Remote Sensing Technologies Event
at the NASA Johnson Space Center

Ultra-Deepwater Produced Water Monitoring

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October 12, 2016
OUTLINE

- Produced Water in Oil and Gas Production
- Produced Water Disposal and Monitoring
- Produced Water Monitoring Technologies
PRODUCED WATER

- Formation Water That Is Produced with Oil and Gas

- Very Large Volume
  - Worldwide approx. 4 times the oil volume
  - Older wells may have 10:1 water/oil ratio

- Must Be Treated and Disposed
  - Injection
  - Discharge
  - Use (small fraction)

- Offshore
  - Mostly treated and discharged overboard
  - A small fraction is injected
OFFSHORE DEVELOPMENT CONCEPTS

- Fixed Production Platforms
  - Shallow water
- Floating Production Platforms
- Subsea Production Systems
TYPICAL SUBSEA PRODUCTION SYSTEM

- Reservoirs Are Produced by Subsea Wells
- Wells Are Tied-Back to Host Platform (Floating or Fixed)
- Separation of Oil, Gas and Water on Platform
- Produced Water (PW) Is Treated and Discharged Overboard
- PW Discharge Is Regulated by NPDES General Permit

Example: Subsea Production System at Chevron Jack and St. Malo

Graph Ref.: Houston Chronicle
Separation of Oil, Gas and Water at Seabed

Oil and Gas Are Transported to Host for Further Processing
- Future subsea factory: subsea treatment to sales quality

Produced Water Is Treated and Disposed Subsea
- Injected (current)
- Discharged (under study)

Example: Subsea 3-Phase Separation and Water Injection System at Petrobras Marlim

Graph Ref.: Drilling Contractor magazine
http://www.drillingcontractor.org/subsea-automation-on-path-for-closed-loop-controls-intelligence-20389
KEY TECHNOLOGY GAPS FOR SUBSEA PW DISPOSAL

- **Produced Water Quality Monitoring**
  - Measurement of PW quality
    - For discharge to sea, Oil and Grease by EPA Method 1664 is not feasible for subsea
    - Inline/Online subsea PWD quality sensors
  - Sampling device

- **Produced Water Treatment**
  - Equipment for treatment stage before discharge
  - Fast acting subsea valves
  - Other

NPDES General Permit

Oil and Grease: EPA Method 1664
- 29 mg/L max monthly average
- 42 mg/L daily max

Toxicity
- Mysid shrimp and Inland Silverside minnow test
- No free oil can be discharged (no sheen)
- No sand discharge

No specific regulations on subsea discharge
Project: RPSEA 12121-6301-03, Subsea Produced Water Sensor Development

Project Objective

- Develop subsea produced water quality sensor with focus on progressing PWD quality sensors to TRL 3 - Performance Tested (API 17N definition) and applicability to injection applications
- Develop a proposed roadmap for further developing and commercializing the sensors beyond the project

Project Goals

- Develop the subsea PWD quality sensor technology toward enabling measurement for regulatory compliance
- Develop the technologies toward enabling process monitoring of produced water treatment and disposal (discharge to sea or injection), for early warning and supporting decisions to shutdown or divert production
EXISTING SURFACE TECHNOLOGIES

**Laser Induced Fluorescence**  
*Graph Source: ProAnalysis*

**Ultrasonic**  
*Graph Source: Roxar / Mimorax*

**Microscopy**  
*Graph Source: J M Canty*

**Light Scattering**  
*Graph Source: Deckma*

**NIR-Absorption**  
Single Beam  
\[ A_{(CU)} = \varepsilon \cdot c \cdot d \]

**Scattered Light**  
Dual Beam  
\[ T = \frac{I_s}{I_D} \]  
\[ I_s = \text{Intensity Scattered Light} \]  
\[ I_D = \text{Intensity Direct Light} \]
EXISTING SURFACE TECHNOLOGIES

UV Fluorescence

*Graph Source: Turner Design Hydrocarbon Instruments*
NEW TECHNOLOGY

- **Confocal Laser Fluorescence Microscopy**
  - High resolution, 3-dimensional imaging
  - Fluorescence of PAH in oil
  - Pinhole aperture to enable image of each focal point with optical resolution to 0.3 micron (~0.5 for the subsea design)
  - Scanning mirrors for making 2-D image at a focal plane (1 micron scan grid used in the subsea design)
  - Stack of 2-D images at different focal planes to make 3D image
FLUORESCENCE OF OIL

- **Strong Fluorescence**
  - Due to PAH components, always present in oil

- **Not Sensitive to Photo-Bleaching**

Source: Semwogerere et al., 2005
Scale: The largest droplet is 11 microns.

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OIL-WET AND WATER-WET SOLIDS

- Measuring Solids and Other Non-Fluorescent Objects with Dual Modal Imaging
  - Confocal (fluorescence) and Contrast (non-fluorescence)
MEASURING OIL COAT ON SOLIDS

Focal Plane 1

Focal Plane 2

Focal Plane 3

Focal Plane 4

Solid

Oil

3-D View 1

3-D View 2
- Side stream valves open for establishing sample flow
- Side stream valves is then closed, and full channel depth is scanned for 3-D image
- Optical window fouling is automatically detected and cleaned with liquid jets. Typical cleaning: twice daily, <1 minute each
Technologies Selected for Development in Phase 2 of Project

- Light Scattering (Digitrol)
- Microscopic Imaging (J.M. Canty)
- Laser Induced Fluorescence (ProAnalysis)
- Confocal Laser Fluorescence Microscopy (Clearview Subsea)

Prototypes Constructed and Bench-Scale Tested
LASER INDUCED FLUORESCENCE SENSOR
FACTORS THAT MAY AFFECT MEASUREMENTS

- **Parameters**
  - Oil: concentrations, types, oil droplet sizes
  - Solids and gas: concentrations and particle/bubble sizes
  - Salinity of produced water
  - Chemicals: types and concentrations
  - Produced water velocity and temperature

- **Memory**
  - Detection of Changes and Return to Normal Measurement

- **Fouling**
  - Effectiveness of keeping optical window clean, or cleaning of optical window
BENCH SCALE TESTING

Existing Technologies

- Sensors generally worked well in conditions calibrated for
- Parameter effects were significant
- No significant memory effect
- Effective in mitigate moderate fouling

New Technologies

- Flow control and imaging operations generally worked well
- Some online image analysis issues, which could be overcome by improved algorithm
- Feasibility as subsea produced water sensor was confirmed
ACKNOWLEDGEMENTS

- Funding for the project (Project No. 12121-6301-03) is provided through the “Ultra-Deepwater and Unconventional Natural Gas and Other Petroleum Resources Research and Development Program” authorized by the Energy Policy Act of 2005. RPSEA is under contract with the U.S. Department of Energy’s National Energy Technology Laboratory to administer three areas of research. More information at http://www.rpsea.org.

- National Energy Technology Laboratory (NETL): Bill Fincham, Roy Long, Gary Covatch

- Research Partnership to Secure Energy for America (RPSEA): James Pappas

- Current and Former Working Project Group Members
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  - Shell/BG: Diana Charles, Hamish McCracken, Sandrine Poteau
  - Fluor: Neal Prescott
  - OneSubsea: John Byeseda, Jagadeesh Unnam, Francisco Vera
  - Petrobras: Alec Johnson, Jeremiah Daniel
  - Statoil: Steven Moseley, Børre Leif Knudsen, Arne Henriksen, Tatiana Issakova
  - Total: Mayela Rivero, Khalid Mateen, Herve De Naurois

- Presenters and Participants at Both Industry Workshops

- Project Team Members from Clearview Subsea, NEL, Clean H2O Services, University of Houston, University of Texas Health Science Center in Houston, Rice University, Deepwater Innovation Consulting, WJM Enterprises, Digitrol, J.M. Canty, ProAnalysis and Fjords Processing
Thank You!