SMART WATER DISCHARGE (SWD^{TM}), THE NEXT REVOLUTION IN PRODUCED WATER TREATMENT, PART I

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ABSTRACT

In modern process automation, the Oil and Gas industry is shifting toward Closed-Loop or Feedback process-control automation to constantly maintain the output at a predetermined set point by means of monitoring and controlling the vital process parameters.

Currently, most produced water treatment systems are acting as a non-feedback process or passive feedback control system (i.e. the outcome of treatment does not dynamically or actively influence the process). The development of an effective and dependable Closed-Loop control system is prevented by the lack of a reliable and accurate monitoring system that continuously measures the concentration of contaminates in the process. However, recent developments in Oil in Water (OIW) analyzers encouraged the authors to conduct a profound study on the development of a Closed-Loop System or Smart Water Discharge^{TM} (SWD).

Goal-oriented Smart Water Discharge (SWD) allows the operator to set parameters for oil concentrations in overboard water at specific values (ppm); the Closed-Loop control system adapts the process conditions and/or employs the excursion tertiary water treatment equipment to maintain the set points.

This paper presents the concepts and algorithms of Smart Water Discharge (SWD), the essential components, the priority of a control system, the control functions, and operator-SWD interactions. Furthermore, the authors illustrate the results of field and lab testing for each component providing valuable information on selection and design of the system (including OIW analyzers, logic controllers and controlling elements).

1 INTRODUCTION

Produced water, an oilfield waste, is underground water containing organic and inorganic contaminants that has been brought to the surface as a result of oil and gas exploration and production. This wastewater is the largest portion of byproduct fluid produced in oil and gas production [1]. Water to hydrocarbon ratio increases during the lifetime of a reservoir; therefore, the demand is increasing for the Oil and Gas industry to find an effective and efficient treatment processes for the removal of oil from large quantities of water. According to Clark and Veil [2] the total amount of water produced in the U.S. in 2007 was 21 MMMbbl/year with respect to 1.75 MMMbbl/year of oil and 24 MMMMscf/year of gas production. The same authors showed that the production of water, oil and gas in Louisiana is 1.15 MMMbbl/ year, 52.5 MMbbl and 1380 MMMSCF/year, respectively. Specifically, they determined the correspondent values for water, oil and gas production in Louisiana and Texas offshore area are 587 MMbbl/year, 467 MMbbl/year and 2.79 MMMMSCF/year, respectively [2].

The existence of toxic materials in produced water has motivated researchers to demonstrate that oil and gas wastewater has an alarming effect on the environment. Therefore, strict regulations have been established to curtail environmental disasters due to discharge of concentrated toxic materials.

Based on the Louisiana regulation for wastewater management (onshore), established by the National Energy Technology Laboratory (NETL) which is part of the U.S. Department of Energy (DOE) National Laboratory System, the treated water is required to meet the maximum runoff value of 15 ppm for total produced hydrocarbon (TPH) in order to be disposable [3]. The offshore regulation in Texas and Louisiana coastal areas, established by the Environmental

Protection Agency (EPA), necessitated oil and gas companies to limit their daily effluent TPH to 42 ppm and a monthly (30 days) average of 29 ppm [4].

Now more than ever, environmental issues are a main concern for the Oil and Gas industry. A production company's demand for reliable treatment systems that can continuously maintain the TPH below effluent limit is steadily increasing.

Smart Water Discharge (SWD) operates on the premise that discharge exceeding government regulations is preventable and controllable. The system allows the operator to anticipate unforeseen events by continuously monitoring the TPH level, and reacting to the changes accordingly.

In this paper the concept and algorithms of Smart Water Discharge (SWD), the essential components, the priority of control systems, the control functions, and the operator-SWD interactions will be discussed in detail.

2 LITERATURE

Control theory is an interdisciplinary branch of engineering and mathematics that deal with the behavior of dynamical systems with inputs. When the output variables of a system need to follow a certain value(s) over time, a controller manipulates the inputs to a system to obtain the desired effect on the output of the system (Figure 1).

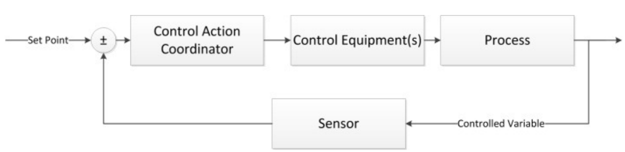

Figure 1. General process control philosophy

Produced water treatment (PWT), is a multi-stage process that utilizes a series of physical, chemical and thermal phenomena to separate contaminates to a point that water will be in compliance with environmental regulations. The process is dynamically being affected by changing the operating conditions, including, change in flow rate, inlet TPH fluctuation, droplet size alteration, and chemical injection type and rate change, or any other disturbance that affects the performance of the PWT. However the end results of the process which is the cleanliness of the water shall remain in compliance with regulations. Therefore, one can say PWT is a highly dynamic process which needs to and has to be controlled for prevention of NPDES (National Pollutant Discharge Elimination System) violation. This control can only be achieved through frequently (or continuously) monitoring the process and reacting appropriately in the case of disturbances (Upsets).

2.1 Definitions and Abbreviations

For the sake of clarity of the concept, the authors dedicate this section to define the key words which will be used frequently in later sections

Feedback Control maintains a desired process condition by measuring that condition, comparing the measurement with the desired condition, and initiating corrective action based on the difference between the desired and the actual conditions. In other words, a control in which a measurement is compared to a set point to produce an error signal. This error is acted upon in such a way as to reduce the magnitude of the error. [5]

Controlled Variable: The variable that is detected to originate the feedback signal for the controller. Depending on the nature of controlled variable, a specific sensor will be used to measure under discussion variable. [5]

Sensor: An input device that provides a usable output in response to the input measurand. The measurand is the physical parameter to be measured. Herein, Sensor is only being used to measure the Controlled Variable. [5]

Control Action: For a controller, the nature of the change in the output of the controller, which is affected by the controller's input. [5]

Proportional Control Action: A control action in which there is a continuous linear relationship between the controller's output and its input. [5]

Derivative Control Action (D): A control action in which the controller output is proportional to the rate of change of the input. [5]

Integral Control Action (I): A control action in which the controller output is proportional to the time integral of the input. In this case the rate of change of the controller output is proportional to the input. [5]

Optimizing Control: Control that does not hold the controlled variable constant but seeks and maintains a value of the controlled variable that will result in the most advantageous operation of the process. [5]

Damping: The progressive reduction or suppression of oscillation in the response of a control system. [5]

Error: The difference between the measured signal and the set point. A positive error denotes that the indication of the instrument is greater than its set point. [5]

Proportional Gain: The ratio of the change in the output of a controller with proportional action to the change in the input of the controller.

Response Time: The time it takes for the output of a device, resulting from the application of a specified input under specified operating conditions to move from its initial value to within some specified percentage of its final steady-state value. [5]

Set Point: An input variable of a controller that sets the desired value of the variable that is being controlled. [5]

Time Constant: If a first-order system is responding to a step or an impulse, T is the time required to complete 63.2% of the total rise or decay. In higher-order systems, there is a time constant for each of the first-order components of the process. [5]

Dead Time (Lag Time): The time interval between the initiation of an output change or stimulus and the start of the resulting observable response. [5]

Transfer Function: A statement of influence of an element or system, in a mathematical, tabular, or graphical form. This influence can be that of an element or system on a signal or action, which is compared at input and output terminals. [5]

Process Upset: Any changes in the process that affect the controlled variable.

Induce Gas Floatation (IGF): Induced Gas Flotation (IGF) is a water treatment process that clarifies wastewaters (or other waters) by the removal of suspended matter such as oil or solids. The removal is achieved by injecting gas bubbles into the water or wastewater in a flotation tank or basin. The small bubbles adhere to the suspended matter causing the suspended matter to float to the surface of the water where it may then be removed by a skimming device. [6]

Operating Expenditure (OPEX), Capital Expenditure (CAPEX): OPEX is an ongoing cost for running a product or system; its counterpart, a capital expenditure (CAPEX), is the cost of developing or providing non-consumable parts for the product or system. [7]

Oil in Water (OIW) Analyzer herein is referred to a sensor which continuously measures the oil concentration in the water stream and sends the measured value to a Control Action Coordinator.

Programmable Logic Controller (PLC) is a digital computer used for automation. PLC manipulates the virtual or real inputs through multiple mathematical formulas and logical processes to control equipment, accordingly.

Excursion Filter herein is defined as a side filtration vessel which receives a portion of the total produced water flow to reduce the TPH to less than 5 ppm.

Total Petroleum Hydrocarbons (TPH) is the weight ratio of all hydrocarbons present in a mixture to the total weight of the mixture. TPH usually is measured in PPM, in PWT.

Human Machine Interface (HMI): Human-machine interface is the part of the machine that handles the interaction of the operators with a computer in a user-friendly manner.

Flux Rate (F): In filtration science, the flux rate is defined as the maximum flow rate per unit area of the filter where the separation efficiency and media sorption efficiency are more than 95% of maximum efficiency.

Absorption Capacity (C_A): In filtration science, absorption capacity is defined as a maximum weight of contaminates that filter absorb per weight of media before break through.

Retention Time (T_R): a measure of the average length of time that a virtual massless particle remains in a specific process.

Pressure Differential Ratio (PDR): the ratio of Inlet - Reject (oil outlet) differential pressure and the Inlet - Outlet differential pressure in hydrocyclones. Normally, PDR is a number between 1.6 to 2 depending on the operating conditions and internal design of equipment.

De-oiling Hydro-Cyclones (herein Hydro-cyclones): Hydrocyclones are equipped with multiple liners or Separators; each fitted in a Liner plate and equally spaced apart across the perimeter of the vessel. Fluid enters our deoiling hydrocyclone through the involute inlet. Its velocity is converted into tangential velocity in the inlet area, thereby creating a centrifugal action. As the fluid moves down the conical section, tangential velocity progressively increases. The water phase, which is subjected to higher centrifugal forces, moves to the outer wall of the cyclone. The lighter phase (oil droplets), are moving toward the inner core of the cyclone. The water phase exits the deoiling hydrocyclone as underflow. The core of the light phase, which is oil, moves axially up the cyclone, due to back pressure on the underflow, and exits out the reject orifice as overflow.

3 CONTROL IN PRODUCED WATER TREATMENT PROCESS

In order to be in-compliance with discharge water quality regulations, a proper control strategy or automation is required. The main cause of overboard water quality issues is uncontrolled conditions which results in Human Error or late response to an upset in the process.

"The only method to eliminate or reduce the human errors and synchronize the response with the upset is proper automation, continuous monitoring and proper Human-Machine Interaction."

Smart Water Discharge (SWD) is a combination of continuous TPH surveillance, regulation of controlling factors (such as retention time, chemical concentration, excursion filters) and Human-Machine interaction to eliminate the water quality issues and automatically adapt to the upset conditions while reducing the OPEX of PWT.

The system consists of three essential components (Sensor, Controller Equipment, and Control Action Coordinator) and multiple auxiliary elements. Smart Water Discharge (SWD), similar to any other feedback control system, utilizes the Sensor to measure the controlled variable (TPH Concentration), accordingly, the Control Action Coordinator compares the measured value with the set point and decides on the appropriate control action to be used, based on pre-determined priority list. The proper control action activates Controller Equipment in the direction that causes the convergence of the controlled variable to the set point or minimizes the error. In other words, the Smart Water Discharge (SWD) control system utilizes an Oil in Water (OIW) analyzer to measure the TPH concentration in water (PPM) and a Control Action Coordinator (CAC) decides on the appropriate action that needs to be taken to prevent undesirable discharge water quality. As the primary control action, the CAC employs the main Controller Equipment, Excursion Filter Vessel, to clean a portion of water and dilute the main stream to achieve a desirable set point. Then Smart Water Discharge (SWD) activates a series of optimization processes to return the process to the original stage (Figure 2).

This section describes the control process in details and clarify the control concepts and primary design criteria of each component.

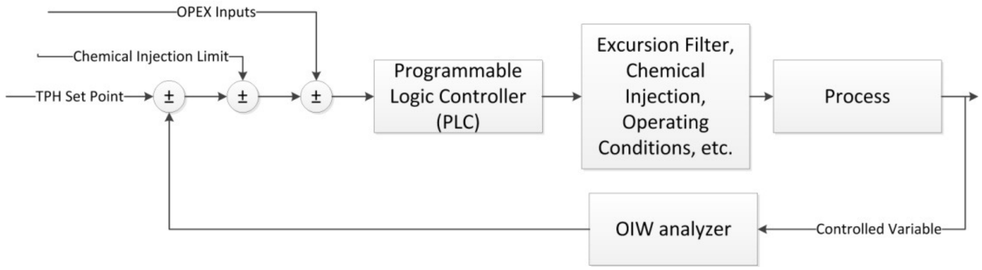

Figure 2. Smart Water Discharge (SWD) process control philosophy

3.1 Sensors

3.1.1 OIW Analyzer

One of the main components of SWD is an OIW analyzer as the sensor. The OIW Analyzer should have the capability to provide constant, online monitoring of oil and grease content in overboard water and send a continuous signal to CAC. The following criteria should be considered in the design and of OIW analyzer:

- The sensor should be placed in proper location that represents correct TPH of the overboard water.
- The sensor should have reasonable accuracy over the range of possible TPH. It should be designed to have the maximum accuracy in ±25% of the regulatory limit.
- The sensor should continuously measures the controlled variable (TPH).
- OIW analyzer should be free to low maintenance with reliable and repeatable output.
- Any fault in the sensor should be reportable with a proper code to CAC.
- The analyzer should be self-cleaning. The self-cleaning procedure should be tested at operating conditions for effectiveness. The self-cleaning procedure is essential to maintaining accurate measurements of TPH.
- Undesirable events, such as human interference, should be alarmed to CAC with the proper code.

3.1.2 Control Action Coordinator (CAC)

Control action coordinator receives the controlled variable and additional variable that might have an influence on the process. The processor utilizes a pre-loaded algorithm and select between pre-determined control actions to manage the upset condition and maintain the water quality in-compliance (Figure 3).

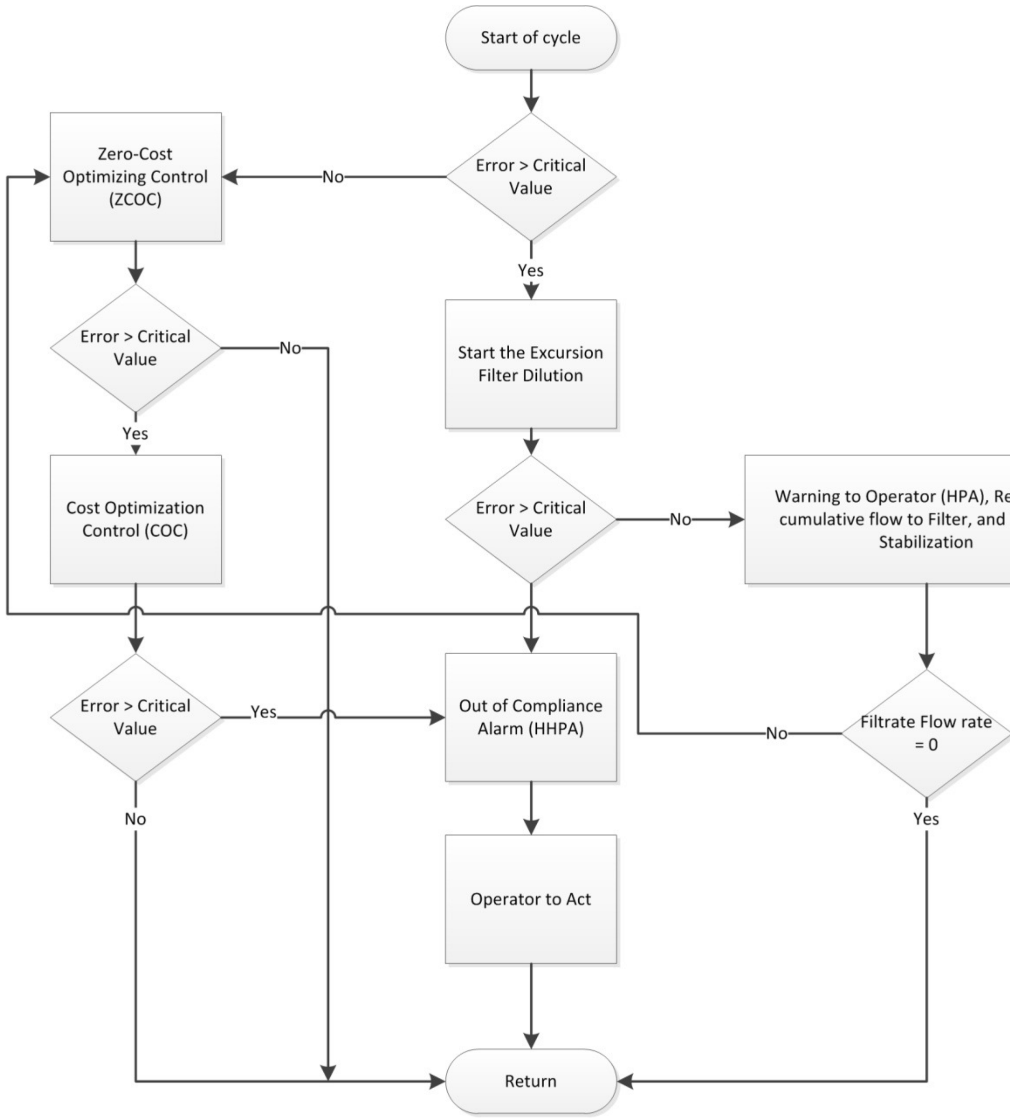

Figure 3. Smart Water Discharge (SWD) general operation algorithm

When the CAC senses a signal from the OIW analyzer that shows the error is higher than the normal operating value, it starts the control process primarily by preventing the non-compliance in overboard water quality by controlling the fractional flow rate to an excursion filter. The fraction will be determined by PID control action to maintain the commingled water quality at the set point. After stabilization of the TPH concentration in commingled water, the CAC starts the Zero-Cost Optimizing Control (ZCOC) with the goal of minimizing the filtrate flow rate. Simultaneously, the operator will be warned about current status of the control system. Generally, ZCOC is only effective in low intensity process disturbance.

If the ZCOC was unable to return the filtrate flow rate to zero, CAC will commence Cost Optimizing Control (COC). The algorithm employs series of cost evaluation mathematical formula to minimize the OPEX (Appendix I) for PWT. At each stage of the CAC will properly interact with the operator to inform him about the current status of SWD. If SWD for any reason was unable to keep the TPH in compliance an alarm will be sent to HMI. At each stage operator commands will override the COC pre-loaded algorithm.

3.1.3 Primary Controller Equipment

The excursion filter vessel is an essential component of SWD which can be considered as the primary response to water quality upset. A short dead time controller is required to regulate the upset condition immediately before optimizing controls start.

Filtration is a mechanical or physical operation which is used for the separation of one phase from another by interposing a medium through which only one phase can pass. Generally, filters utilize one of below four mechanisms to separate the undesirable phase (or hydrocarbons) from desirable phase (or water).

1. ***Adsorption*** is the adhesion of hydrocarbons to the surface of filter media. This process creates a film of the adsorbate (hydrocarbon) on the surface of the adsorbent (filter). Nut shell filters are the most common adsorption filtration process in PWT.
2. **Absorption** is a physical phenomenon or a process in which molecules enter some bulk phase. The molecules undergoing absorption are taken up by the volume, not by the surface (as in the case for adsorption). Activated carbon in granular or powder form are the most common absorption filters in PWT applications.
3. ***Membrane*** filter is a thin, film-like structure that separates two fluids. It acts as a selective barrier, allowing water to pass through, but not hydrocarbons. Membrane filtration is based on the size segregation phenomena. Normally the hydrocarbon contaminates are larger than 1 micron, therefore a membrane with pores smaller than 1 micron can efficiently remove the hydrocarbons.

The excursion filter has to be designed properly and in according to the operating conditions of the process. For proper operation of SWD, the filter size should be designed to dilute the water to a degree that commingled water TPH remains at set point in extreme upset conditions. The equation below can be used to determine the design flow rate of excursion filter vessel.

$$Q_F = \frac{TPH_{Max} - TPH_{SP}}{TPH_{Max} - TPH_F} Q_T \tag{1}$$

The bulk media filter dimensions can simply designed by following equations

$$D_V = 2\sqrt{\frac{Q_F}{\pi F}} \tag{2}$$

$$H_V = R_T \times F \times E_F \tag{3}$$

For canister design filters, number of canister can be calculated from following equation

$$n = \frac{Q_F}{2\pi R_m \times F \times H_C} \tag{4}$$

Where,

$$R_m = \frac{R_O - R_I}{\ln(\frac{R_O}{R_I})} \tag{5}$$

Membranes can simply designed based on the design flux rate of the components. The sizing calculations are highly dependent on the characteristics of the membrane.

As it was discussed in the previous section, the fractional flow rate will be controlled using PID control action and by utilizing a 3-way diverting control valve.

3.1.4 Zero-Cost Optimizing Control (ZCOC)

ZCOC is an optimizing control that reduces the controlled variable (TPH) without affecting the OPEX of the process (Excluding the filter media expenditure). Optimization of the process means, to enhance the performance of the system while maintaining safety and product quality. The criteria for optimization vary with the control algorithm in each case.

A multi-variable non-linear optimizing control will apply to the SWD process to either minimize the fractional flow rate to filter or improve to overboard water quality.

ZCOC usually controls a combination of the following variables to achieve its goals.

1. *Alter the water/oil interface at three phase separator*: SWD control system modifies the oil/water interface at pre-determined range to decrease the TPH at effluent water. However, the interface shall not affect the oil quality.

Therefore, the range should be selected properly to prevent excessive water in the sales line.

2. *Altering the reject rate of gravity and/or flotation separator:* The water level in oil water separator determines the reject (spill-over) rate. Which highly affect the efficiency of the unit, however, higher reject rate increases the total throughput of the PWT.
3. *Controlling the pressure differential ratio in hydro-cyclones:* SWD by controlling the Pressure differential Ratio (PDR) in the pre-determined range, optimizes the performance of the hydro-cyclones and adopts to the governing operating conditions.

3.1.5 Cost Optimizing Control (COC)

After each cycle of ZCOC, SWD conducts a secondary optimization with the goal of minimizing the Operating Expenditure (OPEX) of the process (See Appendix I for OPEX estimation). This optimization mainly balances the chemical injection rates and filtrate rate to minimize the total associated cost, while maintaining the chemical injection dose rate.

Long Dead Time in both COC and ZCOC implicates the control action philosophy. Normal control actions, such as P, PI, or PID, would have a long damping periods or in extreme cases they will diverge and produces an unstable response. In other words, long retention time in produced water equipments causes long phase lag between input and output of the CAC and eventually results in a longer stabilization period or might cause divergence in the controlled variable (TPH).

Dead time is a major constraint in any control system. The effect of dead time is comparable to driving a car (the process) with closed eyes and the steering wheel disconnected. The goal of good control system design should be to minimize the amount of dead time (if possible) and to minimize the ratio of dead time to time constant. The higher this ratio, the less likely it is that the control system will work properly, and once the ratio reaches 1.0, control by traditional PID strategies is unlikely to work at all. In such a case the traditional control action should be replaced by control based on periodic adjustments, called sample-and-hold type control (see Appendix II), or Artificial Neural Network (ANN) (Appendix III).

4 FIELD AND LABORATORY TEST RESULTS

A series of field and laboratory pilot tests were conducted to evaluate the performance of different filtration methods for SWD application. The main objective of the tests were to evaluate the effects of extreme conditions such as high operating temperature, asphaltic contaminates, and high influent TPH on the performance of each component and to estimate the capacity and efficiency of the media in separation of hydrocarbons. The field test was performed on Granular Activated Carbon and Silica-base Glass in bulk media form, and media X in cartridge form.

Additionally, a laboratory tests were conducted on ceramic membranes to investigate the effect of high saline water on performance of the membrane, the efficiency of the filtration, frequency of membrane backwash, and a maximum flux rate before continuous pressure build up.

Furthermore, to evaluate the reliability, accuracy, and maintenance requirements of the sensor, a two month trial of the OIW Analyzer (Advance Sensor EX-100) was conducted in very harsh operating conditions.

The following sections explain the results of each trial.

4.1 Field Test

The field test was conducted at Offshore, California. The purpose of the test was to determine the effect of extreme operating conditions on SWD components (Sensor and excursion filter vessel).

4.1.1 Operating Conditions

Understudied platform was located three miles off the coast of Hermosa Beach, California. The platform produced water treatment system consists of a three phase separator, a degasser vessel, and a vertical IGF vessel.

The produced water contains high concentrations of asphaltenes and wax which can easily cause plugging in equipment. Because of the natural tendency of asphaltinic components to adhere to a solid surface, the sensors would require a powerful self cleaning procedure to clean the lens, effectively. The high temperature of water (180-190° F) and abundance of Hydrogen Sulfide in the stream will create highly corrosive condition, which could affect the operation of the analyzer over time.

The filter test columns and OIW analyzer were situated at downstream of the three phase separator, in order to receive a high TPH concentration and emulate the upset conditions downstream of the float cell.

4.1.2 Sensor (OIW Analyzer)

The Advanced Sensor OIW (EX-100) analyzer was located at downstream of the three phase separator. The OIW-analyzer uses automatic ultrasonic cleaning. The Ultrasonic transducer performs two functions; it cleans the sapphire windows ensuring that measurements do not deteriorate and homogenizes the sample to ensure accurate measurement data. A sound wave is passed along the sensor head and through the sapphire window. Cavitation on the surface of the window causes tiny bubbles of water to burst, effectively jet washing the sensor head. As every produced water setup is different, the intensity and frequency of the ultrasonic bursts can be varied to cater for the effects of different concentrations, oil types, flow rates and temperatures.

An abundance of asphaltines requires high power ultrasonic which runs more frequently to effectively clean the lens, laser and chamber.

After establishing the self-cleaning parameters during the trial period, the ultra-sonics performed efficiently and kept the sapphire lens clean. The efficiency of the self-cleaning was verified by opening the sample chamber after three days of operation and visually inspecting.

The accuracy of the measurements was periodically checked using gravimetric and IR measurement and reported as an average of 9% accuracy. Figure 4 represents the TPH trend at the filter testing period.

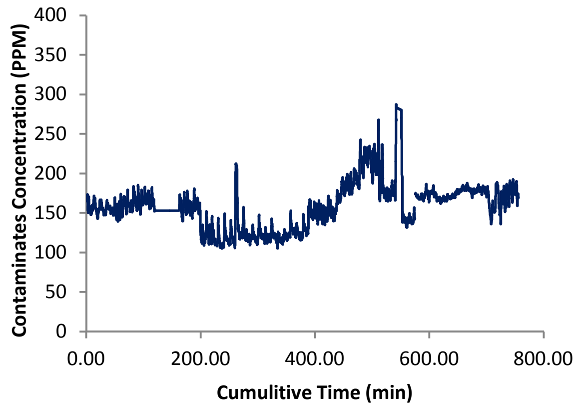

Figure 4. Inlet concentration to all filters, the data were measured by Advance Sensor OIW analyzer EX-100

4.1.3 Granular Activated Carbon (GAC)

Activated carbon has been used for decades in wastewater treatment operations. It effectively removes many organic chemicals, in part due to its very large surface area.

The test was conducted using 6"OD X 18" test column. The column was filled with 8 pounds of 8X30 mesh GAC. The produced water was passed through the media in a down-flow configuration; the test column was equipped with bleed valve at the top of vessel to release trapped gas. Figure 5 shows the configuration of all three filters.

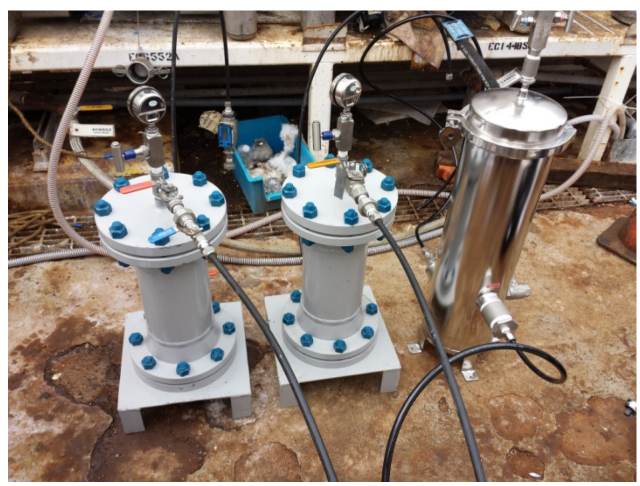

Figure 5. Filter test setup, on right cartridge filter, middle Silica-base Glass bulk media and left granular activated carbon in bulk media form

Outlet concentration was measured periodically by handheld Advance Sensors (HD-1000) and the accuracy of the sensor was confirmed by the IR unit (Wilks) in multiple trials.

According to the test results, GAC performed efficiently for 240 Minutes (4 Hours) which is equivalent to the treatment of 75 gallons of produced water at an average hydrocarbon concentration of 159 ppm. As it illustrated in Figure 7, after three hours of filtration the pressure drop across the media increased significantly and after four hours of flow the media plugged completely. Activated carbon showed total of 1.6% absorption capacity at the separation efficiency of 99%-100%.

In addition to low absorption capacity and plugging issue, ETS observed that high water temperature causes disintegration of carbon grains which darken the filtrated water color (Figure 6).

Figure 6. Water sample from Inlet Water (Left) and Activated Carbon Outlet (Right)

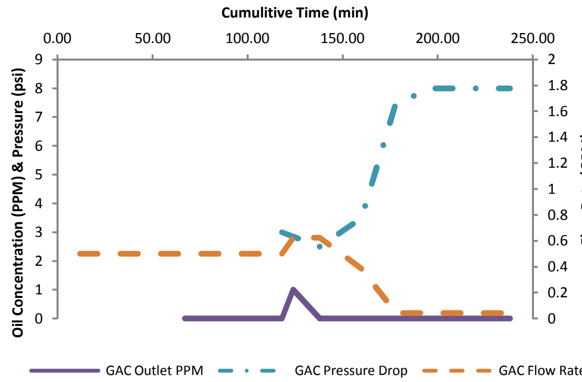

Figure 7. Flow rate, Pressure Drop and outlet TPH trend at GAC test column

4.1.4 Organically Modified Silica Media

Organically Modified Silica media was tested in an identical test column as GAC at the same operating conditions. According to the test results, even after 800 minutes of run time and treating approximately 600 gallons of produced water, Organically Modified Silica media still maintained overboard discharge quality at an average hydrocarbon inlet concentration of 157 ppm. As is illustrated in Figure 8, after 12 hours of filtration the pressure drop across the media increased significantly and after 12.5 hours of flow the media fully plugged. The limiting factor on all medias tested was plugging. The media shows 12.8% sorption capacity, however it was not fully saturated due to non-uniform flow path. Additional optimization is required to maximize the Sorption capacity of media. The Organically Modified Silica Media achieved 98.7%-99.3% removal efficiency for the first 400 minutes of testing, comparable to the GAC performance but with 2 times the operating time / volume treated.

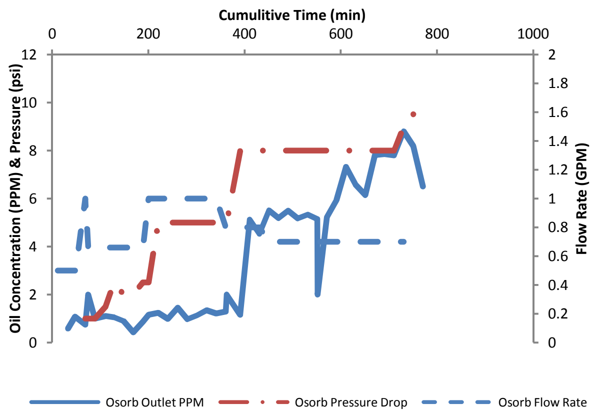

Figure 8. Rate, Pressure Drop and outlet TPH trend at Organically Modified Silica Media test column

4.1.5 Cartridge Filters

Cartridge filter housing contained five 2.7" OD X 20" cartridges. The produced water was introduced into the vessel from the bottom and passed through the cartridges at the inward radial flow pattern. According to the test results, Cartridge Filters performed for 480 Minutes (8 Hours) which is equivalent to treatment of 325 gallons of produced water at an average hydrocarbon concentration of 167 ppm. Cartridge Filter shows the separation efficiency of 83%-98%. The main reason behind unsatisfactory performance of cartridge filters was the saturation of the top section of cartridges where oil pads were formed and caused contact of cartridge with free oil and short circuiting of contaminates through cartridge filters. The authors recommend to change the internal structure of the vessel to have an oil collection reservoir to remove the oil pad before reaching the cartridge and causing local saturation of media. Therefore, the results obtained from cartridge filter are invalid and cannot be used for decision making and analysis.

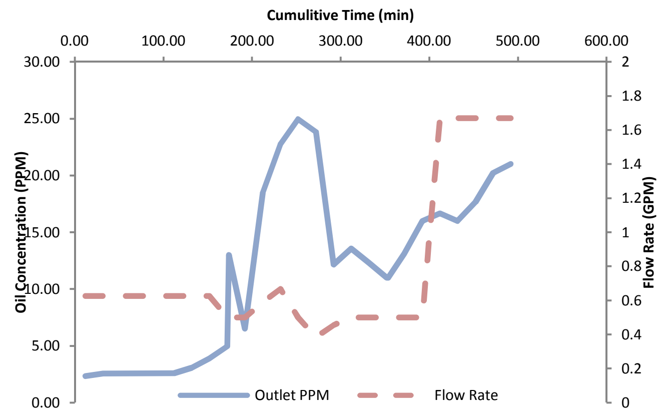

Figure 9. Cartridge Filters Results

4.2 Ceramic Membrane Laboratory Test

The membrane used in the study is a hydrophilic 100% alumina ceramic material. The microstructure contains a tight filtration layer and a porous support layer. The pore size is 0.1 micron. The flat sheet submerged membrane elements utilizes an outside to in the flow path, trapping oil and solids on the surface. A continuous scrubbing from gas bubbles and periodic backwash keeps the membrane surface clean. A periodic chemical back wash is required to remove high adhesive contaminants. A backwash uses filtered water in a reverse flow direction to force material off of the surface of the membrane (Figure 10 and 11). Authors currently in testing different filtration strategy for ceramic membrane to optimize the performance, durability, and minimize the chemical back wash.

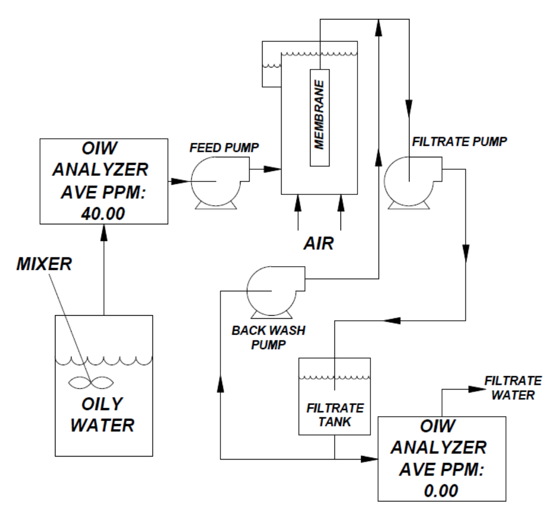

Figure 10. Experiment flow diagram

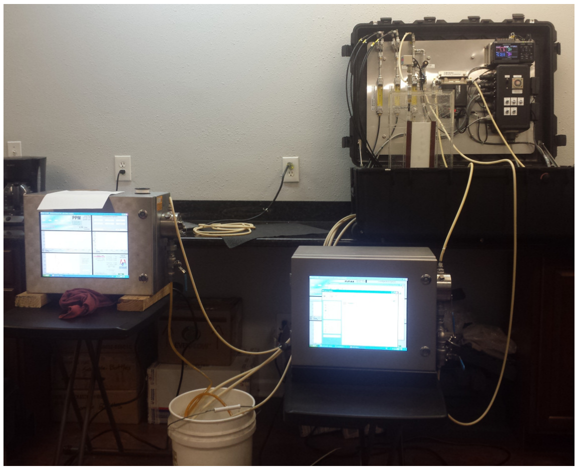

Figure 11. Experiment Setup

5 CONCLUSIONS

This paper presents primarily, a new concept to control the TPH of overboard water and optimize the produced water treatment actively. The control system will prevent any upset or noncompliance condition caused by operational issues or human error. As the secondary goal of this paper, a proper control algorithm was developed to overcome possible upset conditions and overcome the major issue of long dead time using an Artificial Neural Network and a Sample-And-Hold Control Action.

As the tertiary goal, authors conducted a series of field and laboratory tests to investigate the best options for each component of Smart Water Discharge (SWD).

The results of the test demonstrated that Advance Sensor OIW analyzer can perform reliably with no major operational issues and acceptable accuracy.

Based on the filter test results and observations, Organically Modified Silica media was selected as the most effective media for use in an excursion filter vessel.

6 ACKNOWLEDGMENT

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Authors are greatly thankful of Produce Water Society (PWS) to provide the opportunity to release this information.

7 COST OPTIMIZING CONTROL PHILOSOPHY

The formula and procedure for Cost Optimization Control is proprietary to Enviro-Tech Systems and they cannot be released prior to approval of the patent.

8 APPENDIX II: SAMPLE-AND-HOLD CONTROL ACTION

When the dead time of a control loop exceeds the time-constant of that loop, the conventional PID algorithms cannot provide acceptable control. This is because the controller cannot distinguish between a nonresponsive manipulated variable and one that is responding but whose effect cannot yet be detected because of the transportation lag (dead time) in the system. This lack of response to a change in output during the dead-time period causes the controller to overreact and makes the loop unstable. For such applications the sample-and-hold type algorithms are used. These algorithms are identical to the previously discussed PID algorithms except they activate the PID algorithm only under stable system conditions. After the output signal (*m*) is changed to a new quantity, it is sealed at its last value (by setting the measurement of the controller equal to its set point) and it is held at that constant value until the dead time of the loop is exhausted. When the dead time has passed, the controller is switched back to automatic and its output (*m*) is adjusted based on the new measurement it “sees” at that time, using the PID algorithm. Figure 12 shows how these periods of manual and automatic operating modes are alternated. A timer sets the time period for which the controller is switched to manual. The timer setting is adjusted to exceed the dead time of the loop. The only difference between conventional PID and its sample-and-hold variety is in the tuning of the loops: the sample-and-hold controller has less time to make the same amount of correction that the conventional PID would and therefore needs to do it faster. This means that the integral setting must be increased in proportion to the reduction in time when the loop is in automatic.

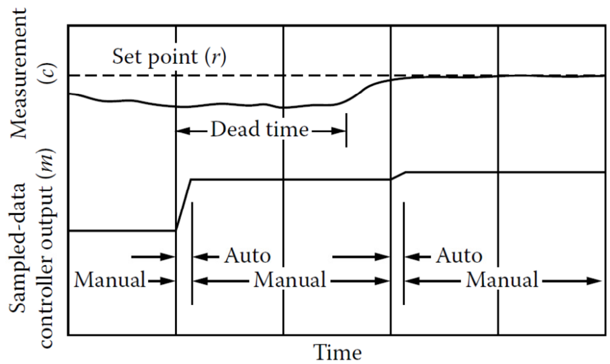

Figure 12. Sample-and-hold controllers are periodically switched from manual to automatic and back again. They are used mostly in dead time processes. [5]

9 APPENDIX III: ARTIFICIAL NEURAL NETWORKS (ANN)

Neural networks can be used to solve highly nonlinear control problems.

A neural network is a system with inputs and outputs and is composed of many simple and similar processing elements. The network consists of an input layer, hidden layer which might divides to several sub layers, and an output layer. [8] The processing elements each have a number of internal parameters called weights. Changing the weights of the element, therefore, will also alter the behavior of the whole network. The goal here is to choose the weights of the network to achieve a desired input/output relationship. This process known as training the network. Let's consider input vector of X which contains n components, a single output of y, and a weight vector of W which also has n components. The output y equals the sum of inputs multiplied by weights and then through a non-linear function in the form of signum. The goal is to train the network to the process conditions and then use trained neurons to predict and control the process (For further information on network training refer to [9])

To further explain the logic behind ANN controller let's consider the following example:

Consider a SWD control problem with output (y) (TPH in overboard water), and input variables of primary and secondary water clarifier injection rates and the skimming rate at IGF vessel ($X = \{x_{1,}\ x_{2,}\ x_3\}$). The inputs after normalization to the interval of -1 to +1, they will be sent to the first neuron ($N_{1,\ 1}$) which transfers them using transfer function f (x_i). The transferred values will be summed by weight and sent out to the rest of the neurons for further processing. The same process will happen at each neuron, in each hidden sub-layer. At the final hidden sub-layer, all neurons will send their output to the final layer which passes through final summation to the output layer for the Signum transfer (Figure 13).

The control system for SWD can be a combination of sample-and-hold control action and an artificial neural network to compensate for the training period. [10]

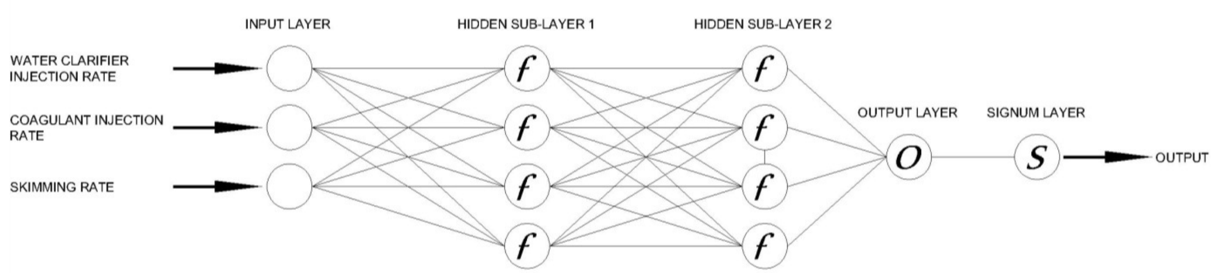

Figure 13. Artificial Neural Network (ANN) structure with two hidden sub-layers

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