Introduction to Produced Water Treatment

As per current regulations, Oil and Grease (O&G) content of produced water (PW) discharged into the Gulf of Mexico (GoM) is limited to a 29 mg/l monthly average with allowable excursions to 42 mg/l. Compliance to regulations has historically been the design basis for produced water treating systems.

Environmental stewardship is now becoming a key priority in the industry, especially among major oil producers. This, together with the inherent uncertainty in the performance of any produced water system, the potential for water soluble organics (WSOs) and some uncertainty in future regulatory requirements, has led many companies to target lower discharge design limits.

Produced Water Definition

Generally, produced water is a combination of formation water, connate water and injected seawater with the concentration of each varying over field life. A small amount of water will result from condensation of water in the gas compression system and a small amount will result from injection of water based chemicals.

Design Basis Flow Rate

The prediction of oil, gas and water flow rates is uncertain and varies over field life. Prediction of water flow rates is probably more uncertain than prediction of hydrocarbon flow rates. The design of the produced water treating system should be flexible enough to provide adequate treatment at the low flow rates immediately following water breakthrough and to provide adequate treatment at a realistically possible maximum flow rate and/or to provide an easy means for increasing the capacity of the system in late life.

Oil Removal Science

Most of the oil contained in produced water is dispersed. Some will be dissolved in the water. The amount of oil dissolved in the water is usually very small, but can be significant. Several hydrocarbon species dissolve in water at potentially significant concentrations.

Dispersed Oil

Dispersed oil can be removed by gravity separation. Oil/water separation is governed by the rise velocity of oil droplets in the water. This is modeled by Stokes (Equation 1).

Density Differential

Oil/water separation is driven by density difference. For heavy oil and light water separation will be less effective and less efficient. The density difference can be impacted several ways. If fine heavy solids are present, oil droplets may cling to them and be much less buoyant, or even sink. Methanol, used for hydrate inhibition, can cause a large drop in water density. Flotation units increase the effective density difference by creating fine gas bubbles for the oil droplets to cling to. Heat increases the density difference because the density of oil decreases faster than the density of water with increasing temperature.

Oil Droplet Diameter

Production systems should be designed and operated to maximize droplet size. Chokes, control valves, and pumps cause shearing of oil droplets. Droplet size is related to interfacial tension. Interfacial tension is decreased by some injected chemicals including methanol, corrosion inhibitors, and LDHIs. Produced waters with these chemicals will have smaller oil droplets.

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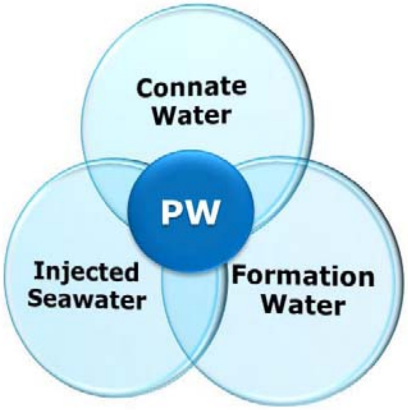

Equation 1: Stokes Law

$$V_s = 0.056 \times g \times d^2 \times (\rho_w - \rho_o) \times \mu^{-1}$$

V_s = Oil droplet settling velocity, m/sec

d = Oil droplet diameter, m

ρ_w = Water density, kg/m^3

ρ_o = Oil density, kg/m^3

μ = Water dynamic viscosity, kg/m-sec

g = G-force applied, m/sec^2

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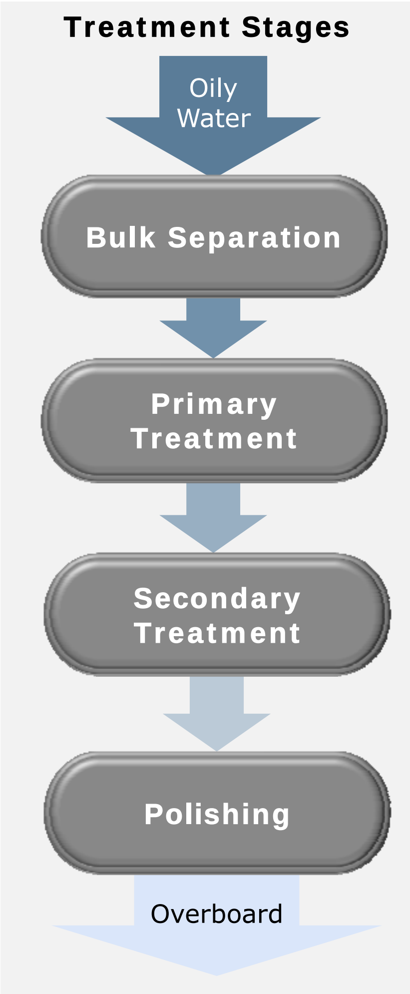

Droplets sheared in choke or pumps will tend to coalesce back into larger droplets if the conditions are right. Factors that prevent coalescing include:

- Electrostatic charges causing the droplets to repel.
- Stabilization by surface-active chemicals.
- Stability caused by fine particles.

The droplet electrostatic charge is higher when the salinity is low. Larger oil droplets are expected in higher salinity water.

Water Viscosity

Rise velocity is inversely proportional to the water viscosity. Water viscosity is decreased by heating, hence heating improves separation efficiency.

G-Force

This is the force of gravity in settling tanks as well as the centrifugal forces in hydrocyclones and centrifuges. The greater the g-force, the faster the separation.

Dissolved Oil / Water Soluble Organics

A few organic compounds dissolve in water in appreciable quantities. These especially include aromatics (benzene, toluene, etc.) and organic acids (carboxylic or fatty acids). GoM regulations (EPA 1664 gravimetric method) define O&G as those compounds which extract into n-hexane solvent from water at a pH less than 2 and which remain after the solvent has been boiled away. The gravimetric method measures organic acids (which partition to the water phase at low pH), but does not measure light aromatics (which are vaporized in the boiling step). Hence, in GOM production, it is typically fatty acids which constitute the bulk of measured Water Soluble Organics (WSOs).

Produced Water Treatment

There are many available water treating systems ranging from the simplistic, such as skim tanks, to the ultra-sophisticated, such as ultra-filtration via membranes. Treatment is performed in stages including:

1. Bulk Separation
2. Primary Deoiling or Primary Treatment
3. Secondary Deoiling or Secondary Treatment
4. Polishing

Typical Treatment Methods

The Best Available Technology (BAT) prescribed by the US EPA NPDES permit system is flotation. For the last two decades, the technology of choice in the North Sea has been hydrocyclones. In the GoM and much of the rest of the world, the industry appears to have settled on a standard process featuring hydrocyclones for primary treatment followed by flotation for secondary treatment. Polishing is usually not required to meet the discharge limit except during process upsets, or unusual events such as well cleanup and/or to remove WSOs. As operators strive for lower O&G target limits, less than 29 mg/l, it is envisioned that polishing equipment will be increasingly used as part of the produced water process.

Future GATEKEEPERs will explore the different equipment and processes used for primary treatment, secondary treatment, polishing, and WSO removal.