DIAGNOSING AND RESOLVING CHEMICAL AND MECHANICAL PROBLEMS WITH PRODUCED WATER TREATING SYSTEMS

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ABSTRACT

An approach is described for diagnosing chemical and mechanical limitations of produced water treatment systems. The methodology is predicated upon the development of a fundamental understanding of the produced water contaminants, the mechanical limitations of installed equipment, and process operations. Examples are presented to illustrate how this fundamental understanding has been applied to identify the causes of and to resolve field problems. In each case the operator was successful at improving the operation of their water treatment systems.

Introduction and Background

Two primary drivers are forcing oil and gas producers to give more consideration to the treatment of produced water. First, water production is increasing as fields mature. The result is that many facilities are required to handle water volumes substantially above the rates for which they were designed. Second, environmental regulations are becoming more restrictive over time. Thus produced water must be cleaner than ever prior to being discharged overboard from a platform or FPSO. Alternatively, regulations require the disposal of produced water by reinjection either into a suitable aquifer or into the reservoir from which it originated. For reinjection, the water quality must often be substantially better than that required for overboard disposal.

For overboard disposal, the US NPDES permits require that Total Oil and Grease (TOG) be less than 29 mg/liter as determined by the gravimetric analytical method US EPA 1664. For the North Sea, the limit is in the process of being reduced from 40 mg/liter to 30 mg/liter as determined by solvent extraction and an IR measurement. Other areas of the world, including much of South America, and West Africa (two very large growth areas for oil production), the TOG discharge limits are <20 mg/liter TOG with the measuring method often not defined.

The cleanliness of water to be injected depends upon the character of the reservoir that will receive the water. For fractured and for carbonate reservoirs, almost no restrictions on water quality are required. However, for sandstone or other low permeability formations, solids removal down to the 2 – 5 micron range may be required. Otherwise it will be impossible to inject substantial volumes of produced water below the formation fracture pressure for substantial lengths of time between expensive well work-overs.

Value of Produced Water

As a “non-revenue” fluid, produced water is generally considered as a cost burden by the operator. However, viewed from another perspective, recoverable reserves can be substantially enhanced if one is willing to produce more barrels of water per barrel of oil recovered. Thus, in one sense, the “value” of produced water can be defined by the volume (value) of incremental oil recovery as a result of water production.

From the disposal side, the “value” of improving the produced water cleaning facilities can be defined by the alternative cost of, for example, injection well maintenance. Often, an improvement in water treating facility performance will pay for itself by avoiding the cost for a single well work-over.

Cleaning Produced Water

There are two interactive aspects of produced water treatment: process hardware and chemical treatment. The selection and operation of process hardware requires knowledge of the chemical and physical characteristics of both the produced water and of the contaminants in that water. Similarly, to properly select a robust chemical treatment program that successfully augments the performance of the water treating equipment, those same chemical and physical characteristics must be known. Table 1 lists key information that is required to diagnose problems with water treating systems.

Much of the information listed in Table 1 is only accessible on the production site itself. The determination of oil droplet size distributions, $CO_3^{=}/HCO_3^{-}$ concentrations, and Total Suspended Solids (TSS) on site is essential. Generally, it is recommended that water samples be pressure filtered directly from a process sample point when possible to avoid subsequent scale mineral precipitation or ferrous to ferric oxidation. Where process pressure is insufficient, laboratory pressure filtration of fresh samples at the field/platform location is far preferable to vacuum filtration.

The design of a gas/oil/water separation process as well as the selection of upstream process hardware is critical for produced water treatment. The diagnosis of a water treating problem and the selection of means to mitigate the problem require

- An understanding of how the mechanical aspects of upstream operations are impacting water quality
- An understanding of the impact that process operating conditions may have on produced water quality
- Knowledge of how the overall process design is impacting water quality. Of particular concern here is the presence of contaminant recycle streams.

The selection of equipment to treat produced water is, for the most part, dependent upon the size distribution of the contaminants to be removed. Table 2 lists commonly used water treating equipment and the oil droplet sizes that are removed by that equipment.

On shore, where space is not an issue, residence time in large tanks is a favored technology. Unfortunately, until recently, the hydraulics of fluid flow through large tanks was poorly understood. Recent studies using Computational Fluid Dynamics (CFD) has revealed much about how water flows through large tanks and suggested designs for tank internals that virtually eliminate this short circuiting.[1] With these designs, fluid residence times in large tanks can be increased from <50% of theoretical to over 90% of theoretical. The CFD studies also show that separating oil droplets <50 microns diameter in these tanks is inefficient.

Offshore, where equipment weight and space must be minimized, the most commonly installed equipment for cleaning produced water is the combination of hydrocyclones and induced gas flotation. Where possible, upstream separator pressure is used to drive water through the hydrocyclones. By installing the hydrocyclones close to the flotation cell, dissolved gas that breaks out of the water as pressure is reduced can be used for the first stage of flotation.

To limit the space required for a flotation cell, single cell vertical flotation units are increasingly popular. One of these designs, illustrated in Figure 1, utilizes both dissolved and dispersed gas in order to effectively provide two stages of flotation in a single vessel.[2] Figure 2 shows a combination deoiling hydrocyclone and induced gas flotation system with a capacity of 40,000 BWPD that is currently operating in the Gulf of Mexico.

Diagnosing and Resolving Water Treating Problems

Table 3 is adapted from a recent article published in World Oil.[3] This table outlines a step by step approach for first identifying the root causes of a water treatment problem and then proscribing a workable and robust solution to the problem.

Example 1

In this example, key fundamental produced water contaminant characterization data allowed an unambiguous solution to a water treating problem to be developed.

An operator requested that a process audit be conducted in order to determine why the deoiling hydrocyclones on his platform were "not working" as expected. Prior to conducting the audit, the operator was asked to conduct a Jorin Analyzer Survey to determine the oil and solids particle size distributions at several points in the process. The Jorin Analyzer is an on-line sampling device that takes several hundred photomicrographs of flowing water. Image analysis software is then used to determine the size distribution independently for oil droplets and solids.

The Jorin survey showed that the oil droplets in the produced water had a median droplet size of 9 to 15 microns and that these droplet sizes persisted from a point just downstream of a high pressure separator operating at about 450 PSIG. The high shear experienced by the produced water across the control valve for this separator generated the small oil droplets which then had insufficient process time to coalesce prior to entering the deoiling hydrocyclones. The hydrocyclones on the platform were of a low efficiency design and were, in fact, performing better than their manufacturer would have specified.

The recommended solution was to replace the low efficiency hydrocyclones with a newer, high efficiency design capable of removing the small oil droplets now known to be present in the produced water.

Example 2

An operator constructed a water treating process on a floating platform that consisted essentially of deoiling hydrocyclones and induced gas flotation. The feed water specification stated that no solids were to be present in the produced water. Unfortunately, this was not the case and the presence of oily solids in the produced water made it all but impossible for the operator to clean the water to <20 PPM TOG. A flow diagram for the process as installed and with a subsequent upgrade is shown in Figure 3.

An audit of the water treating process revealed that fluids from the reject stream of the deoiling hydrocyclones and fluids from the skimming of the IGF were being returned to an upstream separator and recycled through the process. This practice had two significant impacts on water quality. First, fine, oily solids in both of the reject streams were being recycled and sheared into the water phase by pumps and control valves. Second, demulsifier and water clarifier chemicals were also being recycled via the two reject streams. Together, the chemicals and problematic solids were generating interface emulsions that further interfered with contaminant removal.

The solution in this case was to install on the platform, an accumulator vessel to permit oil and oily solids to be removed from the process instead of being recycled. Once the accumulator vessel was installed, it was determined that the location for injection of water treatment chemical could be moved and the treat rate reduced. Subsequent to implementation, the TOG of the overboard discharge water dropped from typical values >30 mg/liter to typical values around 15 mg/liter.[4]

Example 3

An operator installed a new IGF on a floating platform in the Gulf of Thailand. However, when placed into service, the vessel initially appeared to have no impact on water quality. Thus a process audit was requested by the operator in order to ascertain the source of the problem. The audit revealed the following:

- As a result of the presence of methanol in the produced water, there was a high concentration of soluble organics in the produced water, some of which were detected when the water was analyzed by solvent extraction and IR spectroscopy. However, these hydrocarbons were not detected by EPA 1664.
- As in the above example, hydrocyclone and flotation reject streams were being recycled within the process to the detriment of overboard water quality
- The water clarifiers in use did not target the oil-wet scale mineral precipitates present in the water and were thus only marginally effective.
- Water clarifier injection was upstream of a skim tank and was being removed from the system ahead of the IGF. In essence, the performance of the IGF was not augmented by this chemical injection.
- Highly variable water flow rates were experienced as a result of incorrectly sized interface control valves on an upstream separator.

The first action required was to change the analytical method used on the platform so that representative water quality data could be obtained and water quality data could be correlated with other actions and activities on the platform. Next, the contaminant recycle streams were eliminated from the process and control valve sizes changed to match the produced water flow rate. Finally, a higher molecular weight polymer was used as a flocculent water clarifier and this chemical was injected immediately upstream of the flotation cell. The water quality discharged from the IGF over several months time is summarized in Table 4.[5]

Summary

A systematic approach is presented for evaluating the performance of an oil treatment facility and developing recommendations for upgrading performance. The approach is predicated upon first identifying and resolving mechanical issues, then introducing the appropriate process chemistry. Problem solutions are developed based upon an understanding of the fundamentals of both fluid chemistry and process operations. Examples discussed show that this approach can be used successfully to develop recommendations for upgrading process systems. With this approach, investment risk is minimized since the upgrade recommendations are based upon a fundamental understanding of both process capabilities and fluid chemistry.

References

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Table 1. Chemical and physical characteristics of produced water that should be known in order to assess problems with water treating systems

Cation content	Na^{+}, Mg^{++}, Ca^{++}, Ba^{++}, Fe^{++}/Fe^{+++}, etc.
Anion content	sulfate, chloride, carbonate, bicarbonate, sulfide
Organic acids	acetate, proprionate, naphthenic acids
Soluble organics	methanol, other alcohols
Solids	precipitated scale mineral phases formation mineral phases particle size distribution for solids
Dispersed oil	droplet size distribution wax & wax appearance temperature asphaltenes
Upstream chemicals	Corrosion inhibitor, scale inhibitor, biocide, demulsifier, "soap stick", anti-foam, etc.

Table 2. Commonly used equipment for cleaning produced water are listed along with oil droplet sizes typically removed by that equipment.

TECHNOLOGY	**REMOVES PARTICLES (MICRON)**
API Gravity Separator	> 150
Long Residence Time Skim Tanks	> 50
Corrugated Plate Separator (CPI)	> 30
Deoiling Hydrocyclone	> 10
Desanding Hydrocyclone	> 5
Induced Gas Flotation	> 25 without CHEMICALS
Induced Gas Flotation	> 3 with CHEMICALS
Mesh Coalescer	> 10
Nutshell or Media Filter	> 5
Centrifuge	> 2
Membrane Filter	> 0.01

Table 3. A systematic approach is outlined for diagnosing produced water treating problems and developing viable solutions.

1. Review all aspects of a facility's mechanical operations. Fix mechanical problems prior to addressing chemical treating issues

2. Review the facilities process flow diagram to identify issues that may impact water quality, e.g., high pressure drops and contaminant recycle streams.

3. Correlate the appearance of water treating problems with operational practices

4. Take fluid samples for analysis both on site and at a remote laboratory. Jorin Analyzer Surveys have proven to be particularly valuable.

5. Conduct diagnostic tests in the field to understand how the produced water may respond to a particular technology, e.g., sparge tube flotation test.

6. Review data and information developed with operators and asset engineers.

7. Provide relevant data to equipment and chemical suppliers. Work with suppliers to select and test candidate solutions.

8. Where possible, pilot test to confirm proposed solutions prior to committing to the purchase of equipment or a change in the chemical treating program.

Table 4. Water quality discharged from a VersaFlo 1-cell induced gas flotation vessel installed on a spar in the Gulf of Mexico. TOG was measured by EPA Method 1664.

Date	Inlet TOG	Outlet TOG
02-03	52 mg/liter	27 mg/liter
02-03	48	19
02-03	37	13
10-03	47	15
10-03	55	23
01-04		12
02-04		14
03-04		6
04-04		20
06-04		12
07-04		19
08-04		12
09-04		14
10-04		Hurricane Ivan
11-04		low water flow
12-04		13

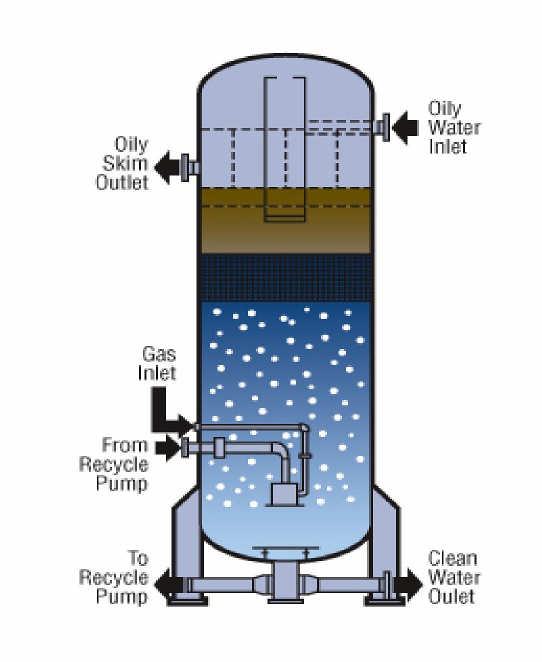

Figure 1. A schematic of a 1-cell VersaFlo IGF that incorporates two stages of flotation in a single vessel.

Figure 2. A 40,000 BWPD water treatment skid is shown that closely couples deoiling hydrocyclones and a vertical IGF vessel.

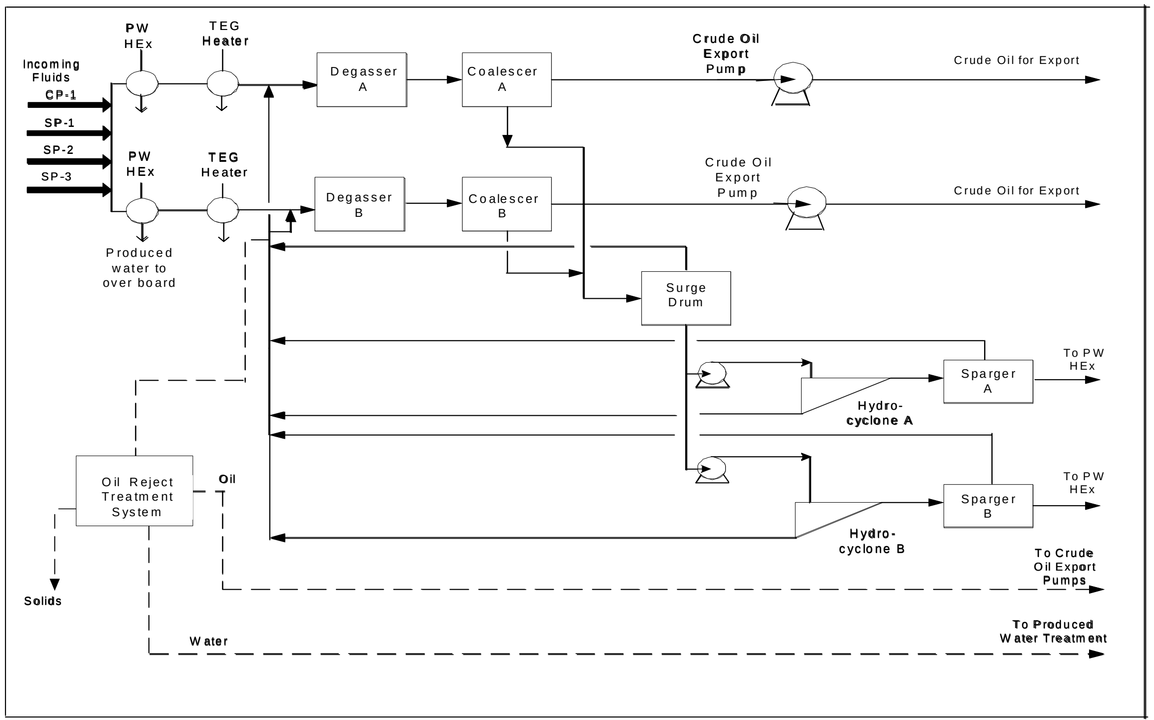

Figure 3. The Process Flow Diagram is shown for a water treatment system before and after the installation of an oil reject accumulation system designed to eliminate contaminant recycle within the process.