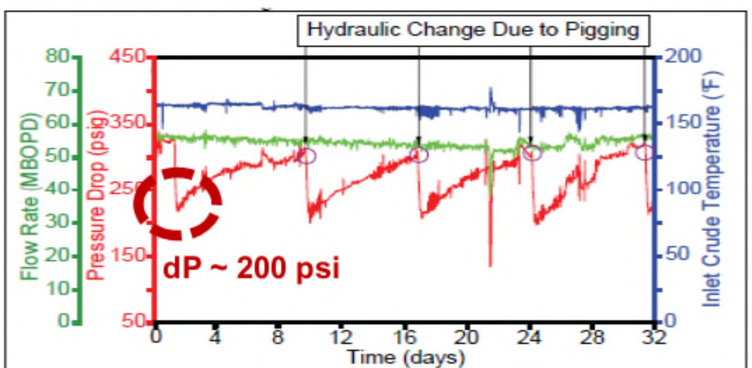
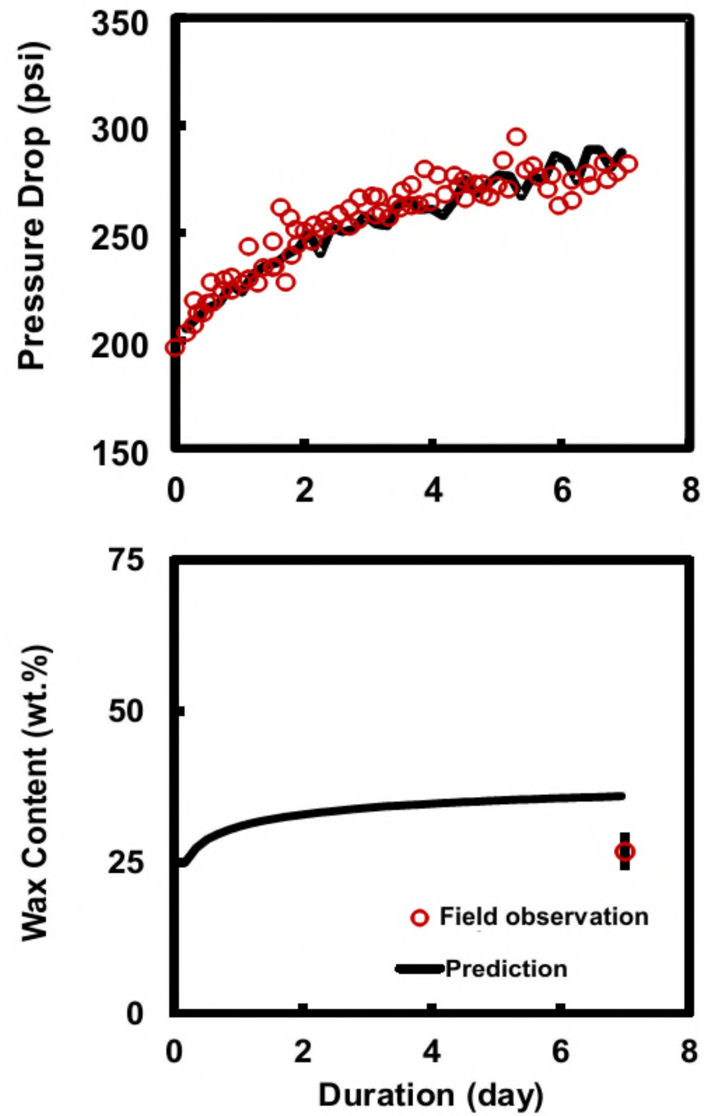


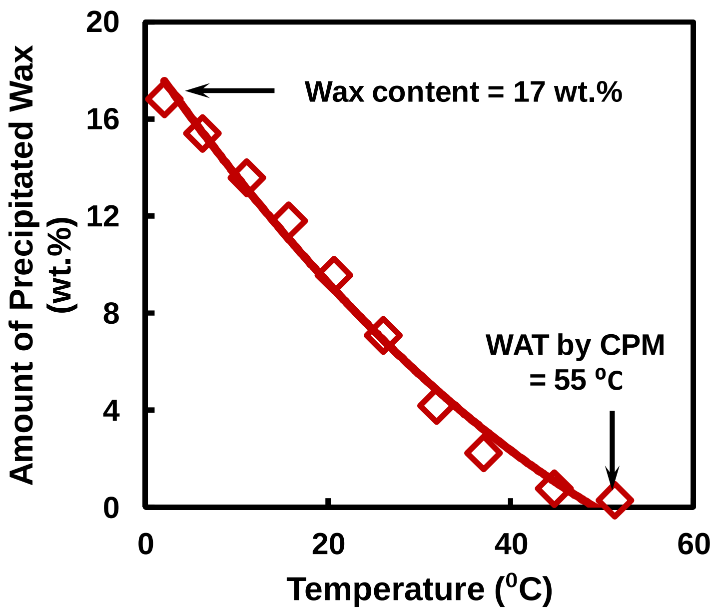
Figure 2. A Sample of Pipeline Operation Conditions

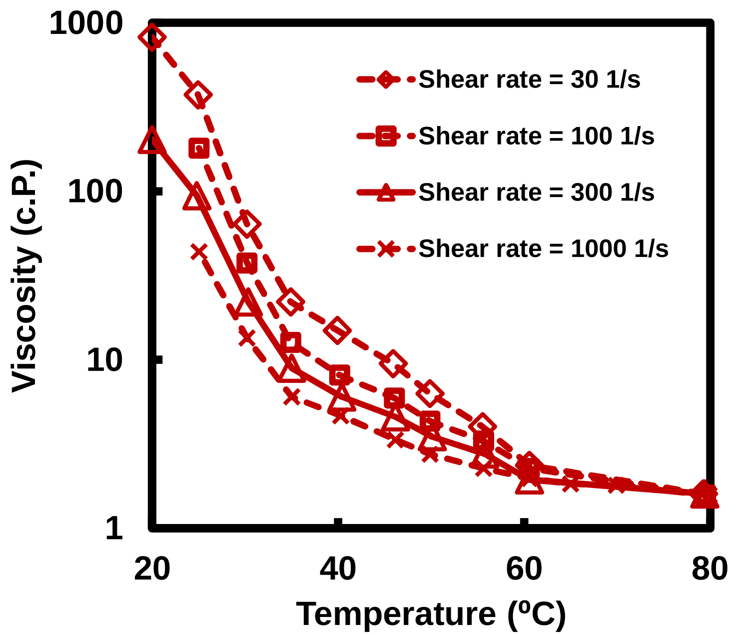


Pressure drop calculation in literature – singh et al. OTC 21641

DESCRIPTION OF THE FIELD AND CRUDE OIL CHARACTERIZATIONS

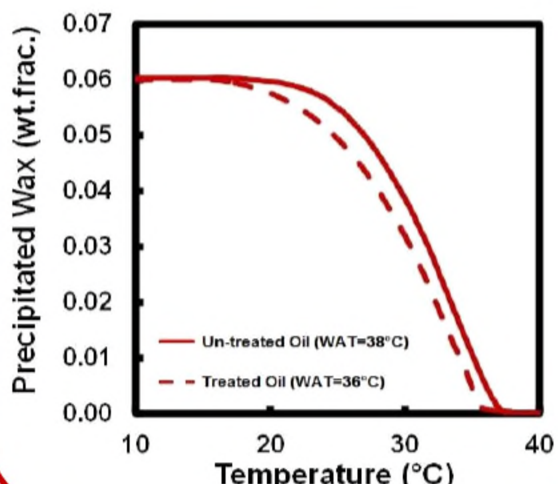
- Field: Off-shore near Indonesia, 23 km/12'' pipeline
- Operator: ConocoPhillips, reported wax deposition



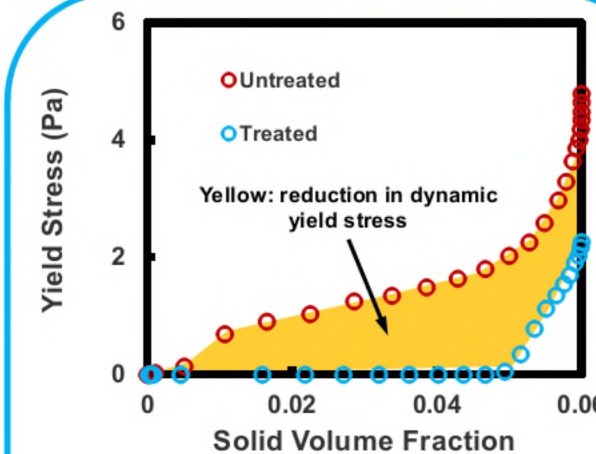


- Relatively waxy crude
  - Viscosity at ambient temperature varies significantly with shear rate
  - Modeling of non-Newtonian fluid characteristics is important

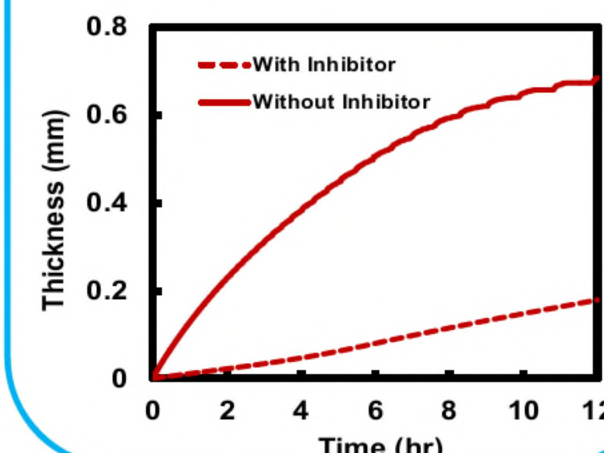
APPLICATION TO EVALUATE THE EFFECT OF CHEMICAL ADDITIVES ON DEPOSITION



Better assessment of inhibitors effect



T_{oil} = 40°C, $T_{coolant}$ = 35°C, Q_{oil} = 0.01 m^3/hr



CONCLUSIONS

- Experimental data required AT better field representative conditions
  - Scaling up – large diameter pipe tests
  - Heat / mass transfer and momentum analogies
  - Time scales for diffusion process vs gelation only process
  - Model oil fluids vs oil and condensate real systems
- Reduce Uncertainties
  - Boundary layer
    - Thermal boundary layer → seems good for loop tests
    - Mass transfer boundary layer → seems better for field (only one case)
  - Diffusion coefficient
  - Thermal calculations
- Hydrodynamic modeling - non-Newtonian characteristics improves reliability in wax deposition modeling and waxy oil flow modeling

JIP TOTAL – CHEVRON (Tridiagonal) performing large scale tests

TUPDP Multiphase FlowLoop / Michigan Univ - addressing some of this points

IN SUMMARY….

Flow assurance optimization is key for development if Deepwater fields
And there is space for improvement by:

- Working on risk management to handle hydrates in oil and gas fields.
  - Improve the understanding of LDHI performance
  - Work on risk mitigation
- Improving wax deposition model
  - Validation in large scale facilities
- Understanding the behaviors of hydrates and wax in Multiphase flow systems
- Understanding the synergies between
  - Hydrates FABP in waxy oils and Wax deposition in hydrates slurries
  - Additives: wax inhibitors – LDHI/AA – THI

DEEP OFFSHORE: FROM R&D TO FIELD IMPLEMENTATION

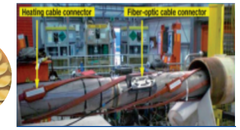
Girassol
Riser
Towers

Rosa
Long
Tie-back

Akpo
All Electrical
FPSO

Pazflor
Subsea G/L
Separation

Islay
Heated Pipe
(ETH PiP)



Subsea Seawater Treatment
Field Trial (Congo)

2001 … 13 2014 2015

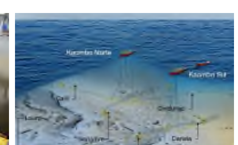
THANK YOU

QUESTIONS ?

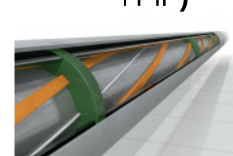
.DHI
Trial
nce)

Rosa (GiRRI)
High Boost
Pump

K5F3
All Electrical
Subsea Well



d Pipe
PiP)



LDHI-AA

2016 2017 2020