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OPTIMIZATION OF PRODUCED WATER TREATMENT PROCESS - A CASE STUDY FOR DISPOSAL IN THE NIGER DELTA

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Abstract

Produced water is the interstitial reservoir water that flows to the surface with the crude oil into the production separators. This study addressed the effects of some chemicals on produced water and the challenges of finding the optimal concentrations of these chemicals for treating produced water. In this study, produced water treatment was carried out in an oil production platform located in the Niger Delta so as to determine the effect of a particular scale inhibitor, biocide, demulsifier and water clarifier, also to obtain the optimum concentrations of these chemicals in the treatment of produced water. The physico-chemical properties and microbial content of the produced water were determined. The results showed that the conductivity, hardness, pH and alkalinity reduced with increasing concentration of the scale inhibitor. The total heterotrophic bacteria count (THBC), heterotrophic fungi count (THFC) and the Sulphate reducing bacteria count (SRBC) were found to reduce with increasing concentration of biocide and exposure time. The increase in biocide concentration from 64 PPM to 100 PPM resulted in the reduction of THBC by 99.78%, THFC by 81.32% and SRBC 99.85%. The water clarifier gave the optimum concentration for oil and grease in the produced water at 7.3 PPM.

Keywords: Produced water, Chemical treatment, Niger Delta, Scale inhibitor, Biocide, Demulsifier.

1. Introduction

Produced water is a mixture of water and impurities such as hydrocarbons, aromatics, polycyclic, water soluble organics, oil, grease, dissolved solids and materials produced along with crude oil. The dissolved water soluble organics in the liquid phase is enhanced by the elevated temperature of the petroleum reservoir and it forms part of the total oil and grease. In the oil and gas industry,

Nomenclatures

AMP	Adenosine Monophophate
ATP	Adenosine Triphosphate
bbl	Barrel
bwpd	Barrel of water per day
PPM	Parts per million

Abbreviations

API	American Petroleum Institute
DPR	Directorate of Petroleum Resources
SRBC	Sulphate Reducing Bacteria Count
TDS	Total Dissolved Solids
THBC	Total Heterotrophic Bacteria Count
THFC	Total Heterotrophic Fungi Count

some of the major challenges encountered by the operators include; the ability to contend with the problems of scale formation, oil spill, bacteria and corrosion associated with produced water in the production facility. These problems results to production drop, increased production cost and hazard to personnel and the environment. To prevent these problems, the treatment of produced water should be properly done before disposal by applying various oil field chemicals such as; scale inhibitor, water clarifier, demulsifier and biocide in a suitable processing facility. From laboratory analysis, produced water associated with petroleum in a reservoir can be identified with its characteristics. The volume of produced water generated from oil reservoirs during production increases with the age of the field and may become enormous with time, leading to storage, treatment and disposal problems. Poor treatment and handling of produced water can cause serious environmental pollution through the adverse effects of oil sheen and oil accumulation on the water surface when the produced water is discharged. These substances are toxic to aquatic lives, contaminate domestic water and pose serious health hazard to man.

If the pH of produced water is equal to or greater than 8.3, alkaline is present mostly in the form of bicarbonates (HCO_3^-) [1]. Veil et al. [2] stated that the total dissolved solid (TDS), pH and bacteria concentration present in the produced water from the pay zone can give a clue to the type of scale inhibitor and biocide to be used to treat the produced water and also to identify wellbore problems. Produced water could also be referred to as connate water although some authors refer to it as fossil water because it had not been exposed to the atmosphere for several years [3]. Enrlich [4] noted that water soluble organics containing cyclic hydrocarbons, partially saturate organic acids such as naphthenic acid, which are then removed from the produced water through acid extraction. This was achieved by adding phosphoric acid based formulations to the produced water to reduce the pH, protonate the acid and preferentially partition the protonated acid in the oil phase while it coagulates and floats to the water surface. Further separation could then be completed by other primary separation processes like skimming. Egwaikhide et al. [5] undertook a research on the utilization of coconut fibre carbon in the removal of soluble petroleum fraction in polluted water. The result disclosed that coconut fibre carbon produced by ammonium chloride activation, possesses sufficient micro porosity to adsorb dissolved organic compounds with varying molecular sizes from

petroleum polluted water. The relative adsorption rate of lighter fractions was more than the rate of heavier ones. 42% pollution remediation was achieved in the experiment conducted by the team on kerosene and diesel polluted water. They concluded that the process could be applied in the remediation of petrochemical waste water. Verla et al. [6] carried out a study on the physiochemical characteristics of produced water and noted that produced water contained dissolved and suspended solids. Their study observed some variations in the average physiochemical content (salinity 6,000 mg/l, conductivity 15,000 us.cm, As 1.08 mg/l, Ni 2.08 mg/l, V 1.92mg/l) of a sampled produced water when compared to the Directorate of Petroleum Resources (DPR) limit. They further stated that the presence of metals, a high conductivity and salinity in large bodies of water or on land could cause leaching in soil nutrient and could be dangerous to human and aquatic lives. They concluded that existing production facilities had not been able to control these contaminants within tolerable limit.

2. Background Information on the Case Study Field

The case study field consists of some producing wells in the swamp, made up of eight (8) low pressure production wells and three (3) high pressure production wells. The wells flowed from the well head to the production platform via three (3) manifolds (MFD KK, MFD LL & MFD MM). At the platform, the low pressure wells flowed into a low pressure separator at 100 psi static pressure while the high pressure wells flowed into a high pressure separator at 200 psi static pressure. The well fluids from the high pressure separator flowed into the low pressure separator where more gas was relieved to the gas line. The crude oil from the low pressure separator flowed to the Chemelectric vessel set at 35 psi static pressure. Both the low and high pressure separators were used as two phase separators, separating the well fluid gas from the liquid. The gas flowed through a flare scrubber, where entrained oil in the gas was scrubbed off, the oil recycled back into the production surge tank and the gas flared.

The Chemelectric vessel which received the well stream from the low pressure vessel, acted as a three phase separator. In this vessel, the well stream oil, water and gas were separated. The gas flowed through the vessel's gas line to the flare scrubber where entrained oil in the gas was scrubbed off and the dry gas flowed to the flare pit where it was burnt. The oil flowed through the vessel oil outlet line to the surge vessel from where it was pumped by three G398 caterpillar pumps to the sales line after metering at the LACT unit, with one shipping pump working at a time while the other two were on standby. The produced water separated at the Chemelectric flowed through the vessel's water drain line to the water skimmer were some oil in the produced water was skimmed off and pumped through the recycling line to the Chemelectric vessel for treatment. The water from the water skimmer flowed through the drain line to the Wemco (floatation cell), from where it was channelled to be dumped overboard.

The oil production platform started production in 1992. It produced 6,000 bbls of oil and 14,000 bbls of water as at August 2015. Produced water from the field was treated to DPR effluent water standard (less than 20 PPM) [7] and it flowed into a floatation cell without adequate floatation aid before it was dumped overboard. This act constituted environmental pollution as some of the oil-in the produced water settled out and formed sheens flowing to the creek, which resulted

in the production of some 'oily-water' that was detrimental to aquatic and human lives and at the same time contributing to loss in revenue. Some of the soluble salts crystallize at that high temperature of the flared gas and vaporize to the atmosphere, thereby polluting the ecosystem.

The field's produced water had increased over the past 3 years from an average of 1888 bbls as at July 31, 2012 to an average of 14,097 bbls as at August 13, 2015. This therefore signals the need to strongly consider a better treatment of the produced water from the field to meet the increasing water production and to help mitigate its negative impact on the environment. Also, the dangers of scale formation of improperly treated produced water cannot be over emphasized [8]. The rate of micro-organisms activities is on the rise, exposing the system to a high rate release of H_2S and danger of a high corrosion rate [9].

3. Materials and Methods

The materials and methods used for this study are discussed in this section.

3.1. Floatation cell

A floatation cell is a water clarification system that removes finely dispersed oil and solid particles from the produced water prior to discharging it overboard into the creek or ocean. Water clarifier chemical is usually added into the floatation unit to destroy the film separating the oil particles in water emulsion. The floatation unit comprises of floatation cells in series. The cells use induced gas floatation to remove the oil particles from the oil in water emulsion. Induced gas floatation disperses tiny gas bubbles throughout the produced water. These bubbles attach themselves to the oil particles and float them to the surface where they are skimmed off into the launder trough of the floatation unit as sludge and pumped into the Chemelectric vessel for retreatment. The floatation unit is designed to handle produced water with small concentrations of oil.

The produced water is sampled downstream of the floatation cell (Wemco unit) of the production platform using one litre sterilized sample glass bottle. At the sampling point, allow the produced water to flow into a container for two minutes to flush the line and have a representative sample. Rinse the sample bottle with the produced water thoroughly before collection. Take the produced water sample to the laboratory in a cooler containing ice cubes wrapped in cellophane bags to maintain a low temperature to inhibit the growth of bacteria and enable one to ascertain the bacteria counts as found in the produced water sample in coli form unit per millilitre (cfu/ml) [10]. It is necessary to note that systems with acid producing bacteria are more likely to have higher rates of corrosion [11].

3.2. The scale inhibitor physico-chemical efficiency test

The scale inhibitor pump was put off for 24 hours in the production platform and produced water was sampled downstream of the floatation cell unit as stated in the previous section and sent to the laboratory for analysis. The result was compared to the produced water analysis at the following scale inhibitor concentrations at different days; 0 PPM, 2.1 PPM, 5.5 PPM, 7.2 PPM, 8.6 PPM at the existing produced water production rate of approximately 14,000 bbls/day.

3.3. Produced water clarifier chemical test

The test method employed was the Bottle test plus spectrophotometric analysis.

The following materials were used; produced water sample of 749.2 PPM, oil, grease, hot plate, 250 and 100 ml beakers, Spectrophotometer [12-15].

1gm of water clarifier (Nalco EC6029A) was diluted in distilled water made up to 1000 ml to have a concentration of 1000 mg/L as the chemical stock for laboratory treatment of the produced water [12-15].

Procedure: 3.7 ml, 5.5 ml, 7.3 ml and 9.2 ml of the diluted stock were separately transferred into 1000 ml conical flasks respectively and further diluted with produced water up to the 1000 ml mark. Applying the principle of serial dilution the concentration was determined as shown below:

$$1 \times 10^{-3}\,{}^{\mathrm{g}}/_{\mathrm{ml}} \times \frac{3.7}{1000} = 3.7 \times 10^{-6}\,{}^{\mathrm{g}}/_{\mathrm{ml}} = 3.7\,{}^{\mathrm{mg}}/_{1000\mathrm{ml}} = 3.7\ \mathrm{PPM}$$

Thus the other concentrations prepared were; 5.5 PPM, 7.3 PPM and 9.2 PPM. The samples were stirred and transferred into 50 ml beaker containers which were placed on a hot plate. The samples were heated to 120^0F (49^0C) for 2 minutes and allowed to cool. The samples of the various concentrations were analyzed for oil and grease using the spectrophotometric method after the filtration of suspended particles.

3.4. Microbiological analysis of produced water

Some of the analysis that were carried out are discussed below

3.4.1. Serial dilution

The serial dilution process was performed using a series of small bottles that contained a specific medium for growing a particular type of bacteria. It involved using a sterile syringe to draw one millilitre of the sample fluid and injecting it into the first bottle. A new syringe was used to draw fluid from the first bottle and injected into the next bottle. This process was repeated with each successive bottle in the series of small bottles. Each "injection step" diluted the bacteria from the previous bottle by a factor of 10. The total number of the specific bacteria in the original water sample was determined by the number of bottles that showed growth.

3.4.2. Accucount

Accucount is a kit used to enumerate bacteria by the presence of Adenosine Triphosphate (ATP). ATP is a molecule found in every cellular process that requires energy (metabolism, protein synthesis, etc.). The kit also measures Adenosine Monophosphate (AMP), a molecule found in all dormant organisms. All actively growing bacteria have approximately the same amount of ATP and all dormant bacteria have approximately the same amount of AMP.

3.4.3. Enumeration of sulphate reducing bacteria

The test method employed was the Spread plate technique. The following materials were used; Erlenmeyer flask, Petri dishes, incubator, cotton wool, anaerobic glass jar containing gas pack and catalyst [12-15].

Table 1 shows the reagent composition of the Sulphate Reducing Bacteria (SRB) growth medium.

Table 1. Reagent composition of sulphate reducing bacteria (SRB) growth medium per litre of de-ionized water.

S/N	Reagent	Weight proportion
A	**$K_2H\ PO_4$**	0.8 gm
B	**NH_4CL**	1.0 gm
C	**Na_2SO_4**	1.0 gm
D	**$CaCl_2.6H_2O$**	2.0 gm
E	**Na lactate**	3.5 ml of 75% solution
F	**$FeSO_4.\ 7H_2O$**	0.002 gm
G	**Na thioglycollate**	0.01 gm
H	**Ferric Ammonium Sulphate**	0.05 gm
I	**Agar**	20 gm

The components of the medium were weighed and dissolved in the de-ionized water made up to 1 litre in an Erlenmeyer flask plugged with cotton wool. The flask was autoclaved at 121^0C at a pressure of 15 psi for 15 minutes to sterilize the medium. The cotton wool was covered with foil to prevent the absorption of moisture or steam in the process. The medium was dispensed into the sterile Petri dishes and allowed to solidify at room temperature. After solidification the Petri dishes were dried at 60^0C for 20 minutes. 0.1 ml of the produced water sample was transferred into the SRB medium plates in duplicates and inoculated by spread plate technique. The plates were inserted into an anaerobic glass jar that contained a gas pack and catalyst that reacted to produce an anaerobic condition suitable for SRB growth. The anaerobic glass jar containing the inoculated SRB medium plates were transferred into an incubator set at room temperature for two weeks to develop the SRB. The presence of Sulphate Reducing Bacteria was indicated by black mucous colonies on the SRB medium plates [12-15].

The colony forming unit per ml (cfu/ml) was calculated using Eq. (1) while the dilution factor was calculated using Eq. (2) as shown below:

$$\text{cfu}/_{\text{ml}} = \frac{(\text{Dilution factor}) \times (\text{Number of organism enumerated on petri dish})}{\text{volume of inoculants plated}} \quad (1)$$

$$\text{where dilution factor} = \frac{3}{\text{dilution of inoculant}} \quad (2)$$

3.4.4. Biocide toxicity test on micro-organisms

The test method employed was the Spread plate technique.

The following materials were used; Erlenmeyer flask, biocide chemical (Nalco VX9298), nutrient agar for heterotrophic bacteria, heterotrophic fungi and sulphate reducing bacteria, produced water sample, glass beakers.

1 gm of biocide chemical was diluted in 1000 ml distilled water in a glass beaker and made to have a concentration of $1x10^{-3}$ g/litre of biocide in distilled water. Four glass beakers were assembled.

To the first beaker, 100 ml of produced water was added to it without adding biocide so as to serve as control.

To the second beaker, 10 ml from the biocide stock was added to it and the content diluted with produced water up to the 100 ml mark [12-15].

Applying the principle of serial dilution, the concentration of biocide in the dilution of the 10 ml of the biocide stock with produced water to the 100 ml mark was obtained as shown below;

$$1 \times 10^{-3}\,{}^{g}/_{\text{liter}} \times {}^{10\text{ ml}}/_{100\text{ ml}} = \frac{1000\text{mg}}{10000\text{ml}} = \frac{0.1\text{mg}}{\text{ml}}$$

To the third beaker, 7.5 ml from the biocide stock was added to it and the content diluted with produced water up to the 100 ml mark. This was equivalent to 0.075 mg/ml of biocide concentration in the produced water.

To the fourth beaker, 5 ml from the biocide stock was added to it and the content diluted with produced water up to the 100 ml mark. This was equivalent to 0.05 mg/ml biocide concentration in the produced water.

To the fifth beaker, 2.5 ml from the biocide stock was added to it and the content diluted with produced water up to the 100 ml mark. This was equivalent to 0.025 mg/ml biocide concentration in the produced water.

Each concentration was given the following exposure time interval; 0 hour, 1 hour, 2 hours, 4 hours, 5 hours and 7 hours respectively. The microbial content of the produced water at the various exposure time and biocide concentrations were determined to ascertain the toxicity of the biocide.

Dry sterile nutrient agar plates were inoculated with the specimen by spread plate technique and inserted into an incubator for 24 hours at 37^0C for the enumeration of the effluent total heterotrophic bacteria.

Sabouraud dextrose agar plates were inoculated and inserted into an incubator for 72 hours at ambient temperature for the enumeration of the effluent total heterotrophic fungi.

SRB medium plates were inoculated and inserted into an anaerobic glass jar to produce anaerobic condition. The jar was put into an incubator for two weeks at room temperature for enumeration of the effluent SRB. The plate counts were carried out to determine the colony forming units per ml of the produced water sample.

It should be noted that negative control plates, that is, un-inoculated sterile plates in triplicates were equally incubated. The 100 ml flask of produced water free of biocide served as positive control. It was also used for the enumeration of the initial micro flora counts for THBC, THFC and SRB

3.5. Crude oil emulsion de-emulsification test with desmulsifier Nalco EC2206b

Figure 1 shows the demulsifier bottle testing.The following materials were used; Toluene, Centrifuge machine, graduated test bottles and Metal sample cans.

Metal cans were used to sample crude oil at the inlet, outlet and the delivery line of the chemelectric separator.

The crude oil (API 34^0) emulsion in the station facility was treated with the following concentrations of demulsifier, Nalco EC2206B; 0.99 PPM, 1.98 PPM, 2.96 PPM, 3.89 PPM, 4.90 PPM, 2.87 PPM, 3.08 PP\M to optimize the produced

water treatment and enhance proper oil-water separation. The performance of the demulsifier chemical was effective because the production platform facility had a functional chemelectric three phase separator that applies electrostatic separation in addition to the chemical treatment. The crude oil samples from the three points were vigorously stirred in the metal sample cans to homogenize the content and then transferred into the centrifuge test bottle filled up to 50% while toluene was added to it to make up to 100% volume. Two sample test bottles were used for each sample point.

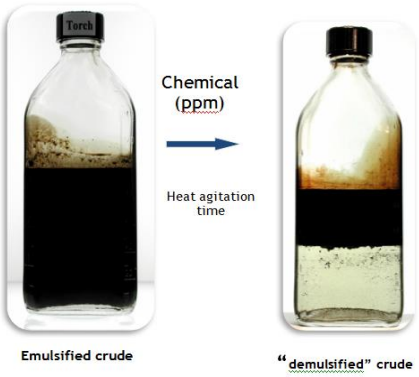

Fig. 1. Demulsifier bottle testing.

To the first test bottle no drop of demulsifier was added so as to serve as control and to the second, one drop of demulsifier was added to it. Centrifuge test bottles were put into the centrifuge machine and the heater put on to heat up the sample for 4 minutes, then later the centrifuge switch was put on to spin the sample in the test bottle for 5 minutes. The water in the crude oil separated from the oil because of the differential densities between the two components. The percentage of base sediment and water was multiplied by two since 50% volume of crude oil was used in the test per test bottle. The bottle test result with increasing base sediment was an indication of excess demulsifier in the crude while the one with clear water without further increase in water content was an indication of the optimal demulsifier concentration in the treated crude oil. Figure 2 still shows the liquid levels in the bottle test while Fig. 3 shows the centrifuge test.

Fig. 2. Bottle testing.

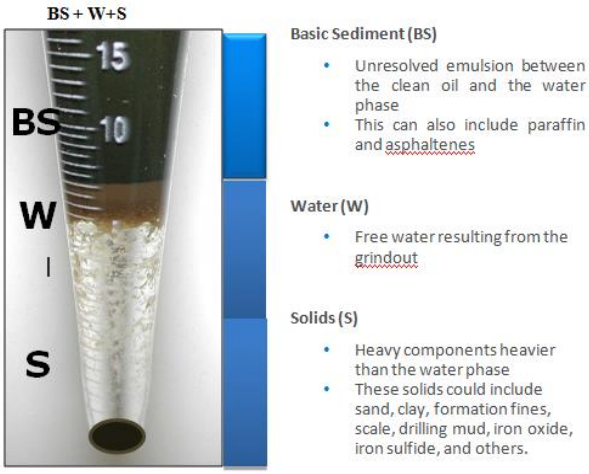

Fig. 3. Grindout/centrifuge test.

4. Results and Discussion

4.1. Scale inhibitor physico-chemical efficiency test

Table 2 shows the effect of scale inhibitor concentration on the physico-chemical properties of the produced water investigated. The result showed that in the absence of scale inhibitor, the concentrations of the metal cations (Ca^{2+}, Na^{+}, Mg^{2+}, Ba^{2+} and Pb^{2+}) and anions (SO_4^{2-}, Cl^{-} and HCO_3^{-}) were less in solution compared to when scale inhibitor chemical was injected into the produced water. This simply indicated that the scale inhibitor in solution retarded the salt crystal formation reaction between the anions and the cations in the produced water. In the sample without scale inhibitor some of the metal cations had reacted with the anions in solution to form salt which was responsible for the observed increased values in hardness, alkalinity, conductivity and the pH of the produced water. This is a proof that the scale inhibitor chemical Nalco EC6080A is effective in the treatment of the produced water. It can also be deduced that the absence of scale inhibitor in produced water could result in tremendous crystallization of supersaturated salts in solution on the internal walls of the produced water drain pipes, crude oil transport pipes and storage vessels. The reason for this is that the scale inhibitor in the produced water diffuses and gets to the ion clusters in the liquid to disrupt the scaling ion cluster growth from getting to crystal stage.

4.2. Water clarifier treatment on produced water

Untreated produced water with 749.2ppm oil and grease from Wemco water outlet was treated with different concentrations of water clarifier, Nalco EC6029A chemicals (as shown in Table 3). From the results in Table 3, at 9.2 PPM there was evidence of water clarifier chemical/water polymer formation which indicated an over treatment. Nalco EC6029A at 7.3 PPM was gotten as the optimal concentration. The introduction of floatation cell in the treatment of the produced water resulted in a reduction of the oil/grease concentration from 749.2 PPM to 15 PPM. With the application of water clarifier Nalco EC6029A at 7.3

PPM, an optimal concentration of 10 PPM was obtained for oil and grease. This confirms the effectiveness of the water clarifier Nalco EC6029A in the treatment of the produced water. Thus oil that would have been burnt at the flare pit was recovered in the floatation cell and reprocessed at the chemelectric separator.

Table 2. Produced water treatment physico-chemical test result.

COMPONENTS	0 PPM	2.1 PPM	3.9 PPM	5.5 PPM	7.2 PPM	8.6 PPM
	24 hours Field Test July8, 15 13560 bwpd	24 hours Field Test July 9 ,15 13389 bwpd	24 hours Field Test July 10, 15 13278 bwpd	24 hours Field Test July 11, 15 13580 bwpd	24 hours Field Test July 12 15 13498 bwpd	24 hours Field Test July 13 ,15 13293 bwpd
Na (mg/l)	7870.6	7870.8	7880.6	7887.6	7888.4	7890.5
Ca (Mg/l)	28.6	28.9	29.0	29.1	29.5	29.7
Fe (Mg/l)	0.155	0.155	0.155	0.155	0.155	0.161
Mg (Mg/l)	43.2	43.2	43.2	43.2	43.2	45.6
Pb (Mg/l)	0.18	0.182	0.185	0.189	0.189	0.19
Cond (uS/cm)	24000	21750	18000	17560	17120	16150
Hardness Mg ($CaCO_3$)/l)	11000	10980	10754	9500	970	800
Alkalinity Mg ($CaCO_3$)/l)	25	23.5	23	23	21	20
pH	7.8	7.6	7.6	7.3	7.3	7.5
Cr(Mg/l)	0.05	0.05	0.05	0.05	0.05	0.05
Ba(Mg/l)	12.85	12.85	12.88	12.89	12.89	12.9
Hg(Mg/l)	0.56	0.56	0.56	0.56	0.57	0.56
Suspended solid	460	456	450	432	423	410
Chloride ion (Mg/l)	12,853	12,854	12,854	12,854.9	12,856	12,857.47
Carbonate CO_3 (Mg/l)	0.08	0.08	0.08	0.08	0.08	0.08
SulphateSO_4 (Mg/l)	10.5	10.6	10.6	10.8	10.85	11
Bicarbonate (Mg/l)	786	865	870	873	873	875
CO_2 (Mg/l)	10.9	10.9	10.9	10.9	10.9	11
Sulfide (Mg/l)	0.04	0.04	0.04	0.04	0.04	0.04

Table 3. Results of water clarifier treatment on untreated produced water samples in the laboratory.

Nalco EC6029A Concentration	Mg water clarifier/ 1000 ml produced water	PPM oil & Grease	DRPR Allowable
3.7 PPM	3.7 mg/ 1000ml water	30	
5.5 PPM	5.5 mg/1000ml water	21	
7.3 PPM	7.3 mg/1000ml water	10	20 PPM
9.2 PPM	9.2 mg/1000ml water	2.5	

4.3. Produced water biocide (NALCO VX9298) treatment

From Table 4, it was Observed that the Heterotrophic bacteria initial counts in the produced water reduced from 2.7×10^5 to 5.8×10^2 cfu/ml (99.78% reduction), the heterotrophic fungi count reduced from 3.8×10^3 to 7.1×10^1 cfu/ml (98.13%

reduction), Sulphate reducing bacteria reduced from 4.2×10^5 cfu/ml to 6.2×10^2 cfu/ml (99.85% reduction) when the biocide concentration was increased from 64 PPM to 100 PPM. Hence from the analysis, an optimal clean out of the microbial organism was estimated at 100 PPM of biocide Nalco VX9298 injection into the produced water.

Table 4. Microbial analysis result after weekly biocide injection.

Parameter	Nalco VX9298 Conc. In produced water		
	64 ppm	87 ppm	100 ppm
Sulfate Reducing bacteria (SRB) cfu/ml	4.2×10^5	2.5×10^5	6.2×10^2
Heterotrophic Bacteria (HB) cfu/ml	2.7×10^5	1.9×10^5	5.8×10^2
Heterotrophic fungi (HF) cfu/ml	3.8×10^3	2.4×10^2	7.1×10^1

The total heterotrophic bacteria and fungi counts in the produced water reduced with increasing concentration of biocide in solution. This confirms the effectiveness of the biocide VX9298 in the treatment of the produced water. Tables 5, 6 and 7 shows the result of the biocide toxicity tests on the total heterotrophic bacteria count, total heterotrophic fungi count and sulphate reducing bacteria respectively.

Table 5. Biocide toxicity test result on total heterotrophic bacteria counts.

Exposure time	Nalco VX9298 conc. In produced water (mg/ml) and Heterotrophic bacteria count (cfu/ml).			
	0.025 Mg/ml Biocide Conc.	0.05 mg/ml mg/ml biocide Conc.	0.075 biocide conc.	0.1 mg/ml biocide conc.
0 hourr	440	300	280	150
1 hour	90	29	58	70
2 hours	70	28	40	20
4 hours	70	21	10	10
5 hours	70	30	10	10
7 hours	40	20	10	10

Initial Heterotrophic bacteria count before toxicity test was 5.8×10^2 cfu/ml.

Table 6. Biocide toxicity test result on total heterotrophic fungi count.

Exposure time	Nalco VX9298 conc. In produced water (mg/ml) and Heterotrophic Fungi Count (cfu/ml).			
	0.025 mg/ml biocide conc.	0.05 mg/ml biocide conc.	0.075 mg/ml biocide conc.	0.1 mg/ml biocide conc.
0 hour	630 cfu/ml	240 cfu/ml	190 cfu/ml	20 cfu/ml
1 hour	20	20	0	0
2 hours	10	0	0	0
4 hours	0	0	0	0
5 hours	0	0	0	0
7 hours	0	0	0	0

Initial heterotrophic fungi count before biocide toxicity test was $7.1x10^1$ cfu/ml

Table 7. Biocide toxicity test result on sulphate reducing bacteria (SRB) counts.

Exposure time	Nalco VX9298 conc. In produced water (mg/ml) and Heterotrophic Fungi count (cfu/ml).			
	0.025 mg/ml biocide conc.	0.05 mg/ml biocide conc.	0.075 mg/ml biocide conc.	0.1 mg/ml biocide conc.
0 hour	510 cfu/ml	320 cfu/ml	300 cfu/ml	162 cfu/ml
1 hour	92	50	48	49
2 hours	75	32	40	24
4 hours	72	28	14	12
5 hours	68	25	10	10
7 hours	38	21	10	10

Initial Sulphate reducing bacteria counts before toxicity test was 6.2×10^2 cfu/ml.

4.4. Demulsifier chemical (NALCO EC2206B) treatment

From Table 8, the function of the demulsifier in bringing about proper separation of the crude oil emulsion was observed. This separation process makes it possible to treat produced water with minimal free oil in it. From the analysis on the demulsifier chemical, Nalco EC2206B, the optimal concentration to treat an average gross emulsion of 20,000 bbl of liquid was 2.98 PPM. The average discharged basic sediment and water (BS&W) at this concentration was 0.10%, with an average oil production of 6,000 bbl (API 34^0) and water production of 14, 000 bbls for the period under review. Table 9 shows how the treated produced water compares with the DPR standards and Table 10 shows the remarks made after treating the produced water.

Table 8. Crude oil emulsion demulsifier Nalco EC2206B optimization test result in the production platform.

Date	Sampling Point	No Drop Demelsifier			One Drop Demulsifier			Chemical Injection Rate (Ppm)
		BS	H_2O	BS& W	BS	H_2O	BS& W	
Day 1	Chemelectric Inlet.	3	30	33	0	40	40	0.99 PPM
	Chemelectric Outlet	0.05	0.05	0.1	0	0.1	0.1	
	Discharge Line	0.05	0.05	0.1	0	0.1	0.1	
Day 2	Chemelectric Inlet.	2	35	37	0	43	43	1.98 PPM
	Chemelectric Outlet	0.06	0.02	0.08	0	0.1	0.1	
	Discharge Line	0.05	0.02	0.07	0	0.1	0.1	
Day 3	Chemelectric Inlet.	1.0	39	40	0	40	40	2.96 PPM
	Chemelectric Outlet	0.06	0.04	0.1	0	0.2	0.2	
	Discharge Line	0.05	0.05	0.1	0	0.15	0.15	
Day 4	Chemelectric Inlet.	1.5	38	39.5	1.0	39	40	

	Chemelectric Outlet	0.1	0.05	0.15	0.12	0.05	0.17	3.89 PPM
	Discharge Line	0.1	0.05	0.15	0.1	0.05	0.16	
Day 5	Chemelectric Inlet.	2	38	40	2.5	38	40.5	
	Chemelectric Outlet	0.1	0.05	0.15	0.12	0.05	0.17	4.90 PPM
	Discharge Line	0.1	0.05	0.15	0.1	0.05	0.16	
Day 6	Chemelectric Inlet.	1.0	39	40	0	40	40	
	Chemelectric Outlet	0.05	0.05	0.1	0	0.1	0.1	2.87 PPM
	Discharge Line	0.05	0.03	0.08	0	0.1	0.1	
Day 7	Chemelectric Inlet.	1.0	43	44	0	45	45	
	Chemelectric Outlet	0	0.2	0.2	0	0.2	0.2	3.08 PPM
	Discharge Line	0	0.15	0.15	0	0.15	0.15	
Day 8	Chemelectric Inlet.	1.0	43	44	0	45	45	
	Chemelectric Outlet	0	0.2	0.2	0	0.2	0.2	2.98 PPM
	Discharge Line	0.05	0.05	0.1	0	0.1	0.1	

Table 9. Comparison of results of treated produced water parameter with DPR standards.

Produced water component	Produced water quality before introduction of flotation cell chemical optimisation	Produced water quality after introduction of flotation cell chemical optimisation	DPR 2002 standard near shore (brackish / saline water)	Remarks
Na (mg/l)	7870.6	7890.5	Not stated	
Ca (Mg/l)	28.6	29.7	Not stated	
Fe (Mg/l)	0.155	0.161	Not stated	
Mg (Mg/l)	43.2	45.6	Not stated	
Pb (Mg/l)	0.18	0.19	Not stated	
Cond (uS/cm)	24000	16150	Not stated	
Oil&Grease (Mg/l)	749.2	15	20	Within spec
Hardness ($mg(CaCO_3)/l$)	11000	800	Not stated	
Alkalinity	25	20	Not stated	
pH	7.8	7.5	6.5 – 8.5	Within spec
Cr(Mg/l)	0.05	0.05	0.5	Within spec
Ba(Mg/l)	12.85	12.9	Not stated	
Hg(Mg/l)	0.56	0.56	Not stated	
Chloride Cl (Mg/l)	12,853	12,857.47	2000	Above spec
Carbonate CO_3 (Mg/l)	0.08	0.08	Not stated	
SulphateSO_4(Mg/l)	10.5	11	Not stated	
Bicarbonate (Mg/l)	786	875	Not stated	
CO_2(Mg/l)	10.9	11	Not stated	
Sulfide(mg/l)	0.04	0.04	Not stated	
Total Suspended Solid (TSS) mg/l	460	8	50	Within spec
Total dissolved solid (TDS) mg/l	21,606	21,723	5000	Above spec

Table 10. Final treated produced water.

	Internal scale formation on pipes	Remarks
$Caco_3$	None	Clean Pipe
$Caso_4$	None	Clean Pipe
$Mgco_3$	None	Clean Pipe
$Mgso_4$	None	Clean Pipe

Generally scales were not found in the pipes due to the sound produced water treatment quality

5. Conclusions

After a thorough experimental analysis and treatment of produced water samples from a field in the Niger Delta region, the following conclusions were made:

- Increase in concentration of Nalco EC6080A (scale inhibitor) from 0 PPM to 8.6 PPM resulted in reduction in conductivity by 32% (24,000 Us/cm to 16,350 Us/cm), in hardness by 93%(11,000 mg($CaCO_3$) per litre produced water to 800 mg($CaCO_3$) per liter) and in pH by 4% (7.8 to 7.5)
- Suspended solids and alkalinity reduce with increase in concentration of scale inhibitor.
- Optimal concentration of water clarifier Nalco EC6029A to treat 14,000 bbl of produced water was achieved at 7.3 PPM.
- Optimal concentration of demulsifier Nalco EC2206B for the separation of 14000 bbls of produced water and 6,000 bbls of crude oil (340) was achieved at 2.98 PPM with average BS &W of 0.1%
- Increase in weekly biocide Nalco VX9298 concentration from 64 PPM to 100 PPM resulted in 99.78% reduction of heterotrophic bacteria, 81.32% of heterotrophic fungi and 99.78% of sulphate reducing bacteria. 100 PPM was proposed for total microorganism elimination to extinction. It is important to state that a total elimination of the bacteria was not necessary because the extra cost in increasing the biocide concentration would not be justified since the bacteria elimination level achieved in this study already rendered the bacteria ineffective.
- Biocide toxicity test carried out showed that the elimination of total Heterotrophic bacteria, Fungi and sulphate reducing bacteria were proportional to increase in Biocide concentration and exposure time.
- Finally, it should be noted that the results from this analysis represent produced water for fields in the Niger Delta. It may also be useful for produced water from other oil provinces with similar formation characteristics to the Niger Delta formation. For instance, the Gulf of Mexico (GoM) has some similarities with the Niger Delta; hence this result may be useful in the GoM.

It is therefore recommended that these optimal chemical concentrations of the various chemicals analyzed in this study be maintained for effective treatment of produced water for fields in the Niger Delta.

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