Challenges Associated with Produced Water Re-Injection for Offshore Waterflood Projects

Gibson Applied Technology and Engineering, LLC

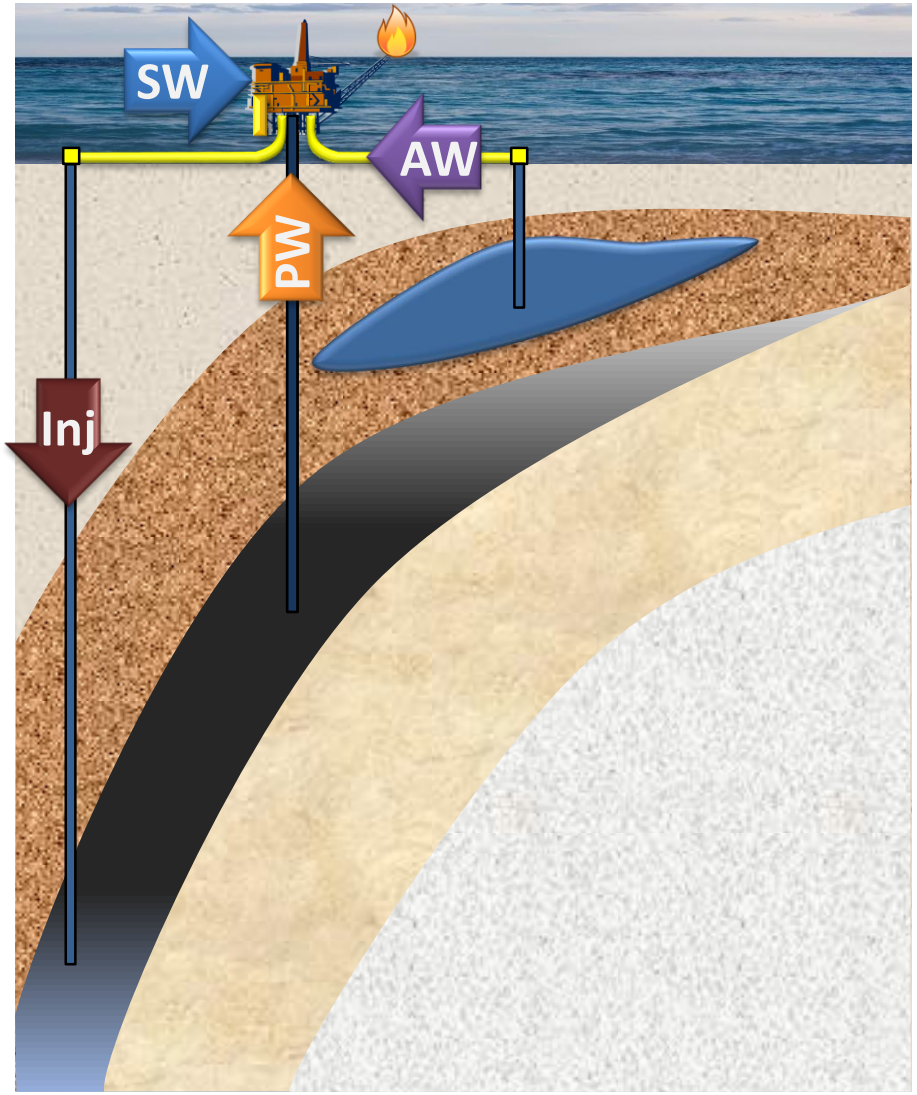
Lee Jordan, Lindsay Anderson

January 2012

Common Sources of Injection Water Offshore

1. **Seawater**
   - Treated seawater (deoxygenated, filtered)
   - Desulfated seawater
   - Raw seawater (may or may not be filtered)
   - Low salinity water
2. **Produced Water**
   - Formation/connate/aquifer water plus:
     - Injected water
3. **Aquifer Water**
   - From non-producing reservoirs

- **Any Combination of the Above**

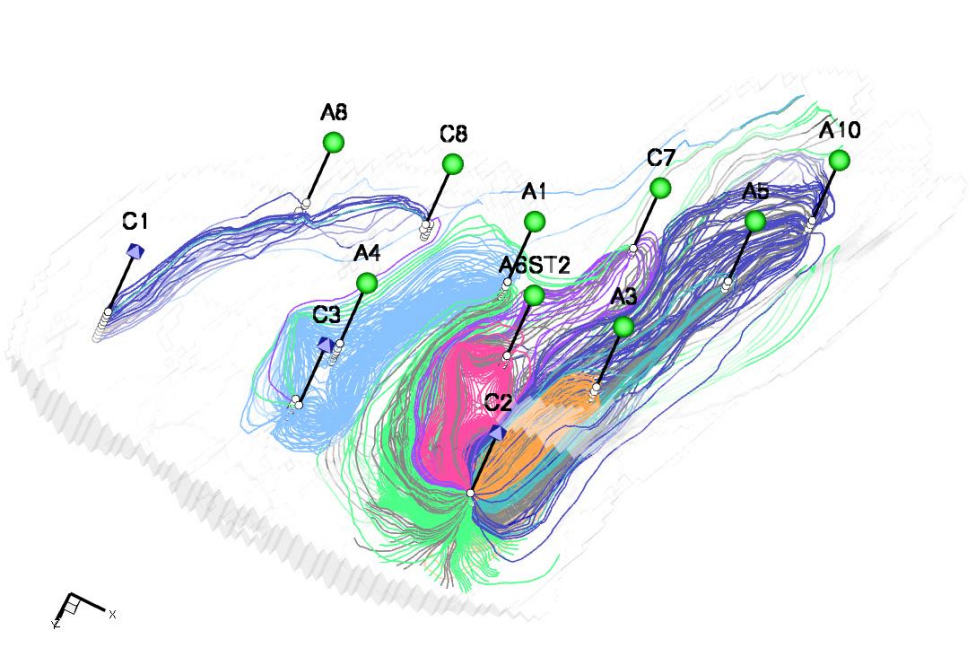


Primary Concerns When Selecting a Water for Injection

1. **Availability**
   - Enough volume to meet demand over the life of the field?
2. **Compatibility**
   - Compatibility with the Formation
3. **Topsides Impacts**
   - Weight, space and power
   - Operations workload
4. **Solids**
   - Topsides filtration requirements
   - Risk of injectivity impairment
5. **Oil and Grease**
   - Impact on filtration
   - Impact on injectivity
   - Reduction of discharges
6. **Scaling**
   - Injection system water incompatibilities
   - Production system scale management
7. **Souring**
   - H_2S production and control
8. **Temperature**
   - Cooling requirements
   - Material limitations
   - Injectivity considerations
9. **Corrosion**
   - Materials selection costs and operational risks

Drivers for Produced Water Re-Injection?

- **Why do we look to inject produced water?**
  - Water injection increasingly attractive in deepwater to maximize overall production and return on investment
  - Reduced environmental footprint
  - Removal of need to lift and deaerate seawater for injection
  - Reduced or eliminated scaling concerns
  - Decreased souring risks compared to mixed or seawater-only systems
  - Aquifer waters generally not available in sufficient location or quality to make extra wells and risers worthwhile



Water Injection in Deepwater

- **So what's different?**
  - Rapid pressure depletion and high hydrostatic head can require immediate or early water injection (e.g. Gulf of Mexico)
  - May need to start injection with, or prior to, initial production to maintain bubble point (e.g. West Africa)
  - Limited injection well stock due to high cost - Increases consequences of losing a well
    - Well workover/stimulation cost
    - Deferred production costs due to reduced injection
  - Materials selection and flow assurance more challenging for subsea developments
    - Consequences of scale formation much more difficult to treat for subsea wells
    - High-pressure wells require high-strength materials that are often more susceptible to souring or require increased qualification testing

Water Injection in Deepwater

- **So what's different?**
  - Limited weight and space for topsides for certain hull types (SPARs, TLPs, Semi's)
    - High incremental cost of hull size increases
    - Particularly challenging for brown-field developments
  - Increased internal and external visibility of operations
    - Increased project sizes and production rates provide an increased impact on global Operator revenues
    - Increased scrutiny due to high profile of large projects and their placement in pristine environments

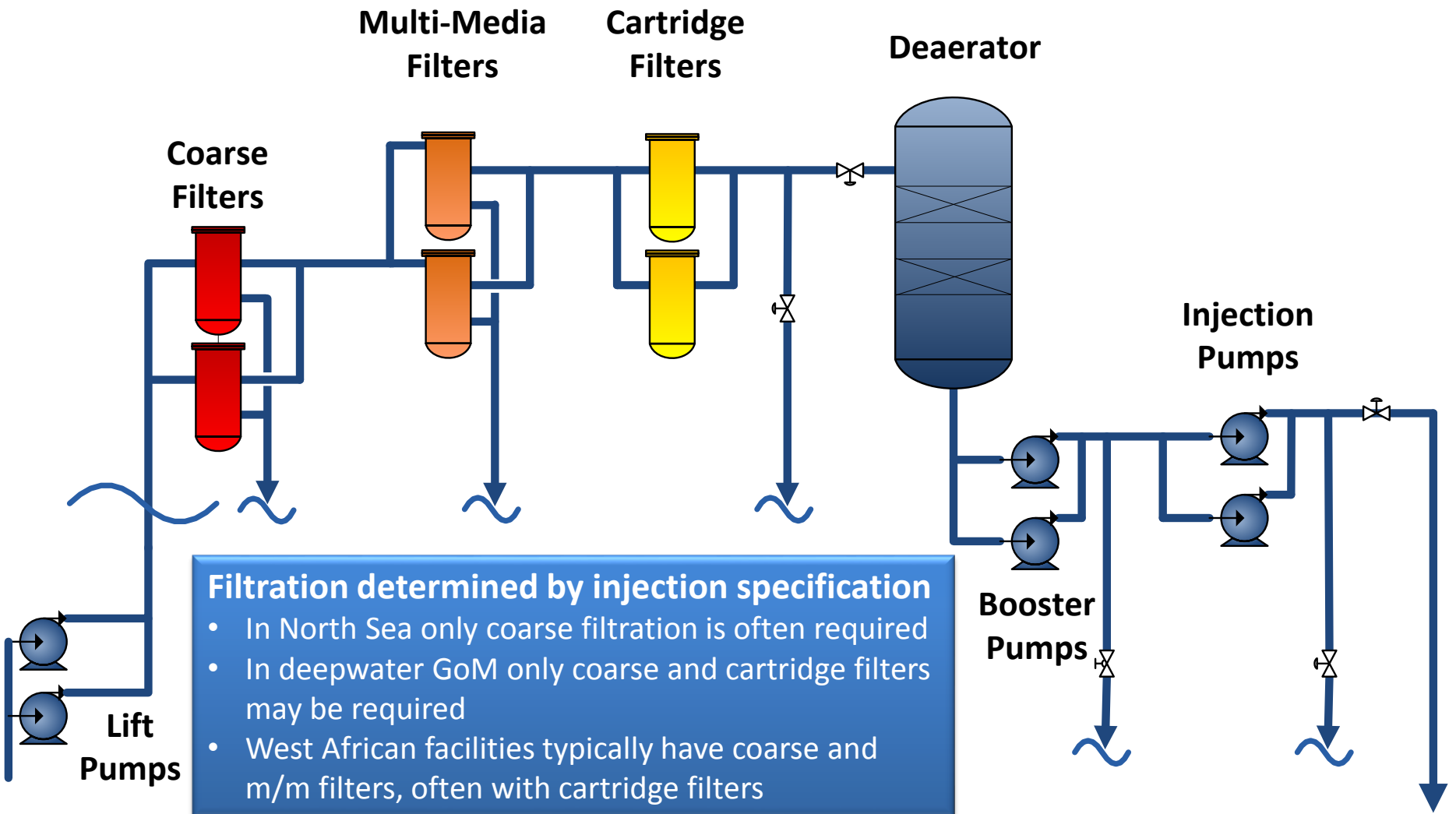
Produced Water Availability

- **Biggest hurdle in early life**
  - Can drive a move towards seawater injection
  - Also a problem for fields planning water diversion/water shut-off in late life
- **Typically requires make-up with seawater during field life**
  - Means that some infrastructure is required for seawater injection
- **Injection profile is important**
  - If early injection rate is the maximum required rate then low incentive to consider PWRI as seawater system capacity meets full-life requirements
  - If more injection is required in later life then a smaller seawater package for early life and later make-up by produced water becomes more attractive

Topsides Impacts

- **Seawater only**
  - Commonly use coarse strainers to fine filters to deaerator
    - Some operators place final filters downstream of deaerator
  - May need sulfate removal for scaling and souring control
    - Large and heavy equipment
    - Operator intensive
  - Deaerator placement can be a big issue
    - High CoG of vacuum and gas stripping towers
    - Operator intensive operation of compact systems
  - Higher-grade alloys or FRP needed for corrosion resistance

Basic Seawater Injection System Layout



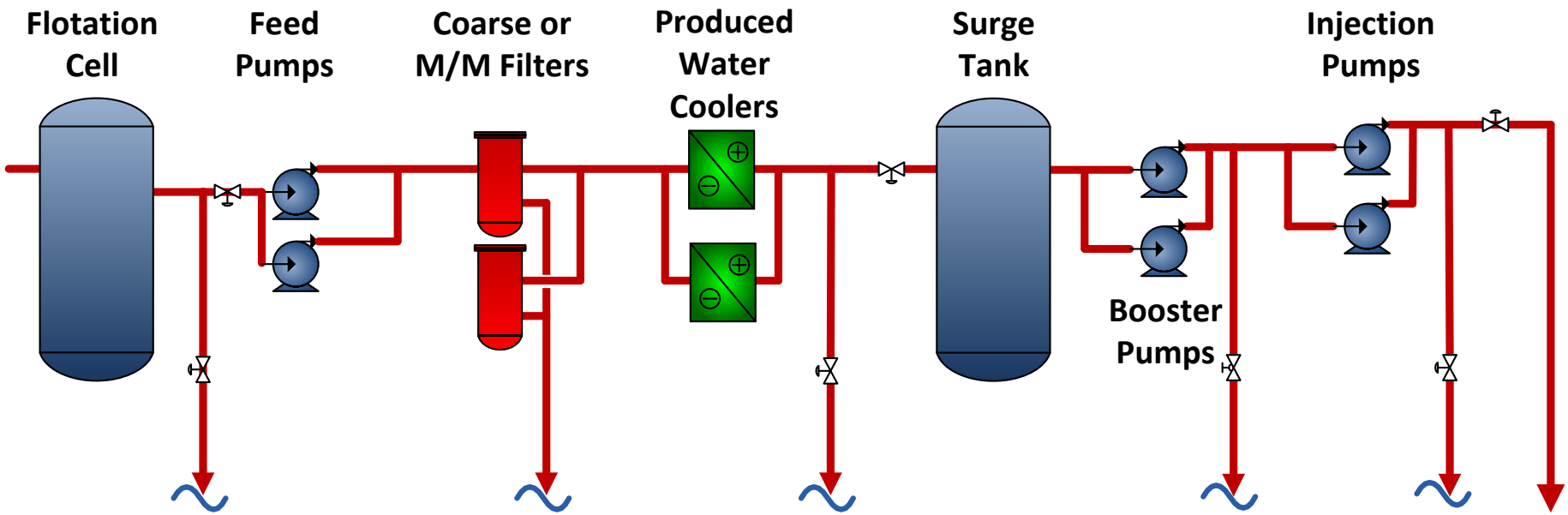
Filtration determined by injection specification

- In North Sea only coarse filtration is often required
- In deepwater GoM only coarse and cartridge filters may be required
- West African facilities typically have coarse and m/m filters, often with cartridge filters

Topsides Impacts

- **Produced Water only**
  - Commonly use fine filters to surge drum
    - Variability in instantaneous produced water rates makes a surge drum a common requirement
    - Filter design can be difficult to determine, especially for new-build developments
  - Prior chemical application needs to be considered
    - Benefits of scale inhibitor and corrosion inhibitor carry-over
    - Minimal concerns regarding biocide discharges
    - Issues due to water clarifier floc and oil and grease may increase filter size
  - Materials selection based around carbon steel
    - Minimal oxygen in the system means that the use of carbon steel is the preferred materials selection option

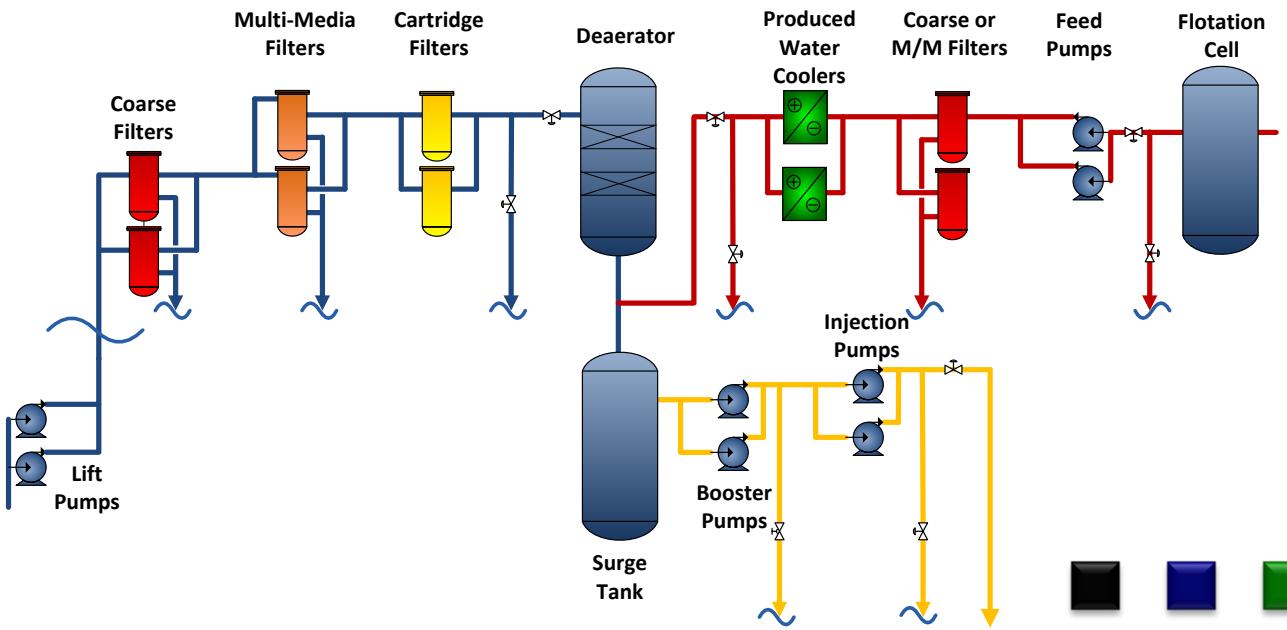
Basic Produced Water Injection Layout



- Level of filtration determined by injection specification
- Surge tank needed to provide constant flow to injection pumps without need for overboard discharge

Topsides Impacts

- **Mixed Systems**
  - Combine the worst points of both systems
    - Deaerator, surge drum and multiple filtration packages
    - Materials selection and corrosion control issues
  - Increased concerns around bacterial control and scale formation downstream of the mixing point
    - Mixing with desulfated seawater is an option to support scale and souring control



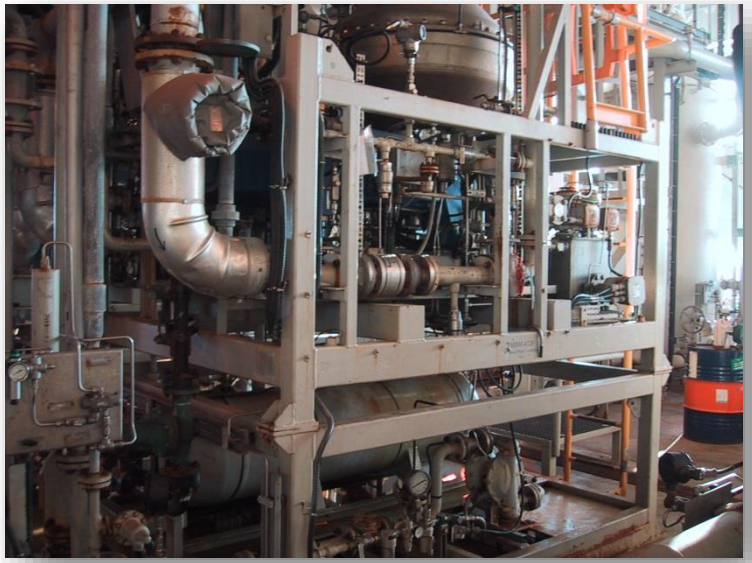
Solids Control and Injectivity

- **Often the biggest hurdle from a facilities design standpoint**
  - Sand carry-over from high-rate production wells
  - Corrosion products from carbon steel piping
  - Wax, scale and asphaltenes
  - Floc from produced water treatment

- **Erosion is usually a minor issue due to relatively low flow velocities in liquid-packed systems**
  - Usually the limiting factor is the injection pumps, rather than valves or piping
- **Solids can impair well injectivity above pre-determined levels**
  - Limits based on completion design and formation properties
  - Matrix versus fracture injection has a profound influence on solids limits

Solids Control and Injectivity

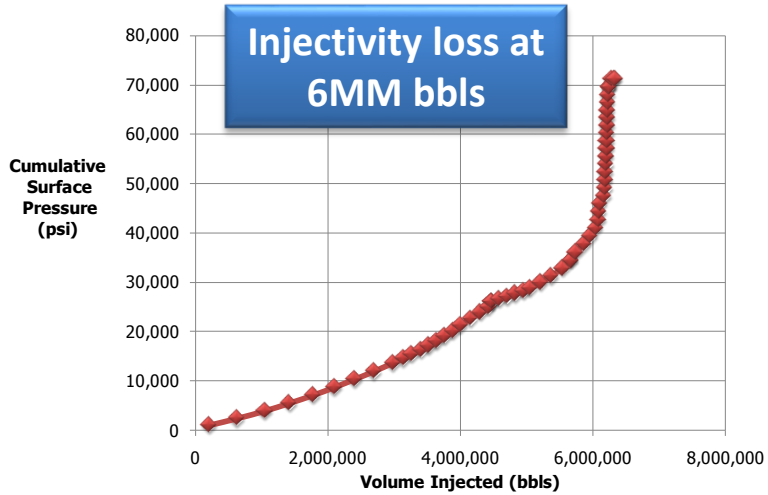
- **Solids tend to be higher in produced waters than in seawater and generally more difficult to remove**
  - Problem with filter plugging as a result of oil-wet solids
    - Generally higher risk of injector plugging with produced water
    - 1/3 bridging rule for seawater often modified to 1/6 solids to pore throat size for PWRI
  - High solids loadings also impact oil and water separation, further increasing water quality concerns
    - Decreased chemical performance
    - Decreased vessel residence times
    - Decreased hydrocyclone performance

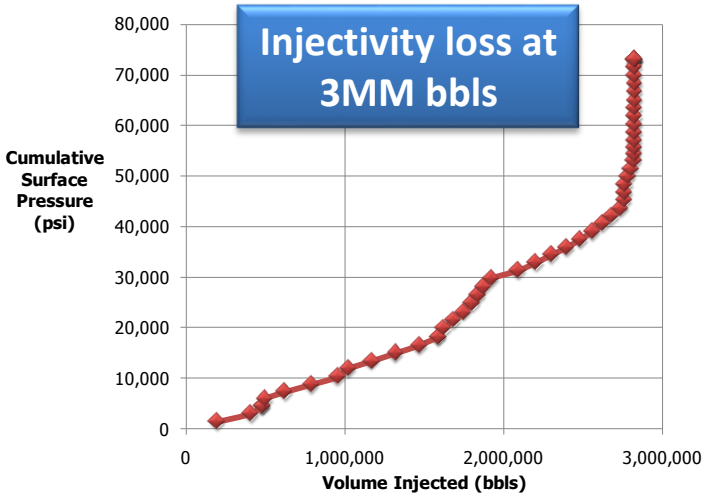


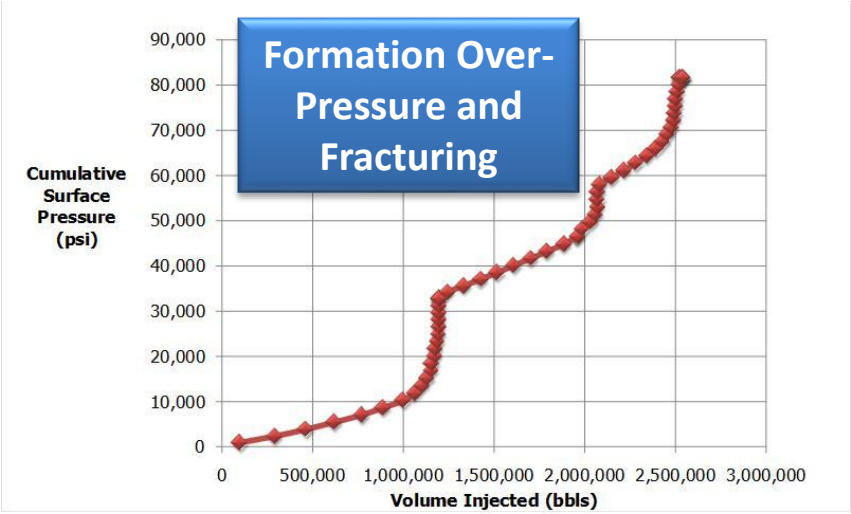
Monitoring for Solids Contents: Process Management

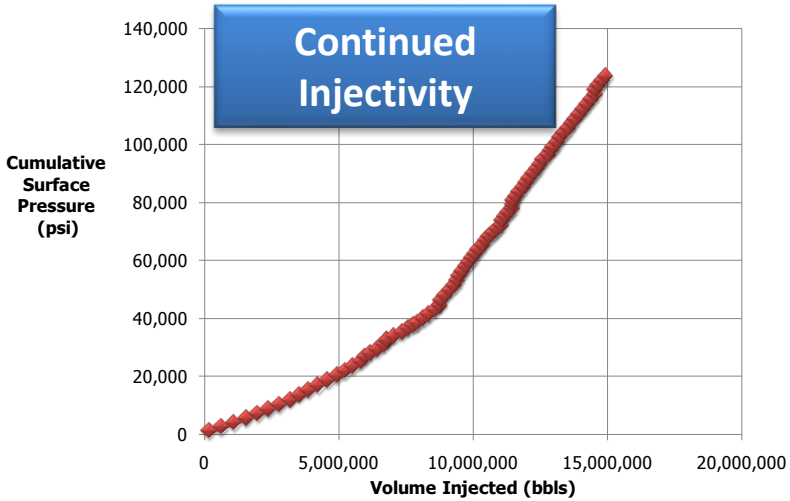
- **Direct Filtration (spot measurements)**
  - For TSS and stacked filters (for TSS and mass profile) downstream of filters and pumps
  - Good to have results from the extreme downstream end of the system, but do not routinely sample from high-pressure systems after injection pumps
- **Turbidity analyzers (on-line)**
  - Typically not reliable due to large number of small particles commonly present in produced water and the range of sizes and reflectivities
  - Useful for trending performance once correlated with other methods
- **Particle size analyzers (spot or on-line)**
  - Good at detecting trends and changes in the data
  - Generally reliable and robust

Monitoring for Solids Contents: After the Fact









Produced Water Filtration Options

- **Anything that removes solids prior to the injection system is a good thing**
  - Sand-control hydrocyclones
    - Primary solids-control option
    - Can operate at 5 psi DP, but 20 to 60 psi generally provides better performance
      - Erosion rates increase with increasing pressure drop
    - Usually good for solids down to 10 µm
      - May see operational problems with 2 to 5 µm units due to fouling of smaller-diameter elements
  - In-line separators
    - Attractive for retrofits as no pressure drop
    - Generally only provide efficient removal of solids down to around 50 µm

Produced Water Filtration Options

- **Common performance limits for various filter types**
  - Centrifuges have also been used offshore – typically with poor outcomes

Filter Type	Maximum Effective Solids Removal (µm)	Inlet O&G Limit (mg/l)	Inlet TSS Limit (mg/l)	Notes
Multimedia Filters	2 to 5	-	-	
Nut Shell Filters	2 to 5	150	-	Reduces O&G
Cartridge Filters	2 to 5	5	-	Plugging at Tighter Specs
Membrane Filters	<1	50	15	Usually for SW

Oil and Grease

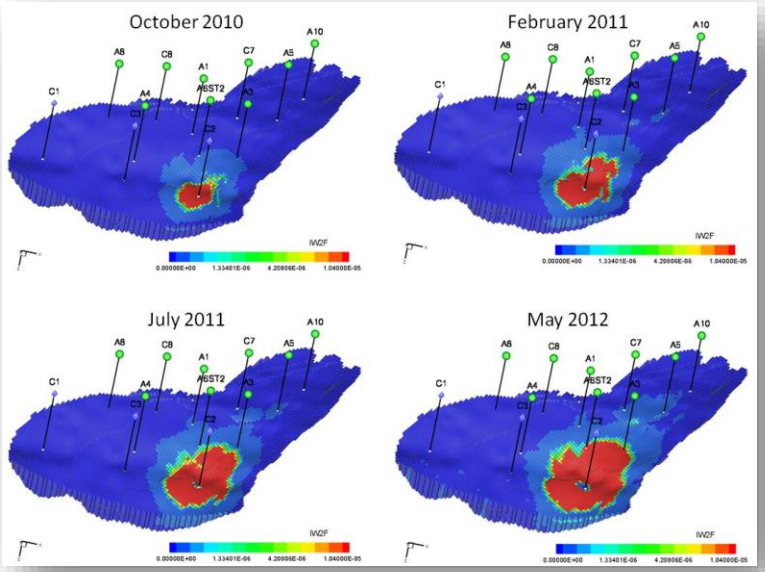
- **Primary driver for PWRI in the late 90's was the belief that re-injection would save on chemicals and treatment facilities**
  - Injectivity impairment usually only a concern above ~ 100 mg/l
  - GoM discharge specs are 29 mg/l (avg) and 42 mg/l (max), leaving scope to reduce treatment requirements without impacting injectivity

- **Reality is that we can't generally inject above discharge limits**
  - Impact on production when operating outside of discharge spec
    - Any injection system trip often drives a shut-in of production as cannot divert off-spec water overboard
    - Option on FPSO's if large produced water tanks are available
  - Generally easier to maintain water at spec than have to bring the system down to spec from a higher point in a finite time

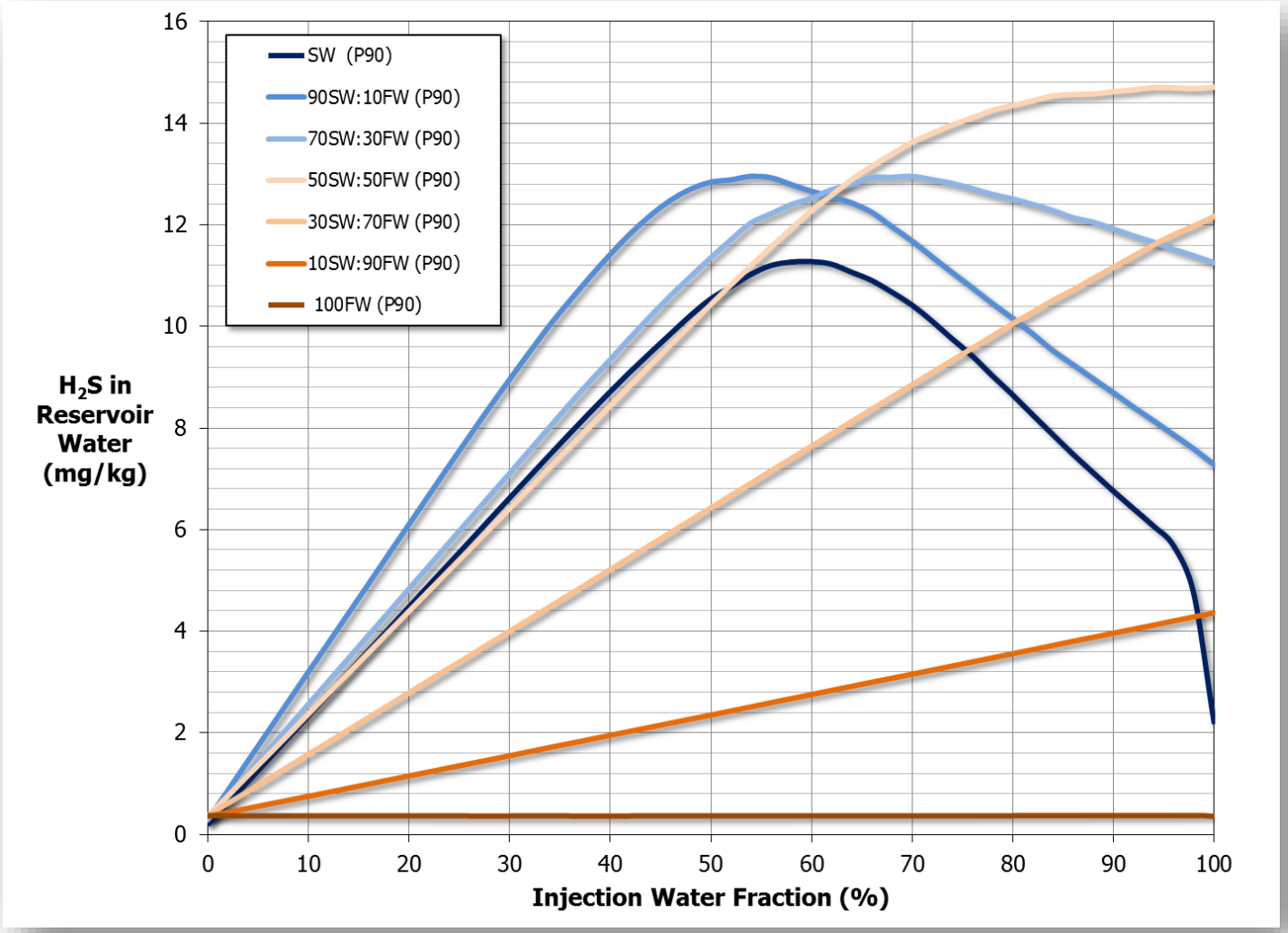
Reservoir Souring

- **Decreased (but not zero) risk of souring with PW only**
  - Offshore experience is limited, but plenty of onshore examples of souring following PWRI

- **High risk of souring if mixed with seawater**
  - Much greater risk of souring if produced water is commingled with seawater than if either water is injected
    - Due to high sulfate from seawater, coupled with high nutrient and carbon loading of produced water
    - Contributed to by poor seawater system or production system biological control



Comparisons of Mixed Injection Regimes

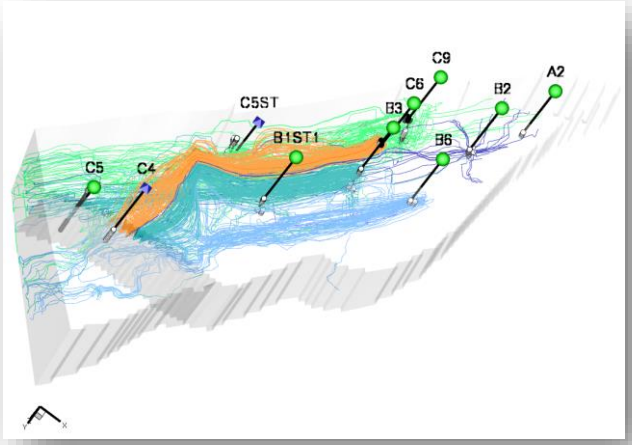


Controlling Souring

- **Lower risk of souring for well-managed systems**
  - Maintaining injection and production system cleanliness with bacterial monitoring and batch biociding is always a good start
- **Nitrate injection**
  - Now widely accepted as a souring mitigation tool
  - Works in most cases, especially when employed from the start of injection
  - There are serious concerns regarding corrosion in mixed seawater/ produced water systems that have caused some applications to be halted
  - Treatment rate for SW/PWRI systems depends on water compositions, but are generally higher than for seawater treatment alone
- **Sulfate removal**
  - Accepted as a means of decreasing souring risk for seawater systems
  - At least one field mixing low-sulfate seawater and produced water has soured

Scaling and Water Incompatibility

- **Produced water generally better than seawater injection**
  - Possible issue when injection to various different zones with different formation water properties
    - Significant issue for deepwater developments covering large areas or multiple reservoirs (e.g. for many West African developments)
  - Mixing at the injector can be controlled with scale inhibitor treatment to the initial flood front
  - Scale management at the producers will depend on the degree of incompatibility and the type and location of the scale formed
- **When injecting produced water to non-native reservoirs or intervals then coreflood testing is a necessity**
  - Differences in salinity or water composition can drive clay swelling in susceptible reservoirs



Temperature Limitations

- **Limited cooling capabilities on brownfield projects can impact produced water injection feasibility**
  - Decreased thermal fracturing at higher arrival temperatures can impact well injectivity performance
    - One reason why North Sea water injection projects tend to have lower filtration requirements than their GoM and West African counterparts
  - Riser flex joints are typically limited to around 120°F for continuous operation
  - Flexible risers and flowlines often have similar operating limits, depending on the choice of polymer liner
    - HDPE is commonly used for water injection systems and is limited to around 140°F

Corrosion Mechanisms

- **Produced water typically much more benign than seawater**
  - Issues are carbon dioxide, possibly H_2S, and bacteria
  - Management typically as required for the water-leg of the separation system
    - Carry-through of corrosion inhibitor usually protects from CO_2 corrosion
    - Batch biociding used for bacterial control – no overboard discharge, so can be more aggressive than comparable seawater systems
    - Need to monitor for oxygen ingress through low-pressure water system and pump seals
  - Unlike seawater systems, carbon steel is generally suitable
    - Potential large savings on subsea flowlines and downhole tubing over seawater injection

Conclusions

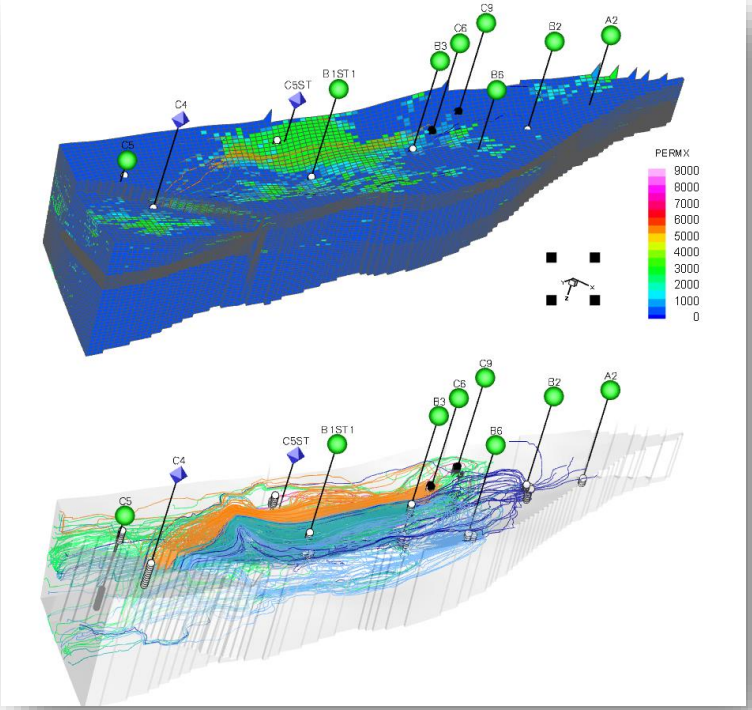
- **Produced water re-injection was adopted as a 'default' position by the majors in the late 1990's**
  - Response to the North Sea regulatory environment and growing public awareness of produced water discharges
- **Translation of this into practice for deepwater developments has been challenging**
  - Increased awareness of the facilities and operational impacts of PWRI
  - More recent move away from PWRI as the default design case for non-FPSO hull types and typically discounted completely for retrofit projects
    - Availability and topsides design impacts are the largest impediments to PWRI use, with souring and injectivity concerns following in importance
  - High well costs in deepwater, limited well numbers and limited topsides real estate have driven a trend towards seawater injection with overboard produced water discharge

The Future?

- **Increasing public pressure to limit produced water discharges World-wide – potential for regulatory changes in the long-term**
  - Early requirement for water will continue to see a need for seawater injection, with occasional aquifer water injection where available
  - Increased use of low salinity or smart water operations may limit produced water injection or the timing of this
  - Weight, space and power requirements for injection make disposal wells more costly in deepwater than for North Sea and Shelf operations
    - Likely to drive increased use of commingled SW/PW injection streams in the mid to late life of facilities
    - May enable the use of lower-capacity seawater systems for early life, with higher volumes from produced water make-up as the field matures

The Future?

- **Emphasis on the produced water treatment industry to develop compact and reliable technologies to overcome current issues**
- **Need to develop integrated produced water treatment and water injection systems**
  - Require less operator intervention than current systems
  - Accommodate produced water upsets
  - Account for the capture and removal of solids – recycling back to the production system isn't an option
  - Reliably deliver high-spec water that promotes long injection well lives and high sustained injection rates



Questions and Discussion

Lee Jordan, Lindsay Anderson
info@gatellc.com

Produced Water Society Seminar
January 2012

CHALLENGES ASSOCIATED WITH PRODUCED WATER RE-INJECTION FOR OFFSHORE WATERFLOOD PROJECTS