Produced Water Management
Oil Production & Processing Operations

Kris M Bansal, PhD

Produced Water Society Conference

Sugar Land, Texas

January 20, 2017

Presentation Overview (1)

- Produced Water
  - Background: What is it and its Chemistry?
  - Non-produced Fluids
- Produced water management
  - Overboard disposal (especially in offshore operations)
  - Injection: disposal and/or waterflooding
  - Recycle: reuse (becoming more and more important especially in unconventional production operations (such as shale gas) and heavy oil. Heavy Oil and shale gas (tight gas) will **not** be the focus in our presentation.
- Produced water treatment equipment
  - Dispersed oil removal
  - Soluble oil removal
  - Suspended solids removal

Presentation Overview (2)

- Produced Water Injection : waterflooding /pressure maintenance / disposal
- Considerations for the design of a cost-effective water injection project
    - Water quality
    - Injectivity decline
        - Impact on oil production rates
        - Well remediation

Produced Water – What is it?

- Conventional Oil/Gas Production Operations: Produced water refers to the water brought up from the hydrocarbon bearing strata during the extraction of oil and gas, and can include:
  - formation water (present originally in the formation (connate water)),
  - injection water (injected for waterflooding or pressure maintenance),
  - chemicals added downhole or during the oil/water/gas separation processes.
- Non-associated Gas Production Operations
  - Produced water includes condensed water and in some cases connate water
  - Volumes are generally very small. Very good candidate for recycle / reuse.
- Unconventional Operations – Connate water, condensed water, residual water from fracking operations. Volumes generally small.
- Produced water from heavy oil operations – Not a focus here
- State of Produced Water
  - It is in a chemically reduced state and constituents will react with the oxygen in the air.

Produced Water Characteristics

- What is in Produced water?
  - Dispersed Oil, Soluble oil (e.g. organic acids, phenol, BTEX)
  - Ions dissolved in water including mineral ions - calcium, magnesium, sodium, barium, strontium, iron, chloride, carbonate, bicarbonate, sulfate, pH, etc.
  - Suspended solids
  - Hydrocarbon and non-hydrocarbon gases (CO_2, H_2S, C_2H_6 etc.)
  - Treating chemicals (scale control, corrosion inhibition etc.)
  - Residual drilling, workover, and stimulation fluids and chemicals.
  - Can have scale forming components, Corrosion products
  - May have sulfate reducing bacteria
- PWQ is never uniform over the field life and amongst other things also depends on oil/water separation system design for processing.

Non-produced Fluids

- Non-produced fluids include – stimulation, completion, workover fluids, miscellaneous fluids from the rig, fluids from unloading of the wells after remedial operations, flowback from fracturing operations, spent acid, deck washings, facility drains, and commonly used rig wash, facility and platform cleaning chemicals.
  - Chemicals present in these fluids can cause enhanced droplet stability and inhibition of droplet coalescence rate resulting in reduced efficiency of oil/water separation process.
  - pH of the fluids in the acid flowbacks could be low (pH < 1) so can contain high levels of corrosion products, formation fines, and several of the chemicals used in acidizing fluids.

Produced Water Management

- Offshore – Preference is to treat water to meet overboard disposal regulatory requirements. Treatment equipment – dispersed oil removal.
  - EPA overboard water quality requirements in the US - NPDES (National Pollutant Discharge Elimination System)
    - Oil & grease 42 mg/l daily maximum.
    - Oil & grease 29 mg/l monthly average
    - Toxicity is 7 day NOEC (no observable effect concentration). Measure both acute and chronic toxicity.
    - No sheen.
- Onshore – treat water to meet injection water quality guidelines. Treatment equipment – dispersed oil removal, suspended solids removal. Chemical treatment to control corrosion, scale and microbiological growth (minimize deterioration in WQ from the facilities to the injection wells).
- Very little emphasis on recycle / reuse offshore. Onshore injection is recycle/reuse.

Water Treatment System – Stoke's Law

- Most commonly used water treating equipment such as skim tanks, flotation cells, hydrocyclones etc. rely on gravity to separate oil droplets from the continuous water phase. In these cases, the vertical velocity of the rising oil droplet in a quiescent zone is approximated by Stoke's law:

$$V_0 = \frac{1}{18}\frac{d^2(\rho_w - \rho_o)}{\mu} * g$$

This equation can be easily reduced to:

$$V_0 = 1.78 * 10^{-6}(\Delta\rho)\frac{d^2}{\mu}$$

Where V_0 is in ft/sec, d is in microns, μ in centipoise, and $\Delta\rho$ is the specific gravity difference between water and oil.

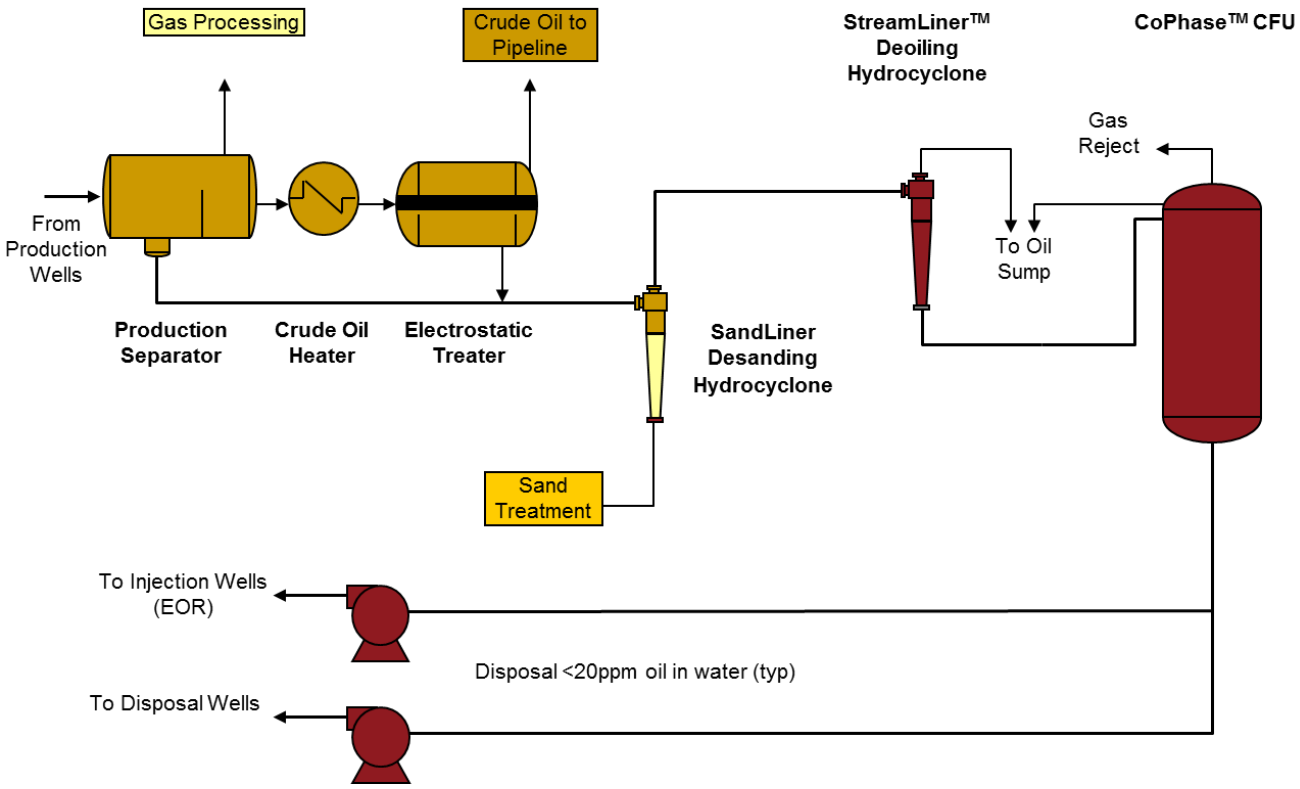
Produced Water Treatment Equipment (1)

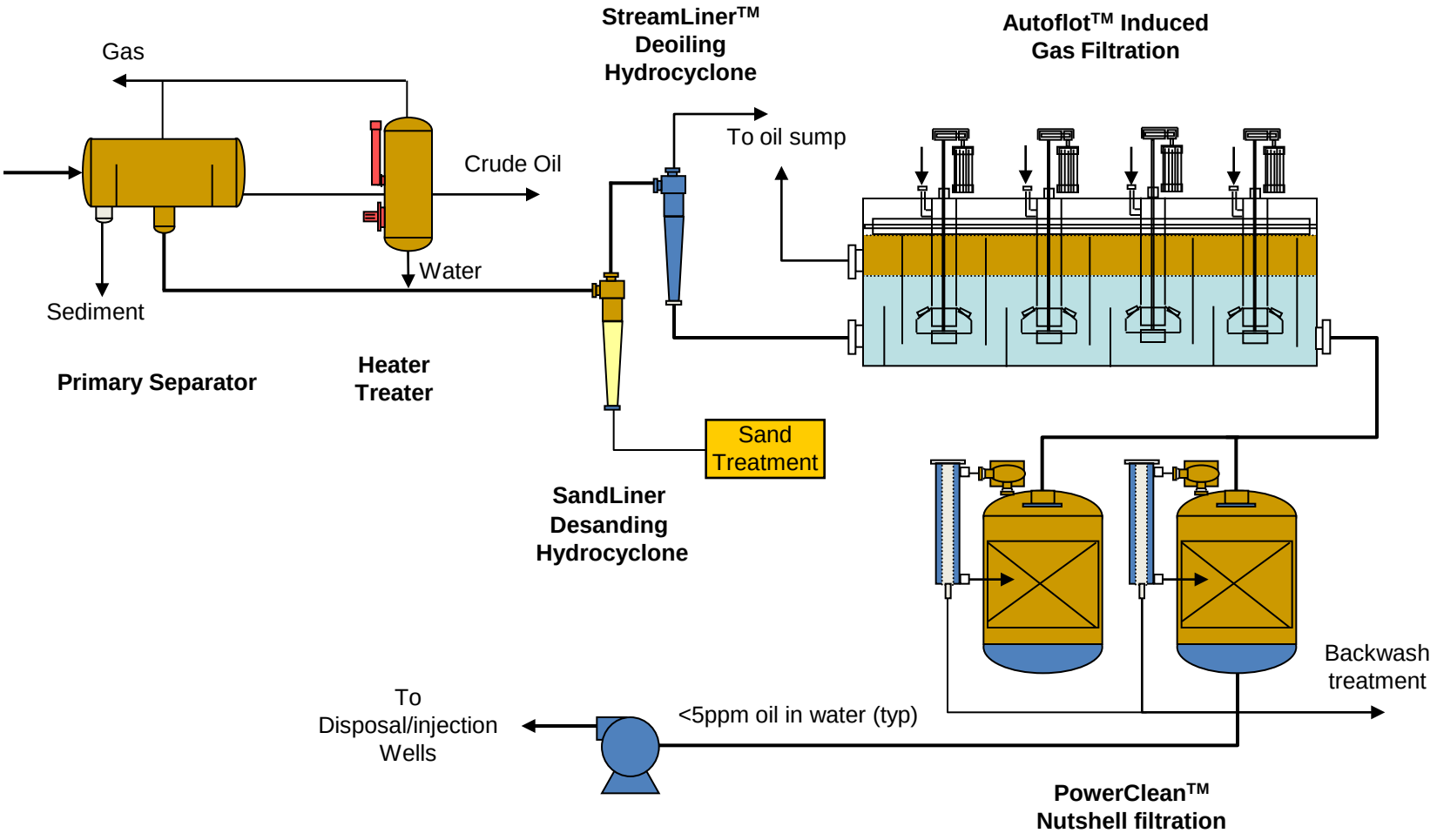
- Sand Removal (wellhead desanders) – Desanders
- Dispersed Oil Removal
  - Skim Tanks
  - Corrugated Plate Interceptors
  - Hydrocyclones *
  - Flotation Units* – Hydraulically Induced, Mechanically Induced, Compact Flotation Units
- Dispersed Oil and Suspended Solids Removal
  - Multimedia Filters*, Walnut shell media filters, Cartridge Filters
  - Centrifuges
  - Membranes*
- Soluble Oil removal*
- Equipment selection – Depends on the end goal in mind
  - Overboard disposal – Hydrocyclones + flotation units
  - Injection – Hydrocyclones + flotation units + media filters or membranes

Produced Water Treatment Equipment (2)

- Primary treatment – Dispersed oil Removal (such as liquid / liquid hydrocyclones)
- Secondary Treatment – Flotation units (includes compact flotation units)
- Tertiary Treatment – Media Type Filters (such as mixed media, walnut shell type), ceramic membranes (micro or ultra filtration)
- For Overboard disposal – primary + secondary treatment
- For Injection – primary + secondary + tertiary

Offshore Produced Water Treatment (Typical)




Gas
Crude Oil
Water
Sediment
Primary Separator
Heater Treater
StreamLiner™ Deoiling Hydrocyclone
To oil sump
Autoflot™ Induced Gas Filtration
Sand Treatment
SandLiner Desanding Hydrocyclone
Backwash treatment
To Disposal/injection Wells
<5ppm oil in water (typ)
PowerClean™ Nutshell filtration

Liquid – liquid Hydrocyclones

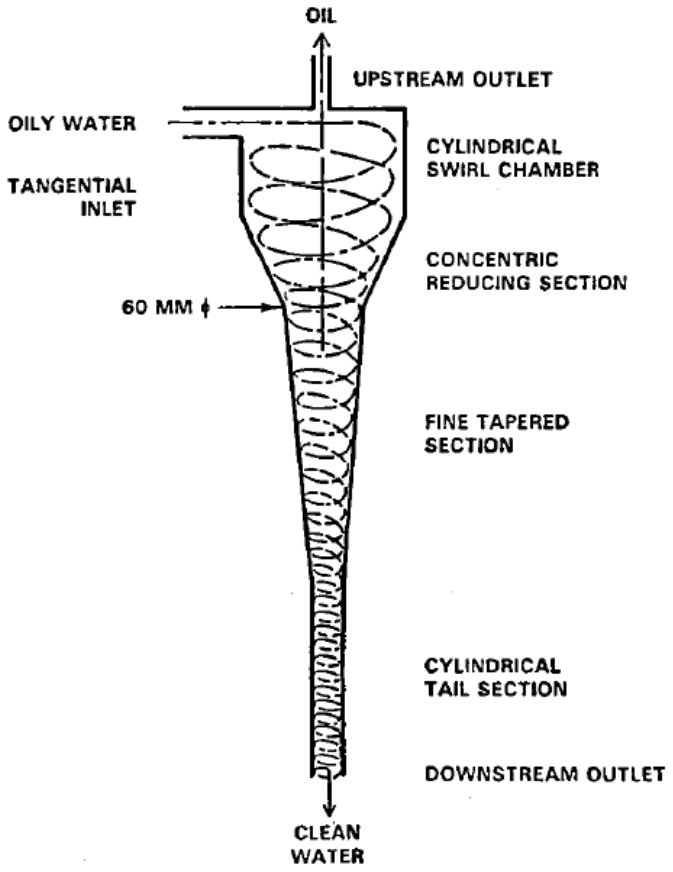
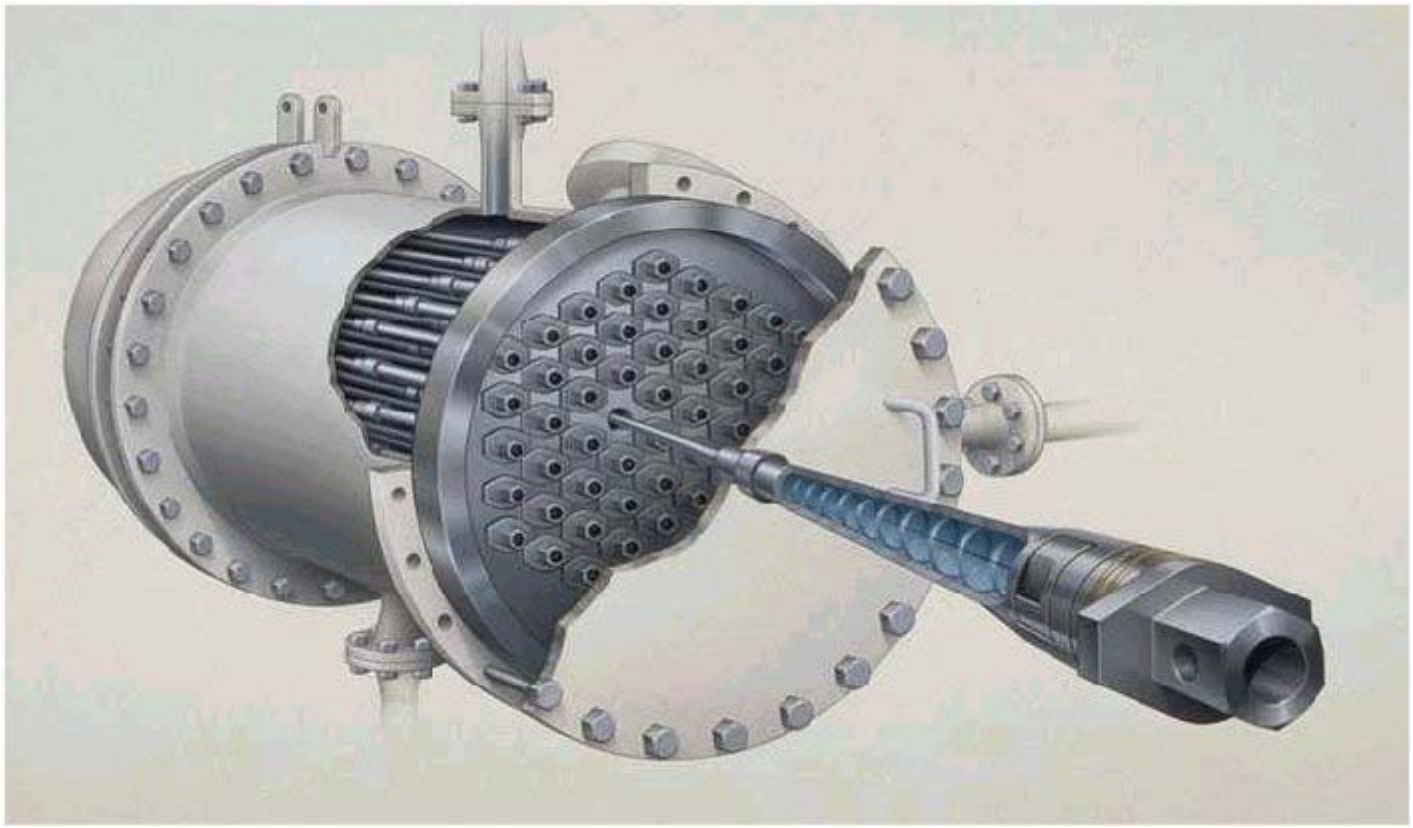


Fig. 15 Vortoil Flow Profile

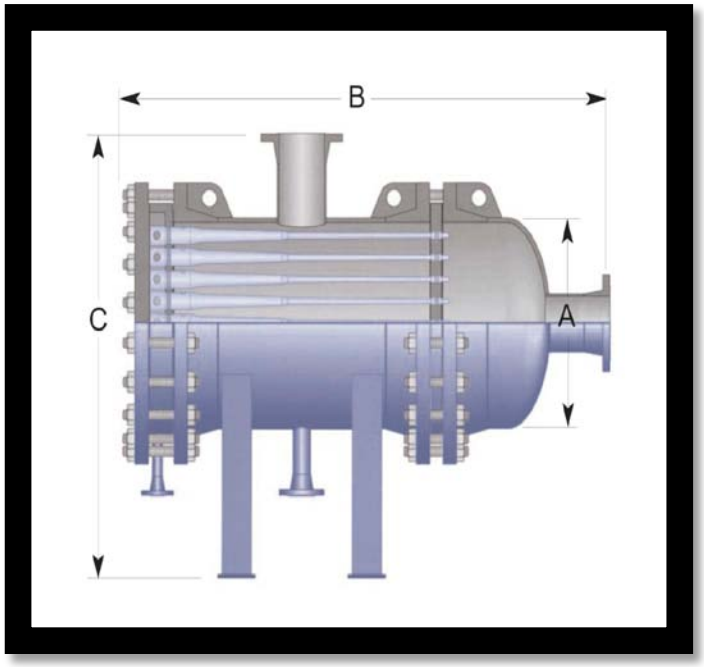
Individual hydrocyclone liners (8 total). This system is manually operated and is used for batch cleanup of tank inventory. It allows easy variation of the number of liners but is not a compact design, has limited throughput, and requires a relatively large number of valves.

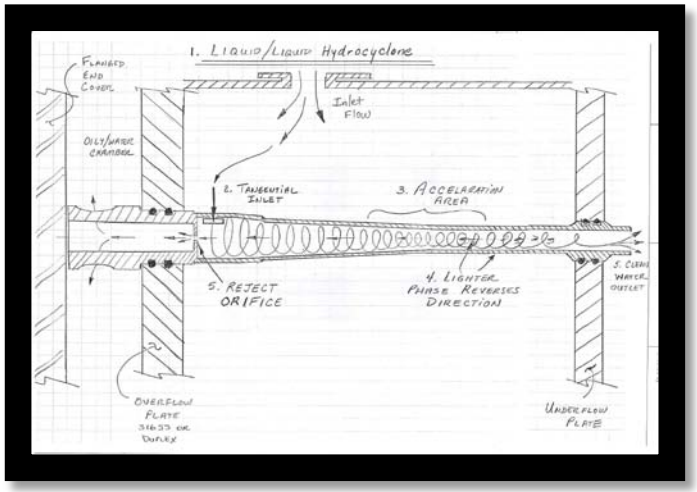


Packaging of many liners within a single pressure vessel. This figure shows the reject header.

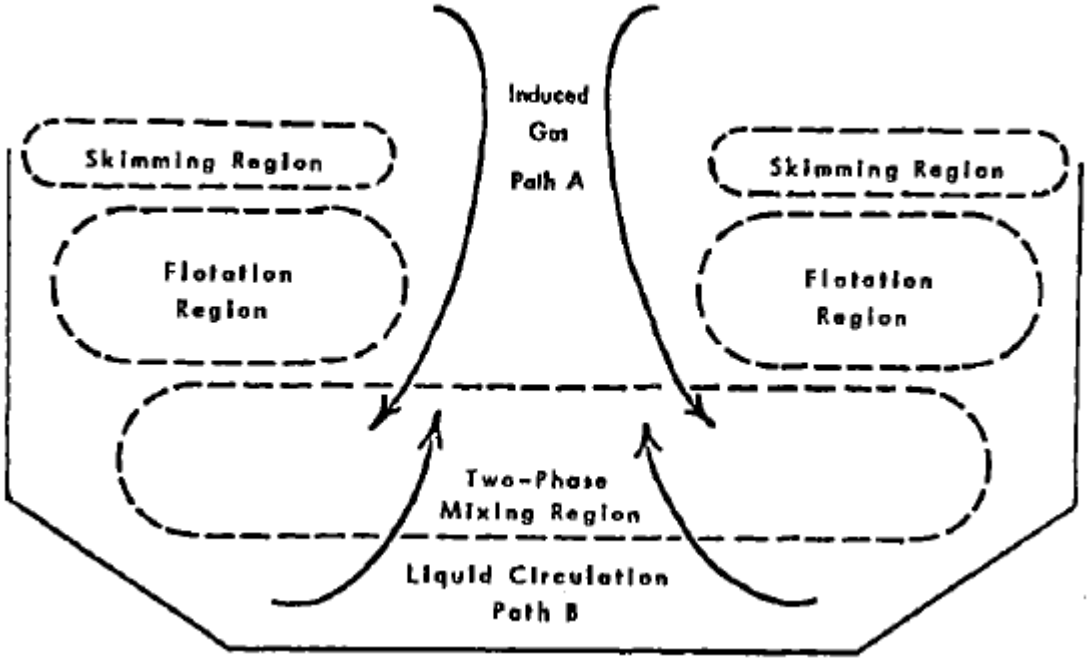
Liquid - Liquid Hydrocyclones (summary)

- Requires pressure and operates on delta P.
- Uses high centrifugal force (800 – 1000G) to separate the oil from the water.
- Small footprint and handles motion on FPSO's and floating vessels
- Used extensively in offshore operations. Limited use in onshore operations.



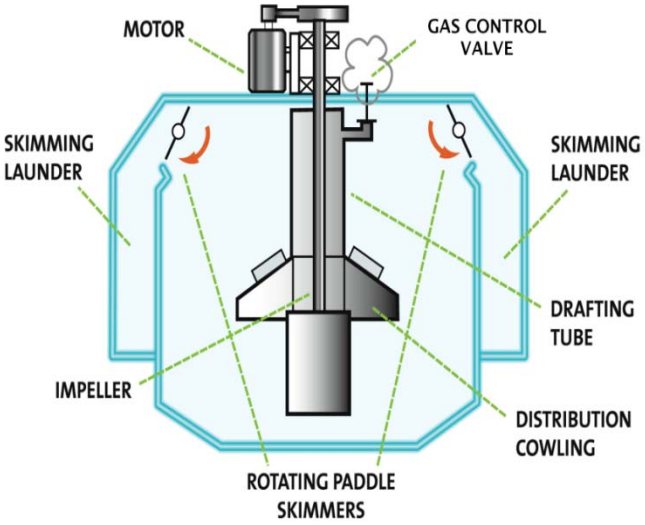


Flotation Cells (1)



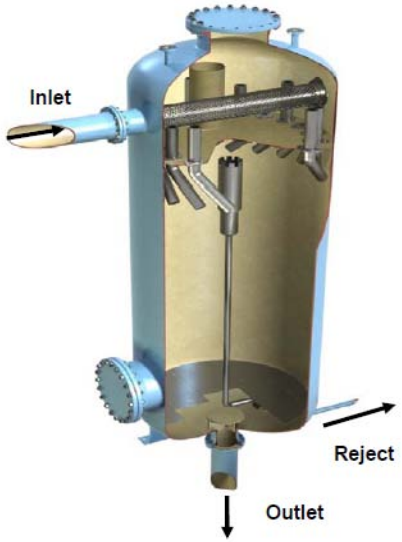
Flotation Cells (2)

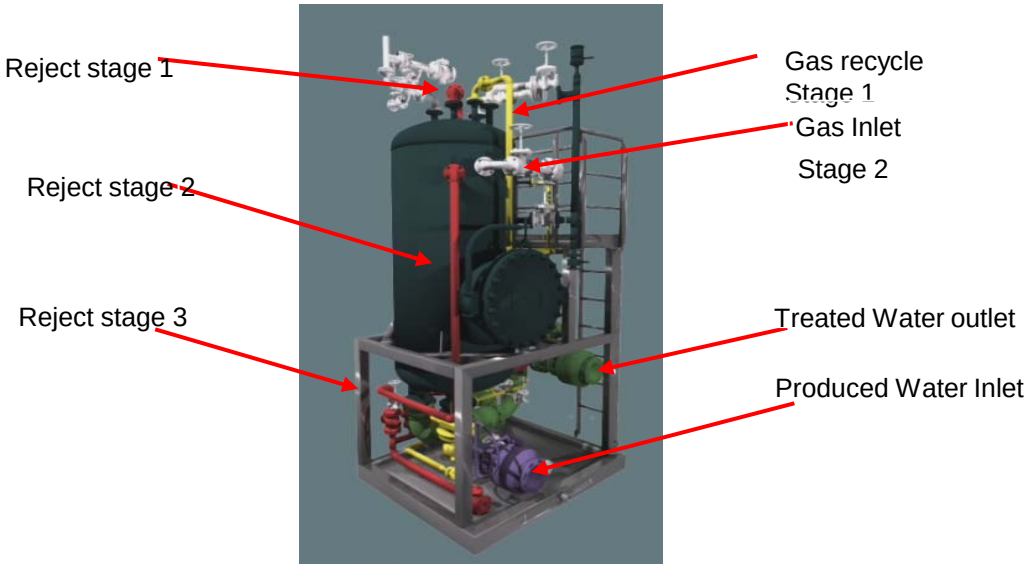
- Oil/water separation using induced gas flotation is a well proven technique and is an established onshore produced water treatment process
- The Autoflot™ IGF units from Veolia are a field proven design with many installations world-wide
- Normally 4 cells in series with fluid retention time of 1 minute in each cell. Total fluid retention time 4 to 5 minutes.



Flotation Units (Compact)

- Oil/water separation using a combination of gas flotation, oil droplet coalescence and centrifugal separation
- The Cophase™ CFU from Veolia is a state of the art second generation CFU and offers a number of benefits.
- The TST-CFU is available as a single stage vessel or as a single vessel with multiple internal stages from Cameron.



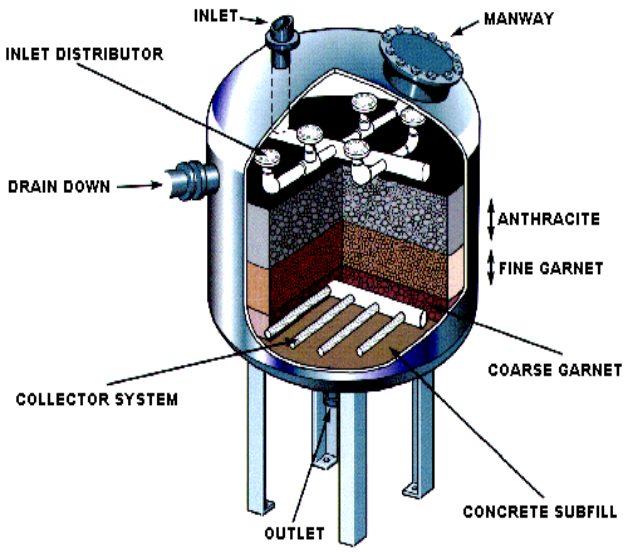


Flotation Units

- Primary factors affecting the performance of a vertical CFU (such as TST-CFU) are:
  - Quantity of gas bubbles formed
  - Size of gas bubbles formed
  - Proper distribution of gas bubbles across the vessel cross-sectional area
  - Proper distribution of produced water across the vessel cross-sectional area
  - Downward velocity of the produced water (flux)
  - Proper water chemistry to promote bubble-contaminant interaction
  - Particle size of the contaminants
- Most offshore operators generally use deoiling hydrocyclones followed by conventional flotation, degasser, or compact flotation cells prior to overboard discharge to consistently meet increasingly stringent overboard water quality specifications.

Multi Media Filtration – Suspended Solids removal

- Used to remove particulates and as a pre-treatment for membrane processes
- Can remove about 85% of particles greater than 2 microns.
- Generally used downstream of the dispersed oil removal equipment when treated produced water is injected for waterflooding / pressure maintenance. TSS removal critical to reduce injection well plugging.

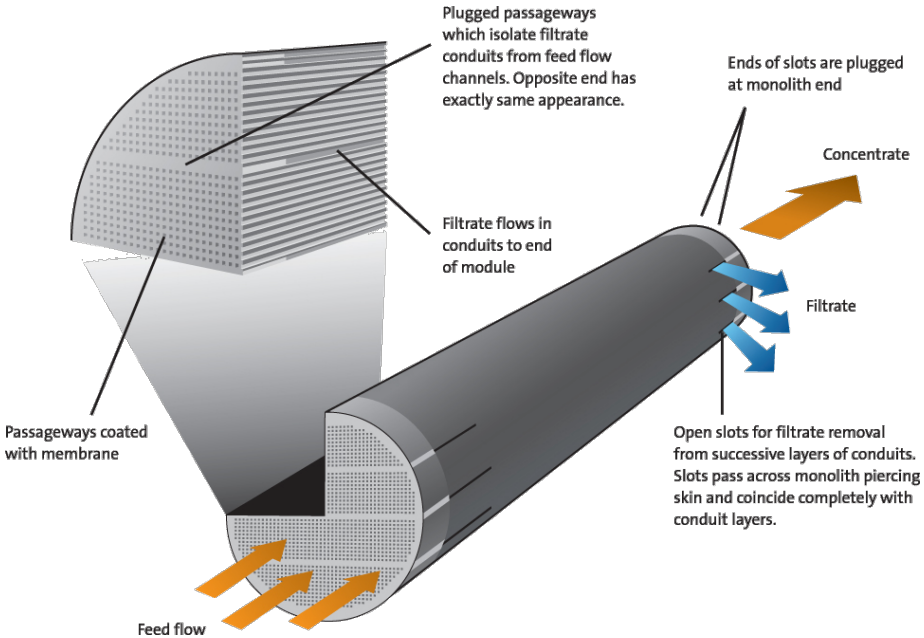


Nutshell Filters

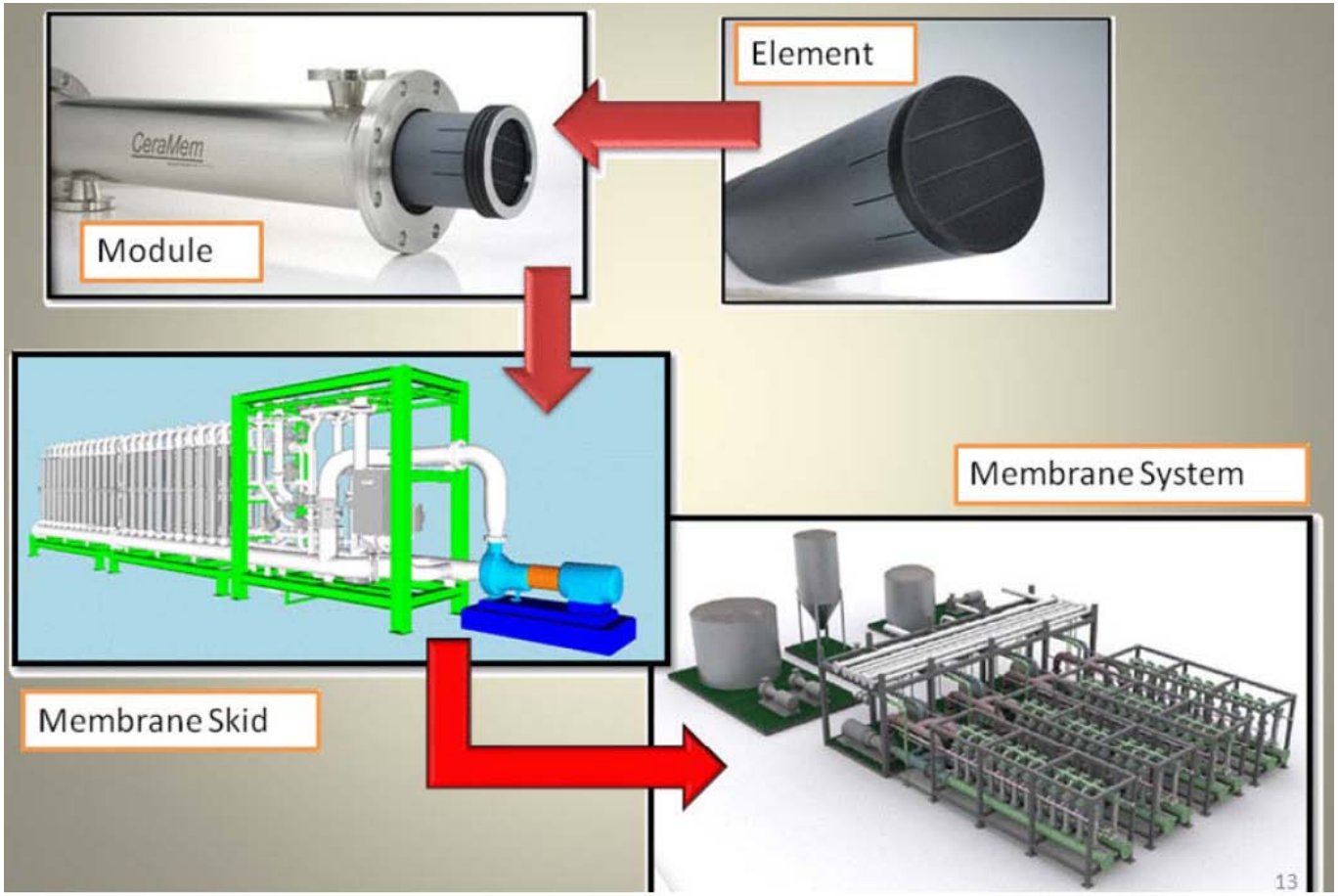
- Black walnut shell media (single media) is used in these filters. Operated in a downflow mode.
  - Walnut shells have a strong affinity for oil but are not as good for suspended solids removal.
  - Unique backwashing process. Significantly less backwash volume when compared to multi-media filters.
  - No mudballing

Ceramic Membranes for Produced Water Treatment

- All suspended solids >0.1micron removed
- Excellent water quality for injection

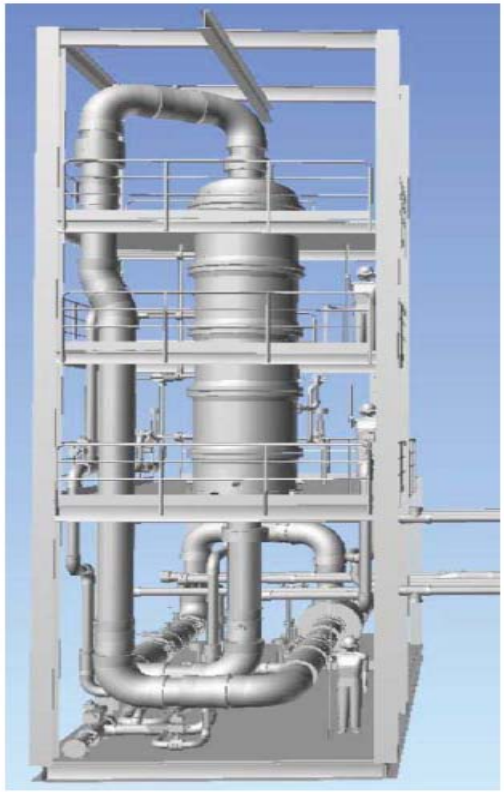


Ceramic Membranes

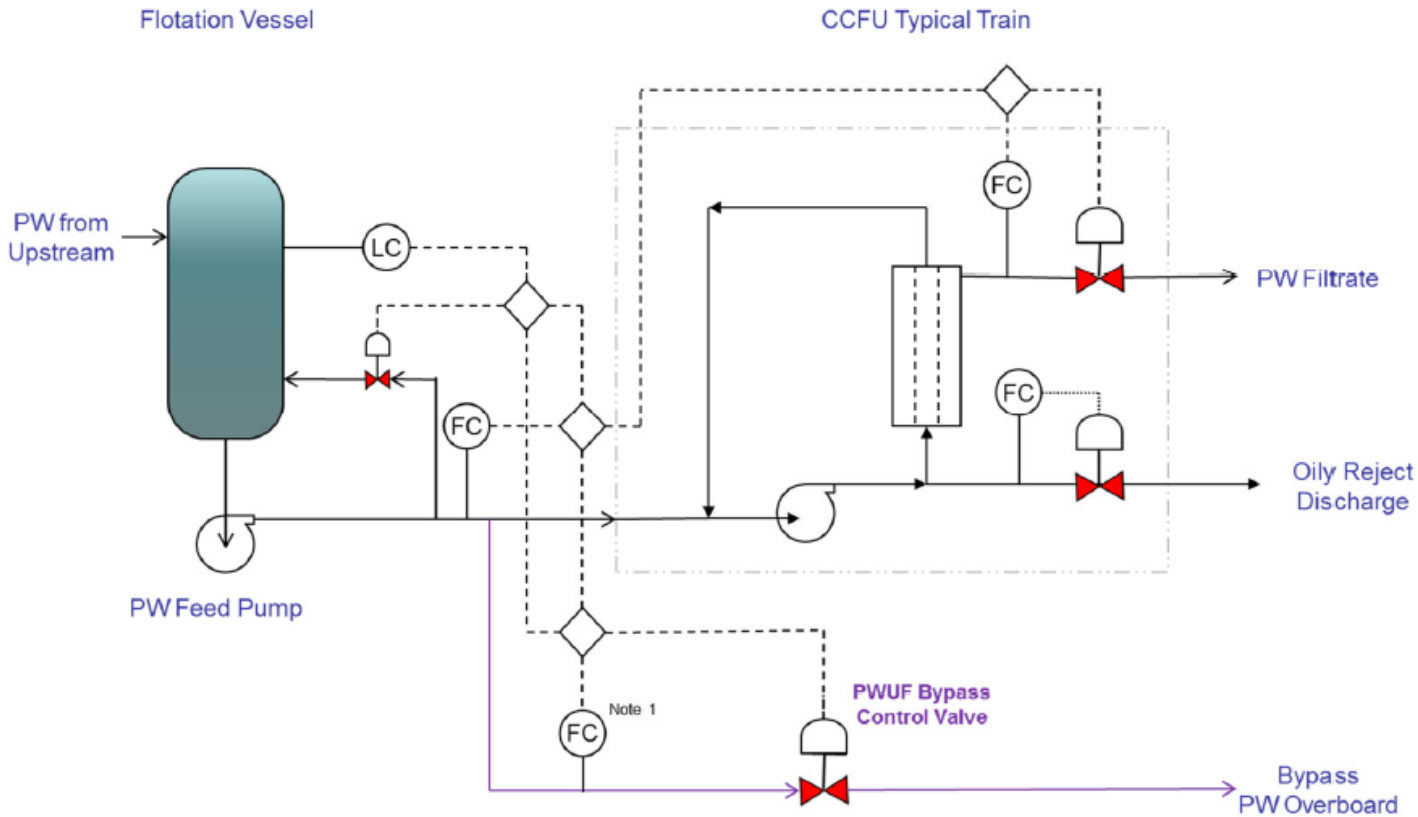


Ceramic Membranes

- Emerging technology for micro and ultra filtration. A range of silicone carbide membranes has been developed.
- These membranes provide a positive barrier and can handle episodic upsets in PWQ.
- Membranes have not been used in offshore operations to our knowledge. Still need to do additional development wor



Membrane Filtration Process



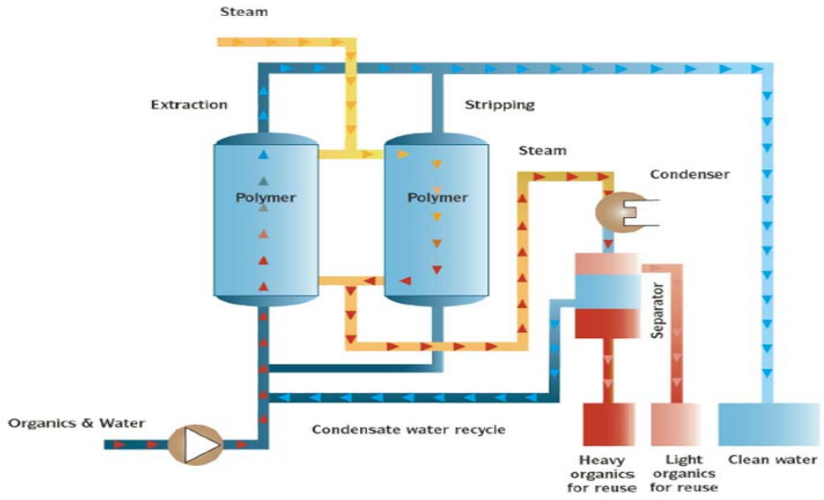
Typical PW Ceramic Membrane Filtration Process (with Upstream Flotation)

Separator Type	Separation Method	Oil Droplet Removal Range
Skim Tanks, API	Gravity	>150 micron
CPI	Gravity Coalescer	>50 micron
Flotation cells	Flotation	> 15 Microns
L/L Hydrocyclone	Centrifugal Force	> 15 micron
Centrifuges	Centrifugal Force	> 5 micron
Coalescing Filter	Filtration/Coalescence	> 2 micron
UF,RO, Micro, Nano	Membrane	> 0.1 micron

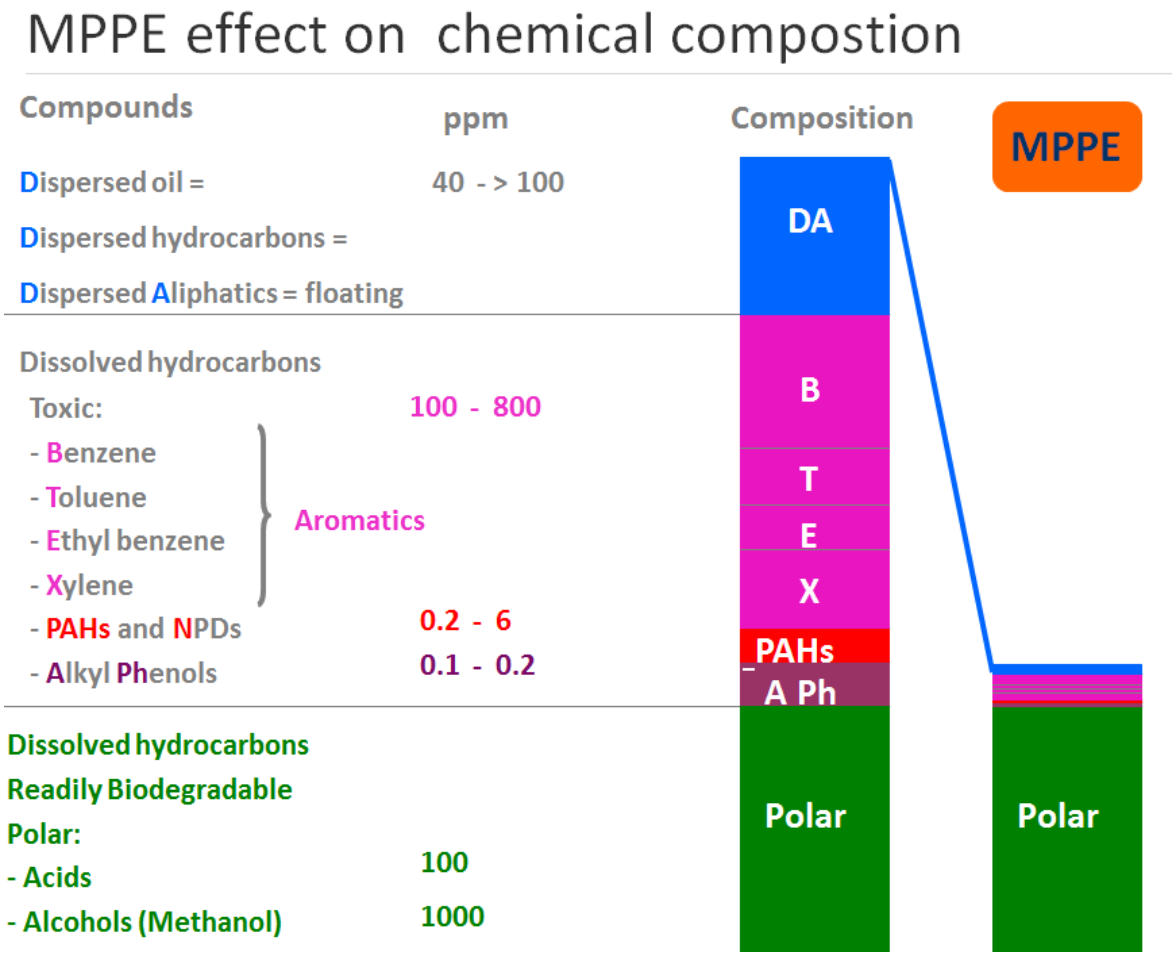
Soluble Oil Removal (MPPE Process)

MPPE Process – Macro-porous Polymer Extraction

- The MPPE process is a liquid – liquid extraction.
- The liquid that does the extracting is encapsulated in a porous plastic.
- MPPE can remove both dispersed and dissolved hydrocarbons.
- The media is regenerated with steam.
- The extracted hydrocarbons are recovered as oil – not sludge.



MPPE Effect on Chemical Composition



Injection Water Quality

- Water Quality (WQ) – In waterflood operations, water quality is usually defined in terms of the plugging tendency of the water. Formation plugging can cause a reduced sweep efficiency and, thereby, decreased secondary oil recovery and ultimately loss of revenue. The cost of obtaining and preserving good water quality must be balanced against the loss of revenue sustained as a result of decreased oil recovery and increased workover and remedial operations requirements.
- Injection WQ depends on: reservoir characteristics, type of formation, injection mode (injection below or above the frac pressure), and presence of natural fractures in the formation. Fractures can be natural or induced.
- Contaminants responsible for WQ fall into 3 categories:
  - Present in source water
  - Generated within the system (e.g. corrosion and scale products, includes pipeline injection system and injection tubing)
  - Added to the system either intentionally or unintentionally – e.g. oxygen ingress into the system.
- Difficulty of preserving WQ depends on the length & system complexity.

Water Quality and Injectivity (1)

- How clean the injection water has to be for a cost effective waterflood project?
  - No simple answer. Analogs. 98% removal of particles greater than 2 microns.
  - The water quality at the injection wells is the most important one and determines the success or the failure of a cost effective operation of the waterflood system.
- Matrix Injection – Injection below the reservoir fracture pressure.
- Injectivity decline and injection well half-life – Injection well half-life is the time it takes for injectivity to decline to half it value.

Water Quality and Injectivity (2)

- Remediation (such as acidization) is normally done to restore the lost injectivity.
- In most waterflood operations, injection above the reservoir fracture pressure becomes a reality for an **economic** project.
- Problems & consequences associated with injection above the fracture pressure.
  - The fracture is not necessarily limited to the oil pay. Fracturing can be to an aquifer or non-productive interval resulting in ineffective injection with less water sweeping the oil pay and lower ultimate recovery.
  - The direction of the fracture is not necessarily predictable. Premature breakthrough to a producer can occur resulting in poor sweep efficiency.

Process Trouble Shooting

- Total System Approach includes:
  - Appropriate system design (fit-for-purpose, clear end goal in mind)
  - Coordinated operation, and
  - Communication between personnel who operate all the sub-systems
- Some of the specific items that should be addressed include:
  - Water/oil separation system design
  - Process monitoring
  - Optimum chemical control program
  - Design to minimize impact of surges on oil/water separation equipment
  - Optimum chemical usage in acidizing fluids and proper handling of non-produced fluids
  - Minimize oxygen ingress
  - Proper handling of fluids from wellbore and vessel clean out chemicals.