Produced Water Treatment and Reuse – A Global Perspective

John Walsh
Worley Advisian
17-July 2019

1

Produced Water Locations in this Webinar

Global oil production ~ 80 mln BOPD
produced water ~ 260 mln BWPD (40 mln m^3/day)
injected water ~ 330 mln BWPD (52 mln m^3/day)

Slide 2

Introduction & Highlights

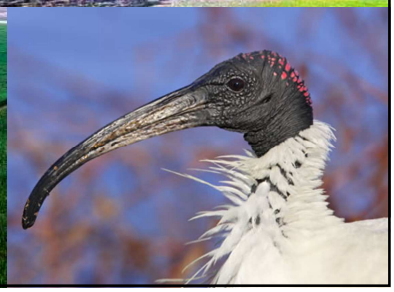
- Different ways of handling, treating, managing produced water:
  - e.g. surface discharge, subsurface injection, beneficial reuse, reuse for hydraulic fracturing
- What factors cause the different handling methods?
  - e.g. hydrocarbon characteristics, development strategy, produced water type, disposal options, water scarcity, regulations, water volumes.
  - e.g. chemistry of the oil and water, production chemicals, fluid mechanics, oil conc., suspended solids conc., particle size dist., emulsion types.
- Subjects:
  - Salinity
  - Deepwater (GoM) vs Shallow Water (N. Sea)
  - Fine Solids
  - Water Soluble Organics

Slide 3

Low Salinity Fields

Low Salinity Fields:

Wyoming CBM	surface discharge
Brisbane CSG	expensive
Oman PW	reed beds
Brunei Condensed Water	extensive treatment
Steam Floods	treatment for recycle



Wyoming vs. Brizzy – low salinity Coal Bed Dewatering

PRB:
- Low salinity in some regions
- Moderate SAR
- Direct surface discharge allowed in the low salinity regions

Coal Bed Methane (Wyoming) / Coal Seam Gas (Brisbane) – Dewater the coal to produce the gas

Variable	Brizzy Queensland	Regions within the PRB
pH	8.1 to 8.7	8.1 to 8.4
TDS	1,500 to 10,000	< 2,000
B	< 5	< 5
SO_4^{2-}	< 2	< 2
hardness	30	80
alkalinity	400 to 2,200	400 to 3,000
CO_3^{-2}	20 to 200	20 to 300
SAR	> 500	~ 50

Brizzy:
- Slightly higher salinity
- Higher SAR
- Environmentally sensitive area
- No disposal Aquifer
- Desalination required $$$

Nimr Oilfield Oman – Reed Beds

<u>Nimr Oilfield Reed Bed system</u> – 1 million BWPD
Originally Deep SWD

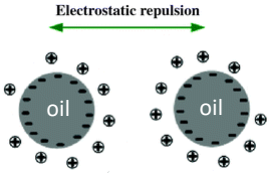
Oil-in-Water:	100 ave to 1,000 max
Total Dissolved Solids:	7,400 ave to 8,600 max
Boron	4 ave to 5 max

Suitable for salt-tolerant reeds

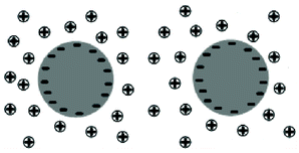
Miri Sarawak – Condensed Water from Gas Production

- Condensed water has low salinity
- Low pH from low alkalinity (corrosive)
- Small highly stabilized oil droplets from high pressure shearing and use of corrosion inhibitor
- Coagulant and flocculant water treatment chemicals required

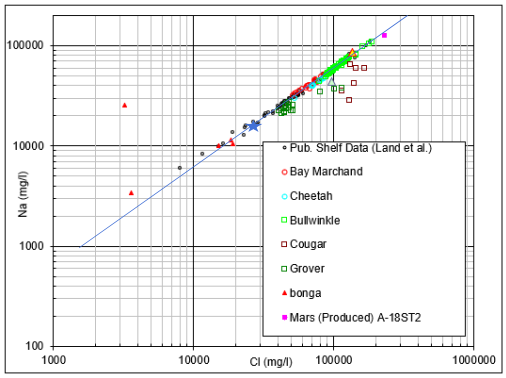
DLVO Model:



Add a coagulant for charge neutralization, less repulsion, greater flocculation & coalescence

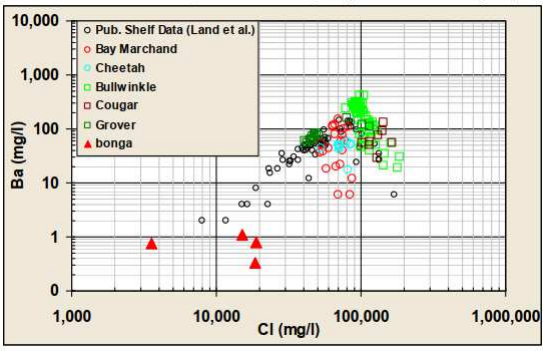


Sea Water Evaporites & Barium Ion Exchange



- Sea water Cl^{-1} = 19,162 mg/L; Na^{+1} = 10,679 mg/L
  - Most produced water originated as seawater trapped in depositional sediments together with clay, sand, and organic matter
  - Water molecules diffuse through the rock and the formation water typically becomes more concentrated

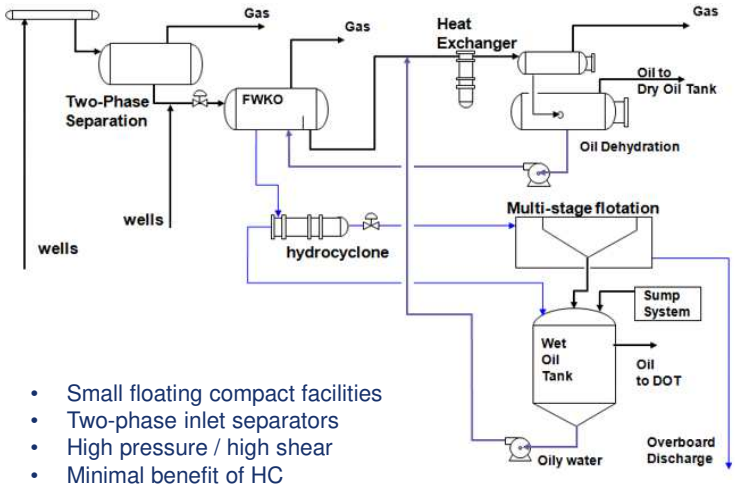
- Some seawater ions exchange with mineral ions
  - Barium is a good example
  - There is a NE/SW trend due to evaporation
  - There is a NW/SE trend due to ion exchange



Deep Water – Gulf of Mexico

Deep Water –
- 240 km offshore
- 1,000 m subsea (water depth)
- 4,500 m subsurface
- 5 to 20 k BOPD per well

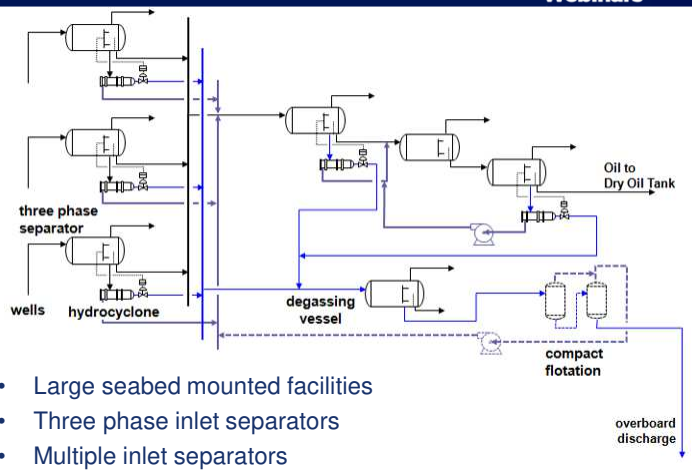
Gulf of Mexico – Deep Water Facilities



- Small floating compact facilities
- Two-phase inlet separators
- High pressure / high shear
- Minimal benefit of HC
- Large multistage horizonal flotation

Slide 10

North Sea – Shallow Water Facilities



- Large seabed mounted facilities
- Three phase inlet separators
- Multiple inlet separators
- Hydrocyclones on each separator
- Hydrocyclones are workhorses
- Optional compact vertical flotation

Slide 11

North Sea vs Deepwater Gulf of Mexico

- North Sea:
  - warmer fluids (lower viscosity)
  - primary separation all 3-phase, w/ HC & degasser
  - hydrocyclones (multi-configuration) on all primary separators
  - **no flotation required or just 2-stage vertical compact flotation**

- Deep Water Gulf of Mexico:
  - cooler fluids (higher viscosity)
  - primary separation (HP, IP) 2-phase (sized for G/L separation)
  - **large horizontal 4-stage flotation required**

Weight of North Sea process line-up is almost double that of Deepwater GoM.
Both regions appear to utilize Best Available Technology within the regional constraint of cost of weight and space and fluid characteristics.

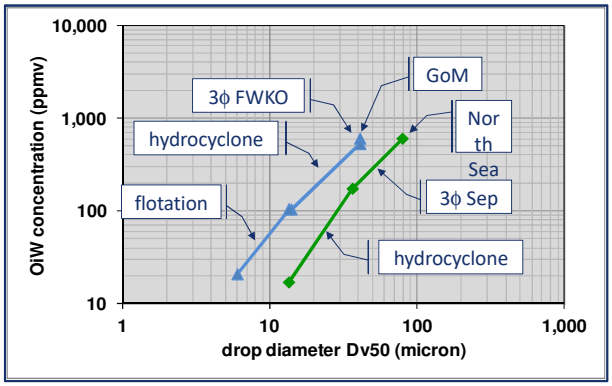
Slide 12

GoM vs North Sea – Process Performance Diagram

Gulf of Mexico:

- Shearing
- Low water volumes
- Two-phase inlet separators
- Large flotation required

- Also … solids, and oily solids, can be a major problem



North Sea:

- Less shearing
- Greater water volumes
- Three-phase inlet separators each with a hydrocyclone
- Small or no flotation required

- But … there are exceptions! e.g. Shearwater (high CI)

Slide 13

W. TX, Offshore Brazil, Alberta – Small Solid Particles

Solids: mineral, organic, oily solids:

Permian Shale PW	high conc. / small size
FPSO Slops Water	small oily solids
Steam PW & Tailings	small (clay) / naphthenic acids

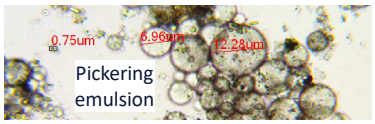
Permian Shale Basin – High Concentration of Small Particles

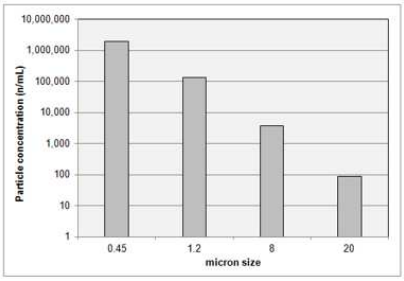
Suspended Solids in produced water from the Permian Basin contain a high concentration of really small particles

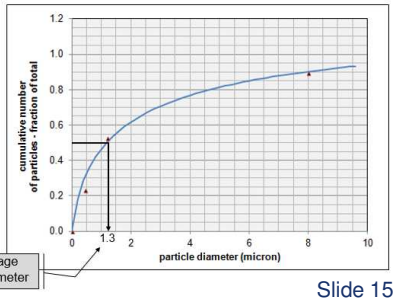
Location of Produced Water	Concentration (mg/L)	Particle Size (micron)
Permian Shale	100 to 1,200	1 to 2
Deepwater GoM	20 to 30	10 to 20
North Sea	10 to 20	12 to 30

Solids compositions:

- iron oxides, carbonate, sulfide
- crushed silica (sand)
- shale fines
- clay fines
- scaling minerals



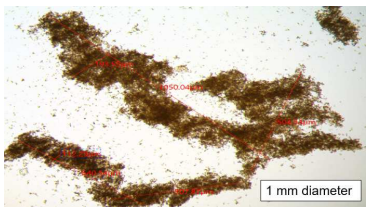


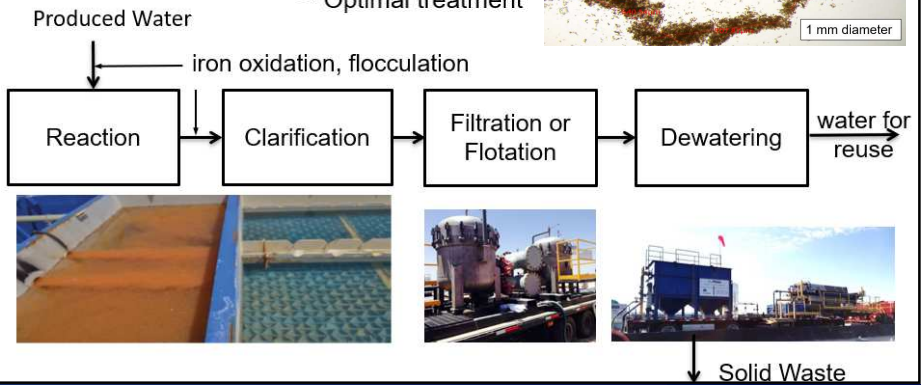


Slide 15

Shale PW Treatment for Reuse

- Chemical Treatment using anionic polyelectrolytes has been found to be effective at flocculating the small particles
- Iron oxidation occurs naturally to some extent but must be driven to completion
- Once large flocs are formed, by adding chemical, they can be separated by settling, flotation or filtration
- Solid (wet) waste must be disposed
- Water is ready for reuse



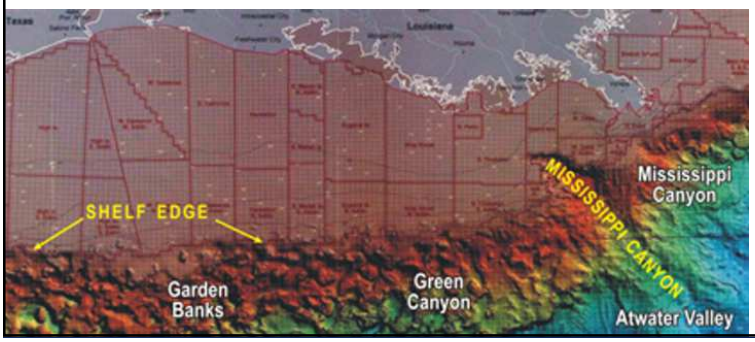


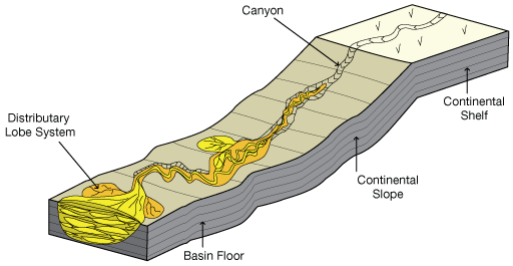
Gulf of Mexico & Brazil – Water Soluble Organics

Turbidite Reservoirs:
Nigeria, GoM, Brazil, W. Ozzy, North Sea, etc.

Type II & Type III organic deposits rich in oxygen containing compounds (e.g. organic acids)

GoM & Offshore Brazil Regulations for Water Soluble Organics





Regulatory Testing – Water Soluble Organics

Dispersed oil – usually means oil in produced water in the form of small droplets, which may range from sub-microns to hundreds of microns. Dispersed oil will contain both aliphatic and aromatic hydrocarbons.

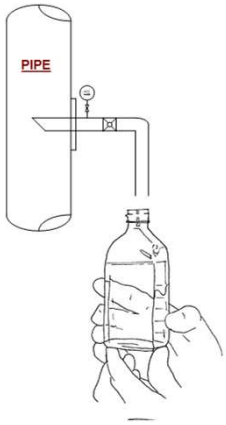
Dissolved oil – usually means oil in produced water in a soluble form. Aliphatic hydrocarbons in general have very low solubility in water. It is the aromatic hydrocarbons, together with things like organic acid that form the bulk of dissolved oil.

TOG = Total Oil & Grease
= extractable by, and less volatile than hexane
= essentially all hydrocarbons and organics

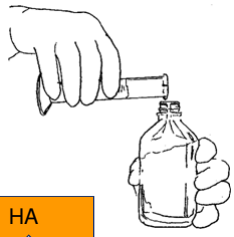
WSO = TOG minus the Silica Gel Treated material
= dissolved (at pH=2) + polar dispersed

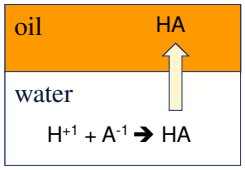
Slide 18

EPA 1664 Test – Water Soluble Organics



Sample + Acid + Hexane → heat → Measure TOG → Si gel → Measure TPH



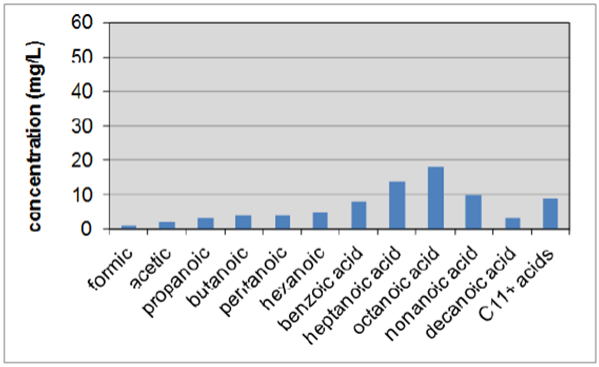


chemical & phase equilibria

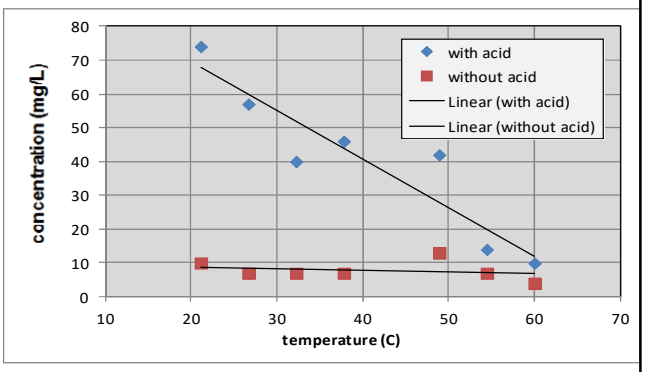
Calculate WSO:
TOG = TPH + WSO

Slide 19

Water Soluble Organics – Mol. Wt., pH and Temperature Effects



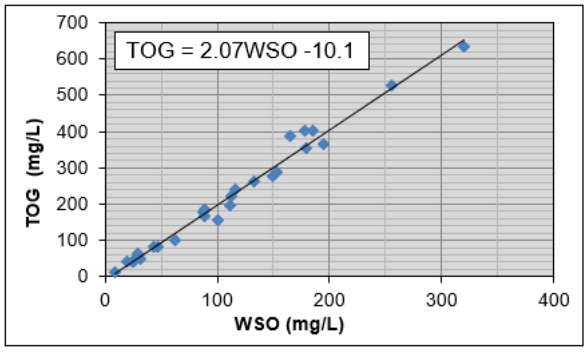
Concentration of various acids extracted from PW into hexane at pH =2. Fatty acids (C6 – C11+ predominate). Short volatile organics acids (< C6) are too polar to extract into hexane.



Concentration of PW as a function of temperature (volatility) and pH (protonated vs ionized). Under the conditions of the EPA 1664 test (low pH, high T), the majority of acids do not contribute to WSO / TOG.

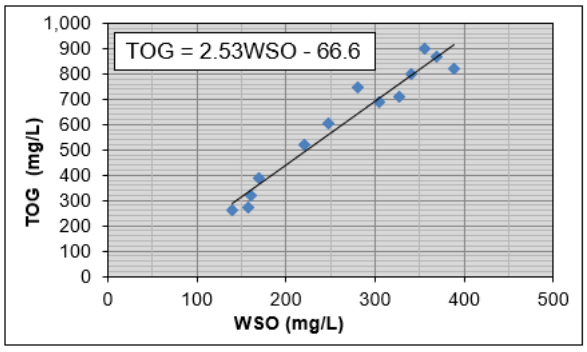
Slide 20

Water Soluble Organics



WSO diagram (above): 10 mg/L

Deep removal of TOG, e.g. filtration



Filtered, acidified sample: 35 mg/L (TPH=0, TOG=WSO)
WSO diagram (above): 44 mg/L

Total volatile acids: 460 mg/L

Adsorbant (GAC, clay, silica), Extraction)

Slide 21

Gulf of Mexico – Dissolved Organic Acids

Table 2. Fluid Properties for the Mars Reservoirs

RESERVOIR	DEPTH	API	Sat.	Aromatics	Resins	Asphaltenes	Atomic Sulfur (wt %)	ACID No.
Lower Pink	11,821	19.6	23.1	58.4	15.2	3.3	2.5	
Pink	13,036	17.3	21.0	61.6	14.0	3.4	2.7	4.35
Lower Green	16,287	31.5	40.9	47.6	9.5	2.1	1.8	0.34
Ultra Blue	16,301	24.6	41.3	37.5	13.9	7.3	2.6	
Orange	16,550	24.4	27.4	54.5	14.5	3.6	2.4	1.00
Upper Green	16,910	23.5	24.3	55.6	14.9	5.2	2.6	
Magenta	17,610	24.2	28.1	54.1	13.5	4.3	2.6	0.61
Violet Ic	18,419	22.5	25.0	59.3	12.6	3.1	2.7	1.20
Lower Yellow	18,476	27.6	30.8	51.8	15.1	2.2	2.2	
Terra Cotta	18,476	22.1	25.2	50.2	13.4	11.2	2.8	0.95

Note the Pink reservoir which is relatively shallow (likely to have lower temperature) has much higher acid number than the others. In the production train, the wells producing from the Pink reservoir always caused water (and oil) treatment problems.

Slide 22

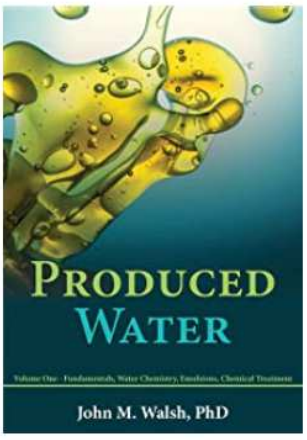
Summary & Conclusions

- What is Produced Water?
  - Water originally trapped in sedimentary basins – rivers, lakes, and sea beds together with clay, sandstone, and lots of organic matter that eventually becomes oil and gas. The water contains dissolved (ions, acids) and suspended material (sand, clay, iron, etc).
- Different ways of handling, treating, managing produced water:
  - Surface discharge for beneficial reuse, subsurface injection, reuse for hydraulic fracturing.
- What factors cause the different handling methods?
  - Development strategy (conventional, shale), produced water type, disposal options, water scarcity, regulations, water volumes.
  - Salinity and toxic ions, shearing, oil conc., suspended solids conc., particle size dist., emulsion types.

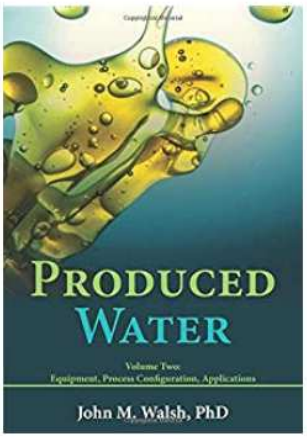
Slide 23

For More Detail –

Amazon search:
"produced water walsh"



Volume 1 Fundamentals: Emulsions, Water Chemistry, Treatment Chemistry, Fluid Mechanics, Sampling & Analysis



Volume 2 Equipment & Applications: Separators, Hydrocyclones, Flotation, Filtration, Process Configuration, WSO, GoM, Solids, Shale, Troubleshooting

Questions / Discussion

25