Understanding the Fundamentals of Water Treatment

The Dirty Dozen

12 Common Causes of Poor Water Quality

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The Produced Water Seminar, January 2001

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ABSTRACT
12 Common Causes of Poor Discharge Water Quality

The key to successfully designing and operating a water treatment system is to first understand the fundamentals of the physics and the chemistry behind the water quality problem. With this understanding, water treatment system designs can be made operationally more robust and problems that develop over time are easier to resolve.

The more common causes of water treatment challenges can be grouped into the following categories:

- Presence of solids (inorganic or organic)
- Excessive or highly varying fluid flow rates
- Gas breakout or slugging in or into process equipment
- Improper chemical treatment programs

This paper discusses several of the more common, often overlapping causes of produced water cleaning problems and suggest means to both identify and resolve those problems by either mechanical or chemical means. Examples are given where the solutions have been implemented a priori in process system designs and in field retro-fits. In addition, some general rules-of-thumb are presented for selecting an appropriate technology for addressing an identified water treatment challenge.

Understanding the Fundamentals of Water Treatment

- If you understand the fundamentals of the physics and chemistry, solving a water quality problem becomes much easier
- Resolving water treatment problems requires
  - A little bit of science
  - A little bit of art
  - A LOT of common sense

Major Contributors to Poor Water Quality - I

1. Upstream separators filled with solids
   (Water quality problems start in the 1st separator)
2. Separators operating outside of their design range for oil, gas, and/or water
3. Recycle streams feeding contaminant laden emulsions to separators
4. Gas slugging below the water line in skimmers or separators

Major Contributors to Poor Water Quality - II

5. Neutrally buoyant, oil coated solids
6. Water soluble, film-forming corrosion inhibitors, especially in fresh waters
7. High shear dispersion of oil droplets, especially as API Gravity increases
8. Excessive or incorrect chemical treatment

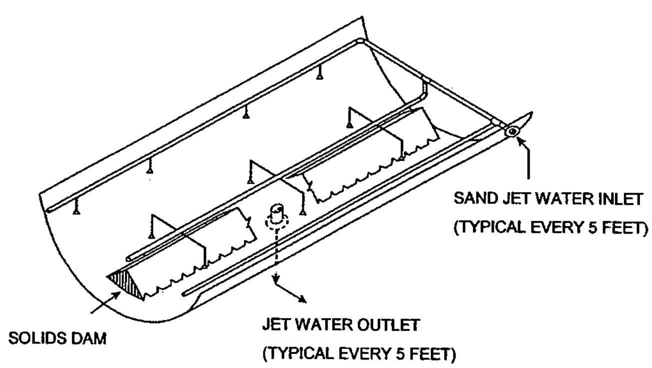
Major Contributors to Poor Water Quality III

9. Ultra-fine scale mineral solids ($CaCO_3$, $CaSO_4$,$FeCO_3$)
10. High concentrations of organic acids in water phase
11. Iron sulfides
12. Highly variable flow rates (e.g., snap acting valves)

Contributors to Poor Water Quality: Solids in upstream separators

- The level of solids can often be detected by feeling tank side for a temperature change
- To Control solids accumulations:
  - Install sand jets and sand pans
  - Automate system to insure its regular use
  - Install desanding hydrocyclones to help remove sand from the produced water or from wash water
  - Sand cleaning systems can, in some cases, reduce oil content to levels which permit disposal in land fills

SAND JETS WITH INVERTED TROUGH

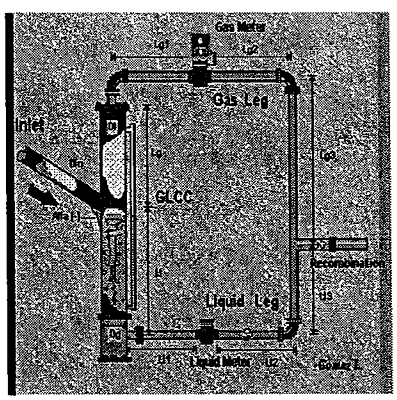


Contributors to Poor Water Quality Separators Operating Beyond Capacity

- Options for significantly increasing separator capacity and improving performance include
  - Install Vortex Tube inlet devices
  - Install Perforated Plates for flow control
  - Use a GLCC to by-pass gas around the separator
  - Convert a bucket & weir configuration to oil-over-weir
  - For oil-over-weir separators, install a distributed water discharge system

GAS-LIQUID CYLINDRICAL CYCLONE (GLCC)

- **Tremendous weight and footprint savings**
- **Inclined inlet piping creates stratified flow**
- **Tangential entry creates centrifugal force and creates vortex inside separator**
- **Separated gas exits top of vessel and liquid exits bottom of vessel**
- **Ideal for test separator applications**
- **Also utilized for two-phase production separators**



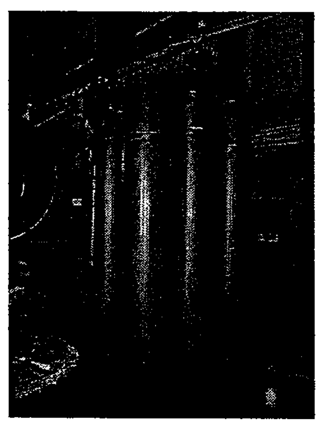
Improving Vessel Hydrodynamics Permits Short Residence Time Separations

- Porta-Test Revolution™ on inlet
  - Contain inlet turbulence
  - Reduce gas carry-under
  - Pre-coalesce emulsions
- Engineered Perforated Plate Baffling
  - Controls liquid short circuiting
  - Contains slug-generated turbulence
- Distributed Water Discharge for Separators with ILC
  - Less oil/water interface disturbance
  - Discharges cleaner water without coning

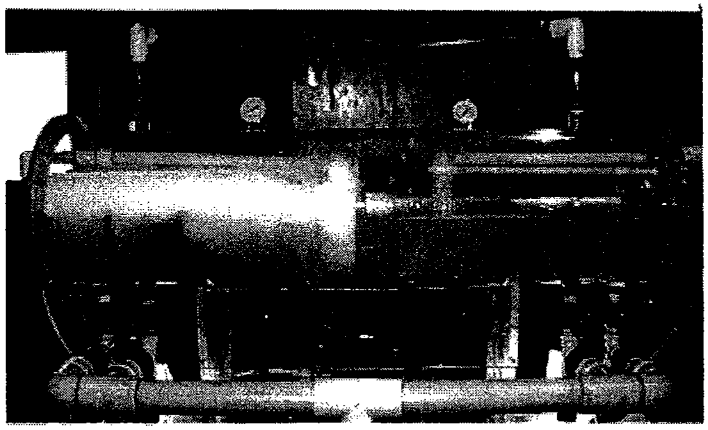
The Porta-Test Revolution™

Revolution

- Eliminate Foam
- Improve Separator efficiency
- Reduce the size of your separation equipment and its required footprint
- Used in horizontal or vertical separators
- Can be designed for any gas-liquid separation
- Always recommended for liquid to gas ratios of 500 (barrels per MMscf) and higher



The Porta-Test Revolution™ Increases Effective Separation Time



Conventional Versus Revolution

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Bucket & Weir Separators

- Advantages
  - Interface level control not required
  - Cleaner water for a given residence time
- Disadvantages
  - Available separation time is lower for a given vessel size compared to spill-over weir type
  - Weir height adjustments require vessel entry
  - Oil pad depth is flow rate dependent
  - Oil pad cannot be adjusted as flow compositions change

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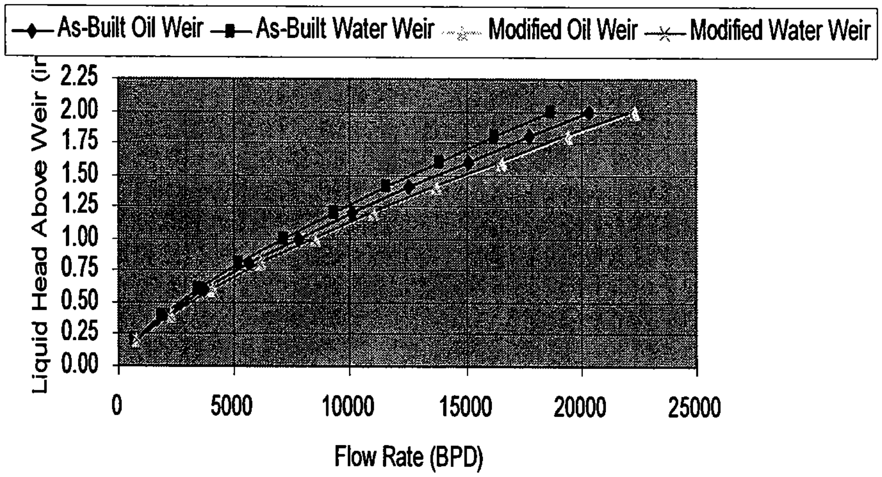
Liquid Head Ht. vs Flow Rate for a Separator with Original and Modified Weir Locations



Calculating the Oil Pad Depth for a Bucket and Weir Separator

Oil Pad Thickness Calculation

A = (Oil weir ht. – Wtr weir ht.)

B = Density of oil / Density of water

Use density at process conditions

Oil Pad Thickness = A / (1 – B)

Note: As a general trend, as oil density increases, oil pad ht increases

Water Crest Height Calculation:

$$Q\ (ft^3/sec) = 3.33\ (L - 0.2\ H_{crest})\ H_{crest}^{3/2}$$

L = length of weir (ft.) H_{crest} = crest ht of wtr over weir (ft.)

Contributors to Poor Water Quality: Recycle Streams

- Once separated, contaminants should be given a positive route for removal
  - Skim tanks
  - Accumulator vessels
  - Secondary hydrocyclone systems
- Recycling solids-laden oil to an upstream vessel generally results in contaminants re-entering the water treatment system
  - The solids loading from recycle streams can easily double or triple the equilibrium solids loading of produced water

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Contributors to Poor Water Quality: Gas Slugging into Skimmers

- Useful numbers for estimating the volume of dissolved gas which is released due to a pressure drop across a control valve or a hydrocyclone:
  - For every 15 lbs of pressure drop in the partial pressure of gas, the following will break out:
    - 0.15 SCF of CH_4 per bbl of water
    - 3.0 SCF of CO_2 per bbl of water

Example: A gas with 90% CH_4 and 10% CO_2 is reduced in pressure from 300 PSIG to 0 PSIG.

The gas released is 18(0.15)+2(3.0) = 8.7 SCF/bbl

(1 bbl = 6.3 ft^3)

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Contributors to Poor Water Quality: Gas Slugging into Skimmers

- Study piping runs to see if break-out gas can accumulate into slugs
  - Risers & down-comers
  - Long horizontal runs
  - Lack of highly turbulent flow
- Catch break-out gas to prevent skimmer upsets:
  - Porta-Test Revolution vortex tubes
  - GLCC external to vessel

PORTA-TEST REVOLUTION IN A SKIMMER REDUCED SKIM OIL BS&W FROM 80% TO < 0.5%

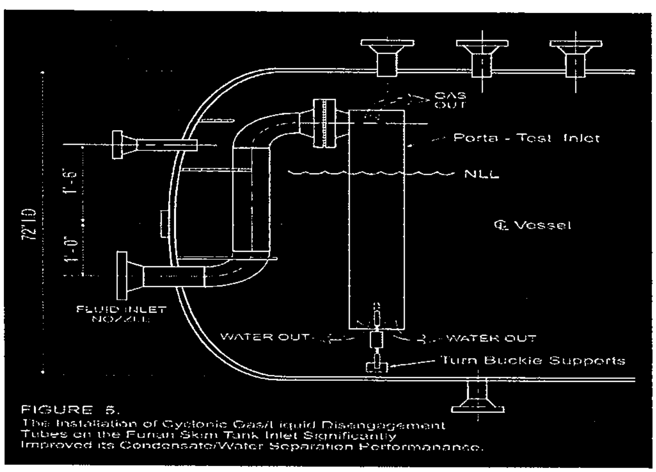

FIGURE 5.
The Installation of Cyclonic Gas/Liquid Disengagement Tubes on the Funan Skim Tank Inlet Significantly Improved its Condensate/Water Separation Performance.

Contributors to Poor Water Quality: Neutrally Buoyant, Oil-Coated Solids

- Must be removed by flocculation and flotation
- High MW polymers are most effective at collecting solids
  - Can be difficult to disperse into water
  - Simple systems are available to easily disperse high MW emulsion polymers into produced water
- Ferric Chloride or Dithiocarbamates are effective solids collectors
  - Both chemicals create heavy flocks that require paddle skimming

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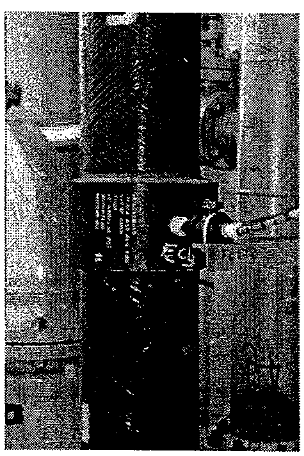
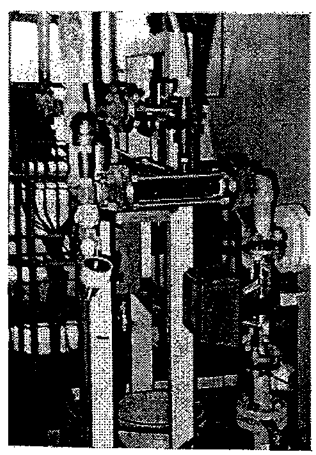
PROPER DISPERSION OF CHEMICALS IS A CRITICAL PART OF WATER TREATMENT



INJECTION POINT FOR CORROSIVE CHEMICAL



MAZZEI® INJECTION FOR CONTINUOUS POLYMER PRE-DILUTION

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Contributors to Poor Water Quality: Corrosion Inhibitors

- Factors favoring dirty water:
  - Use of water soluble corrosion inhibitors
  - Fresh water (<10,000 PPM TDS)
  - High API gravity hydrocarbons (API >45)
  - High CO_2 in gas phase (partial pressure > 5 psi)
  - Presence of fine solids, especially scale mineral particulate <10 microns
- Solutions:
  - Change CI's
  - Minimize use of CI's
  - Coordinate CI's with Mg, Zn, Fe, PEI or other suitable ion.

Contributors to Poor Water Quality: High Shear Dispersion of Oil Droplets

Sources of Oil-Dispersing Shear:

- High pressure drop across control valves
- Pumps
- High velocity flow through pipelines over extended distances

Solution:

- Separate the oil from the water prior to the shearing device
- Hydrocyclones are particularly effective for this service

Contributors to Poor Water Quality Excessive or Incorrect Chemicals

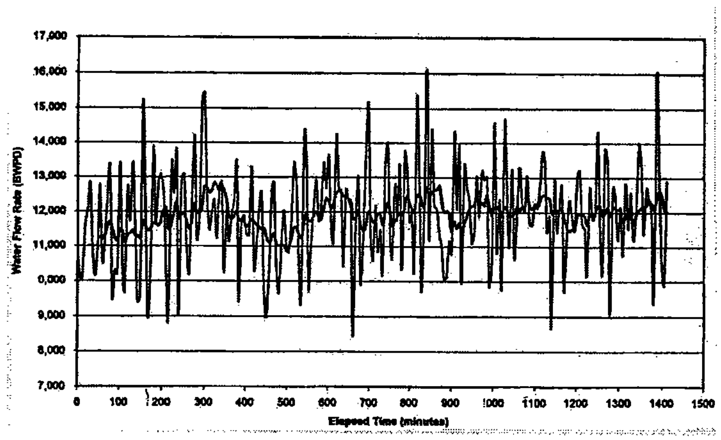
- Over-treating with demulsifier
- Use of water soluble corrosion inhibitors
- Over-treating with certain water clarifiers
- Failure to maintain an effective scale inhibitor program
- Over-treating with or unnecessary use of biocides
- Failure to adjust chemical treat rates to account for variable water flow rates

Contributors to Poor Water Quality: Highly Variable Flow Rates

- Common when long flow lines are present, e.g., from remote platforms or headers
- Deep-water riser slugging
- Snap-acting valves in upstream equipment

- Can result in ± 50% changes in flow rates in the span of 5 – 15 minutes
- Contribute to operator decision to over-treat with chemicals.

Total Water Discharge by Funan CPP vs. Time with 60 min. Running Average Plotted



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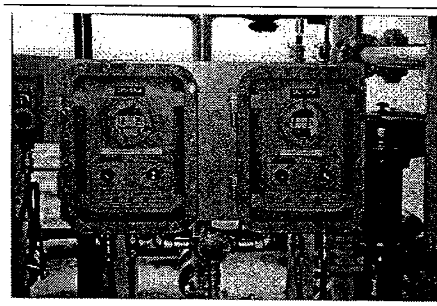
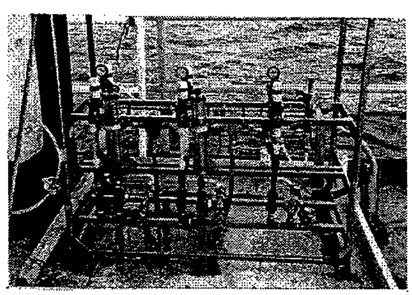
VARYING CHEMICAL INJECTION RATE ACCORDING TO WATER FLOW RATE CAN REDUCE CHEMICAL CONSUMPTION



WILLIAMS WPC-9001-XD CHEMICAL PUMP CONTROLLERS ON FUNAN



CHEMICAL INJECTION PUMPS ON FUNAN

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Contributors to Poor Water Quality: Ultra-Fine Scale Mineral Solids

- Precipitated mineral solids are typically in the 5 - 20 micron particle size range
- Mineral precipitates tend to be oil-wetted
- Most common precipitates include
  $CaSO_4$ $CaCO_3$ $FeCO_3$ $BaSO_4$
- Identify precipitated minerals using XRD
- Carbonate minerals are acid soluble

Contributors to Poor Water Quality: High Concentrations of Organic Acids

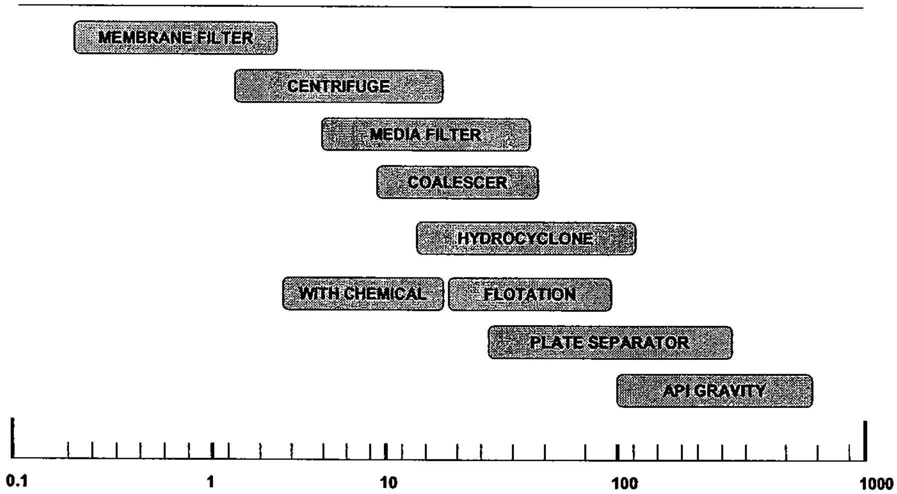
- Common when production is from hot formations
- Naphthenic acids in crude have some water solubility
- Most active in the presence of low concentrations of divalent ions such as Ca^{++}, Mg^{++}
- Requires specialized analyses to find and identify organic acids
- Acetic acid, phosphorous acid, $AlCl_3$, $FeCl_3$ will de-activate the surfactant character of organic acids

Contributors to Poor Water Quality: Iron Sulfides

- Major sources of Iron Sulfides
  - Sour production
  - Sulfate Reducing Bacteria (SRB) activity

- Iron Sulfides often form neutrally buoyant, oil-coated solids
- Dried FeS can be pyrophoric
- Best removed by froth flotation using chemicals specially selected for this service

RANGE OF DROPLET SIZES REMOVED BY VARIOUS TYPES OF DE-OILING EQUIPMENT



Particle Size Helps to Select the Equipment to Recommend

Technology	Removes Particles	
API Gravity Separator	> 150	microns
CPI (Plate pack) Separator	> 40	
Induced Gas Flotation	> 25	w/o chemicals
Induced Gas Flotation	> 3 – 5	w chemicals
Hydrocyclone	>10 – 15	
Mesh Coalescer	> 5	
Media Filter	> 5	
Centrifuge	> 2	
Membrane Filter	> 0.01	

Flotation vs. Hydrocyclones Which should you recommend?

Factors Favoring Froth Flotation

- Highly variable water flow rates
- Low water source pressure
- Treating water from multiple sources at varying pressures
- Oil-coated solids are present
- Flocculent required to generate a coherent skim layer
- Chemically stabilized reverse emulsions present
- Feed water contains < 300 PPM hydrocarbons

Flotation vs. Hydrocyclones Which should you recommend?

Factors Favoring Hydrocyclones

- Feed water contains > 300 PPM hydrocarbons
- High pressure drop across control valves are shearing oil droplets
- Testing shows that water can be cleaned without chemical treatment
- Space or weight constraints are important (offshore)
- Solids contribute to water quality problems

Note: A skimmer or 1-cell DGF/IGF downstream of hydrocyclone is generally recommended

Hydrocyclones: The Simple Rules for Running them Right

- Install an in-line screen ahead of hydrocyclones to catch large solids
- Maintain the PDR (Pressure Drop Ratio) between 1.5 and 2.5
- Maintain a minimum pressure drop across the hydrocyclone (>25 PSI for de-oiling, >10 PSI for desanding)
- For each system, there is a maximum pressure drop, above which efficiency declines due to internal turbulence

Hydrocyclones: The Simple Rules for Running them Right

- Vessel level control valves should be installed downstream of a hydrocyclone
- If possible, avoid pump feeding hydrocyclones
- A simple bench-top centrifuge test can predict the likely performance of a hydrocyclone system
- Install short residence time skimming downstream of a hydrocyclone to collect coalesced oil droplets
- Whenever possible, field test a hydrocyclone liner prior to selecting this technology

Summary and Conclusions

- Water Quality problems start in the 1^{st} separator
- In one way or another, solids often contribute to water quality problems
- Flow slugs resulting from gas breakout must be contemplated in the design of a water treatment system
- Avoid recycle streams
- By understanding the cause of a water quality problem, selection of mechanical and/or chemical means to resolve it is reduced to common sense