Performance of a highly hydrophobic coating for solids management in production systems

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Outline

- Internal coatings for production tubing and flow lines
- Diamond like carbon coatings
- Performance envelops for common production system solids
  - Wax
  - Asphaltene
  - Inorganic scales
  - Hydrates
- Coating facility
- Summary
- Key References

  - ✓ Bethke, G. K., et al, A Novel Coating to Reduce Solids Deposition in Production Systems, **OTC-28902-MS**, Houston TX, May **2018**
  - ✓ Heydrich, M. et al, Impact of a Novel Coating on Inorganic Scale Deposit Growth and Adhesion, **OTC-29218-MS**, Houston, TX May **2019**

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Internal Coatings for Production Systems

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- Why use internal coatings
  - Erosion/abrasion resistance
  - Corrosion protection
  - Flow improvement
  - Anti-fouling
- Common types of coatings
  - Phenolic
  - Epoxy
  - Nylon
  - Diamond Like Carbon DLC

Phenolic, Epoxy, Nylon: Polymeric

- Issues
  - Durability – abrasion/erosion
  - Chemical compatibility
  - Temperature
  - Delamination
  - Performance

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Diamond Like Carbon Coatings

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What DLC Coating is?

- **DLC** is a generic term describing a range of amorphous carbon
- **Diamond** & **graphite** the most well-known allotropes of carbon

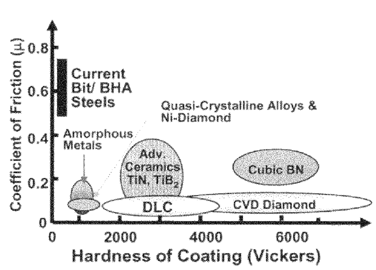
different type of bonding between carbon atoms

Diamond	Graphite
hard	soft and slippery
sp^3 hybridized bonds resulting in strong C-C bonds	sp^2 hybridized bonds forming weak bonding between the atomic planes

DLC - Diamond-like carbon coatings have a mixture of sp^3 and sp^2 bonds

Source: T. Liskiewicz et al. Presentation: DLC coatings in oil & gas production – Feb. 25, 2014

Coefficient of friction (COF) versus Vickers hardness



Source: US 8,261,841 B2 (Patent date 2012)

- Consists primarily of carbon
- Reasonably durable
- Low surface energy
- Non-reactive

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Highly Hydrophobic DLC Coating

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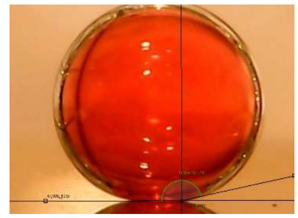
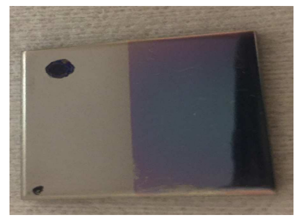
- Anti-fouling not erosion/corrosion
- Functionalized amorphous DLC coating
- Contains primarily carbon oxygen and silicon
- Molecularly bonded via a magnetically assisted plasma enhanced CVD process
- Approximately 200 nanometer thick conformal coating
- Highly hydrophobic
- Surface roughness Ra ~ 3 microns





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Source: Miller, M.A., Wei, R. and Hatton, G.: "Superhydrophobic compositions and coating process for the internal surface of tubular structures," **US Patent US 9,926,467 B2 2018**

Flow Assurance Solids Management Challenges

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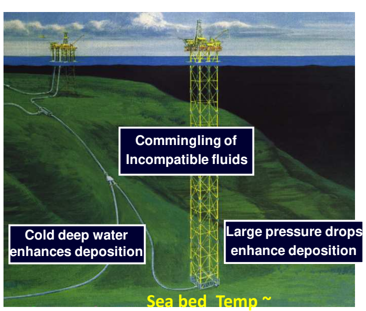

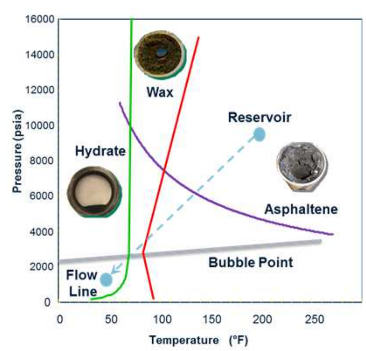

The aim of "flow assurance" is to manage the deposition of solids organic (like those noted above) and inorganics (such as scales) in production and transmission flow lines

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Impact of Coatings on Deposit Growth

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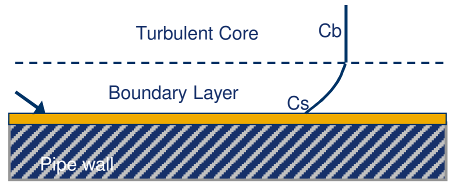
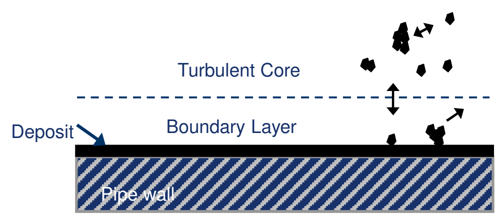
- Reduce deposit growth rate at the surface
  - Surface modification may impact nucleation time
  - Highly hydrophobic surface can stabilize an oil film.
- Reduce adhesion force between the pipe wall and deposit
  - Expand range of flow rates where shear removal is effective
  - Facilitate removal of deposits during remediation
- Minimize intervention frequency and duration
- Decrease solids management OPEX/CAPEX
  - Thermal management (insulation)
  - Chemical injection





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Wax Deposition

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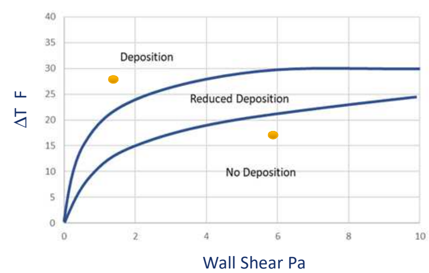
- Deposition tests in 2 inch flow loop
  - 48 total tests uncoated and coated
  - Two oils (condensate and black oil)
  - Re 5000-10000, ΔT up to 40 F
  - Mapped out performance envelope as function of ΔT and wall shear
  - Deposits on coated surface had high oil content (soft)
- Field trial - Africa
  - Reduced cutting frequency (75 %)
  - Soft deposits
  - High GVF well



No Deposition

Reduced Deposition

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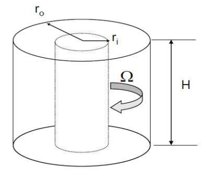
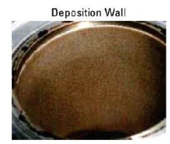
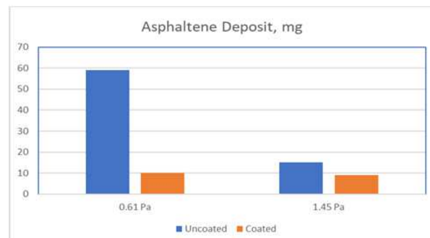
Asphaltene Deposition

- Live oil tests (OSDC)
  - No deposit on coated surface observed over the range of shear investigated (1 Fluid)
- Dead oil tests (OSDC)
  - Reduced deposit on coated surfaces (2 Fluids)
  - Amount of deposited material low on these tests
- Field trial
  - GOM Field Test - While no significant problem observed in coated tubing, operational issues made interpretation of the results difficult.
- Planned
  - Additional live oil tests
  - Identify a field test opportunity





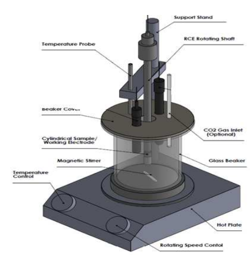
Schematic Representation of OSDC* **Sample Photos of OSDC deposition wall**
***Source:** Zougari et al., Energy & Fuels 20, no. 4 (July 2006): 1656–1663.



Calcite Scale Deposition

- Initial performance testing
  - Reduces deposit growth rate in RCE tests– Function of SR
  - Presence of oil in early heat exchanger tests resulted in reduced and loosely adhered patchy deposits in heat exchanger tests

Rotating Cylinder Electrode (RCE) Apparatus



Calcite Heat Exchanger Test

Calcite Scale Deposition(2)

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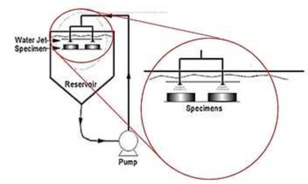
- University of Leeds testing
  - Reduced deposit growth rate in RCE tests
  - Significant reduction in adhesion force in impinging jet experiment
  - Ongoing experiments to determine the impact of oil

Initial Oil Deposition test 10 % Oil

Uncoated | DLC | Functionalized DLC

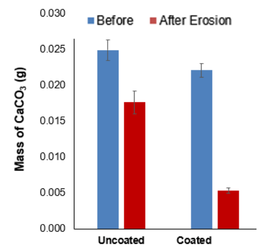
Leeds Erosion Test 100 % Brine



Uncoated | Coated

Before Erosion

After Erosion



Barite and Halite Deposition

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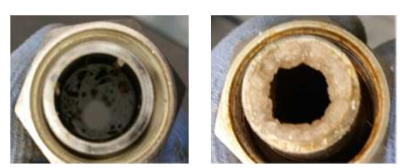
- Barite
  - In a single medium scale flow loop test deposit growth rate was not reduced although adhesion force was significantly reduced
  - Planned to further quantify adhesion force and effect of oil also at Leeds
- Halite
  - Reduced deposit growth rate in medium scale flow loop test
  - Further reduction observed in the presence of oil
- Field Tests
  - Ongoing field test in GOM mixed calcite/barite scale

Barite after Pigging

Halite with Oil



Hydrate Deposition

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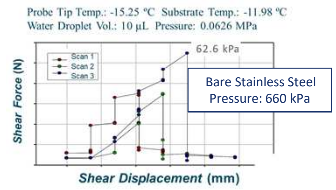
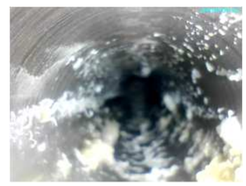
- SwRI
  - SNAIDS* ice adhesion test
  - Order of magnitude reduction in adhesion force (in the presence of oil)
- Colorado School of Mines
  - Visual Rock Flow Cell
  - Qualitative changes in hydrate morphology and deposition extent

Ice Adhesion Test



Visual Rocking Cell Hydrate Test (CSM)

Uncoated Sleeve



Coated Sleeve

*Source: M. Zou et al. / Applied Surface Science *257 (2011) 3786–3792*

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Durability

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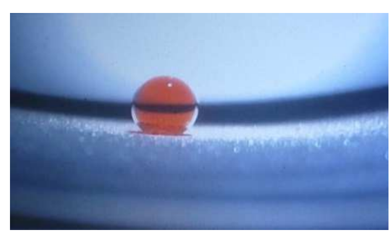
- Not an erosion or corrosion coating
- Erosion
  - Flow loop tests tangential flow
  - WCA related to mass loss
  - Coating life time is a function of particle size, sand load, and flow rate
  - Coating hardness is greater than substrate
- Chemical compatibility
  - Tested to 500 F (in oil) for 6 months no loss of activity
  - No issues with most common completion, stimulation and production chemicals
  - May require further testing for high temperature aggressive fluids
- No indication of delamination or flaking



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Ongoing Erosion Testing

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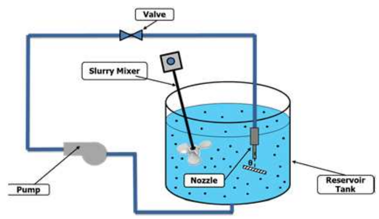
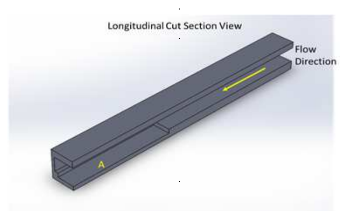
- University of Tulsa Erosion Corrosion Research Center
- Professor Siamack A. Shirazi
- Design requires:
  - Removal of enough mass to be measurable
  - Partial removal of the thin film
- Large relatively uniform eroded area





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Coating Facility - Channelview

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- Plant mobilized and commissioned in November 2018
- Currently coating Shell / Equinor Vito project (asphaltene) -until August 2019-
- Number of lines: 6 single lines, additional lines can be added in the future
- Current pipe size capability: 3” to 8”
- Process and equipment can be easily mobilized to meet market needs

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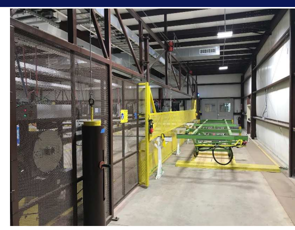
Coating Facility



Summary

- Highly hydrophobic DLC coatings exhibit antifouling activity for common production system solids
  - Wax
  - Asphaltenes
  - Inorganic scales - calcite, barite and halite
  - Possibly hydrates
- Work continues to further refine the performance envelops of the coatings
- DLC coatings are relatively durable and chemically inert.
- Delamination or flaking has not been observed in durability testing to date
- A full scale DLC coating facility is in operation in Channelview.