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EVALUATION OF PRODUCED WATER DISCHARGE IN THE NIGER-DELTA

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ABSTRACT

Water produced during petroleum production often contain chemicals, oil and sometimes, naturally occurring radioactive materials which could harm the environment. Management, which involves significant cost and is guided by strict regulations, is normally aimed at minimizing or reducing the toxicity of discharged volumes. This study evaluated the physico-chemical properties and constituents of produced water from three selected flowstations and two oil terminals in the Niger Delta to determine the extent of compliance with standards and global best practices in the treatment and discharge. It was observed that while physico-chemical properties like pH (8.4±0.25) and BOD (6.2±2.0) were within recommended limits, oil and grease content (60±20), TDS (6200±700) and others exceeded limits. Similarly, ion concentrations of Lead, Nickel, Zinc and Sulphates were within acceptable limits while chloride ions (4100 ±500) exceeded limits. There is therefore the need to improve treatment facilities and procedures, while regulatory agencies must improve current guidelines, ensure proper monitoring and enforcing compliance.

Keywords: produced water, Niger delta, petroleum production, chemical analysis, oil terminals.

INTRODUCTION

Produced water constitutes the largest waste stream from petroleum production operations. They contain chemicals, oil, grease, and sometimes, naturally occurring radioactive materials which could harm the environment. The management of produced water continues to receive attention because of the volume involved, cost of treatment and the potential environmental implications. In Nigeria, at estimated current average water to oil ratio of 1:1, about one billion barrels of water are disposed annually from oil and gas production operations.

The production of water along with petroleum cannot be completely eliminated because water is one of the constituents of most petroleum reservoirs, where they often form a bottom seal. It can however be minimized through shut-off and down hole water separation technologies, water injection for reservoir pressure maintenance or domestic uses.

Water volumes produced from oil wells vary depending on the water saturation of the reservoir, reservoir drive mechanism, completion technique, stage of depletion, and position of the perforation within the producing zones. Other factors include type of well drilled, location of well within reservoir structure, type of water separation and treatment facilities, water flooding for enhanced oil recovery, loss of well mechanical integrity and other subsurface communication problems.

The constituents of effluent waters include: dissolved solids, organic compounds, suspended solids, bacteria, suspended organic compounds, naturally occurring radioactive materials and scales. In general, the characteristics of produced water vary could with location and even with time within a single well. They however need to be determined, to develop effective treatment to reduce the toxicity before disposal.

Most of the instruments used for produced water characterization utilize the calorimetric, titration, or turbidimetric principles while treatment facilities are selected based on operators preference, cost, safety and treatment requirement among others. Treatment facilities normally used include: settling (skimmer) tanks, floatation units, hydro-cyclones, suspended solid removal units (SSRU), coalensers, chlorinators, de-mineralizers and corrugated plate interceptors.

In the Niger-Delta, water effluents are usually pumped through discharge pipelines to streams or the sea. In some land locations, the water could be retained in ponds before release into the environment. In offshore locations, discharge into the sea through slotted pipes is done under the surface of the water. This has the advantage of protecting the surface or upper part of the sea. Before disposal, the main regulatory agency, the Department of Petroleum Resources (DPR) requires the constituents of produced water to be within the limits indicated in Table-1, while mandatory sampling, analysis and monitoring are as indicated in Table-2.

The aim of this study was to evaluate the physico-chemical properties and constituents of produced water from selected flowstations and oil terminals in the Niger Delta to determine the extent of compliance with standards and global best practices in their treatment and discharge.

Table-1. Effluent water discharge limits in Nigeria.

Effluent characteristic	Inland area	Nearshore	Offshore
pH	6.5-8.5	6.5-8.5	No limit
Temperature ^{o}C	25	30	-
Oil/Grease content	10	20	40
Salinity	600	2,000	No limit
Turbidity	>10	>15	-
Total dissolved solid	2,000	5,000	-
Total suspended solids	>30	>50	-
Chemical oxygen demand	10	125	-
Biochemical oxygen demand	10	125	-
Lead	0.05	No limit	-
Iron	1.0	No limit	-
Copper	1.5	No limit	-
Chromium	0.03	0.05	-
Zinc	1.0	5	-
Sulphide mg/1	0.2	0.2	0.2
Sulphate (SO4-) mg/1	200	200	300
Mercury mg/1	0.1	-	-
Turbidity	10 NTU	10 NTU	10 NTU

Table-2. Stipulated rate of monitoring for produced water parameters in Niger delta.

Effluent characteristic	Monitoring frequency
pH Temperature Electrical Conductivity Salinity as chloride Oil and grease Total Organic Carbon (TOC) Total Dissolved Solid (TDS)	Once per week for production platforms, Tank-farms and terminals
Biochemical Oxygen Demand (BOD) Chemical Oxygen Demand (COD) Dissolved Oxygen Phenols Sulphide Ammonia Total Phosphorus Heavy Metals Total Coliform Bacteria	Once per month
Hydrocarbon compounds e.g. Naphthalene, Benzene and Xylene	Once per year as requested by DPR

REVIEW OF LITERATURE

Proper management of produced water should start from accurate estimation of the volume produced. However, the study by Veil and Clark (2010) shows that there is still a lot of challenges on this even in the United States. On the other hand, the need to properly manage effluents from oil and gas operations due to their possible effects on the environment has long been recognized. At its first meeting in 1978, the Paris Commission (Oslo-Paris or OSPAR Commission) established the provisional target for discharges from offshore oil installations at 40 ppm, while discouraging disposal into fresh water bodies.

Neff in 1987 noted that there is more in produced water than water and oil. Often times, there are concentrations of Barium, Beryllium, Cadmium, Chromium, Copper, Iron, Lead, Nickel, Silver, Zinc, and small amounts of natural radioactive materials. In 1992, Jacobs *et al*., presented results of a study conducted on produced water from Shell operated oil and gas fields in the North Sea. They observed that produced waters discharged from gas and condensate platforms are far more toxic than the produced waters discharged from oil platforms. Cox (1992) also presented similar observations made in Alberta. In 1994 the London-based International Exploration and Production Forum (E and P Forum) published a detailed report on the fate and effects in marine environment of produced water in the North Sea. The average oil content of produced water discharged in 1991 alone from all North Sea production platforms was estimated at 34 mg/l amounting to discharge of 160 million cubic metres, 95% of which was from oil installations and 5% from gas. The discharges were estimated to contain about 52,600 tonnes of organic compounds and 1,000 tonnes of heavy metals.

In 1998, Cline noted that produced waters from petroleum production operations are in most cases, more saline than sea water. Smith, *et al.* (1998) has also confirmed the negative effects of produced waters on the Indonesian environment. However, studies have shown that where there is effective dilution, acute toxic effects of effluent water are not expected to be found beyond 50m from the discharge point (Johnsen *et al*., 2000, 2004). Durrell *et al*. (2006) reported that oil companies operating in Norway have since the mid-1990s tried to develop efficient monitoring methods for discharged water. In Nigeria, Oboh, *et al*. (2009) have presented results of experiments conducted on produced waters from an oil field in Nigeria and noted that the discharged waters had high metal ions and total hydrocarbon concentrations which could be reduced by further treatment with *lorffa cylindrical*. Joel *et al*. (2010) however suggested that fresh water dilution of formation waters in the Niger Delta before disposal could be very effective. Okoro (2010) demonstrated that produced water discharges in near shore environment in the Niger Delta leads to substantial accumulation of hydrocarbons and microorganisms up to 500 m from discharge points.

In terms of regulations, the current global best practices are in line with the suggestions of Ekins, Vanner and Firebrace (2005) on a three-stage approach to produced water management, with the long-term stage, aimed at reducing discharges to zero. This agrees with earlier presentations by Knudsen *et al*. (2003), Lystad and Nilssen (2004), and Knudsen *et al* (2004). In Nigeria, the current DPR guidelines and regulations in force were published in 1991 and aimed at maintaining the standards of the 90s.

MATERIALS AND METHODS

Samples of produced water were obtained from three flowstations: X (onshore), Y (Swamp) Z (offshore) and two terminals (nearshore) in the Niger Delta. Sampling was done in accordance with established guidelines and procedures. Measurement of temperature and pH were done at the sampling point due to sensitivity of their values, while the analysis of other parameters was done in the laboratory.

For pH, the pH meter was standardized with buffer solution and calibrated before measurement. For Turbidity, the Jackson candle turbid-meter was set up. Sample was poured from a measuring cylinder into the calibrated glass tube of the turbid-meter. The beam of light from the candle was then observed until the samples cloudiness impelled the light. The reading on the glass tube was done and converted into Jackson candle units.

For Oil and grease content, the gravimetric method was used. 100ml of water sample was measured and poured into the separation funnel. 10ml of toluene was measured and poured into the separating funnel containing sample. The two reagents were mixed together thoroughly by shaking for some minutes. The mixture was then allowed to stand for some minutes during which the toluene attracted to oil and grease in the sample to the top of the liquid in a layer.

The funnel top was then opened and the water ran-off leaving the oil layer behind. The oil left behind was then dried and the water sample was then reweighed and the difference in weight before and after separation gave the oil and grease content.

Calcium content was determined using titration method. 50ml of the sample was measured and transferred into a beaker then 2.0 drops of indicator and 2.0ml of buffer solution (NaOH) were added to the sample, and thoroughly stirred. The burette was filled to zero position with ETDA and then titrated against the sample mixture until the end point was reached when the muroxide indicator changed colour from pink to violet. The ion concentration was calculated as follows:

$$Ca^{2+}\ (mg/1) = \frac{1000 \times \text{Volume of ETDA} \times N}{\text{Volume of sample}}$$

Where, N = Normality of sample

Chlorine ion content was determined using the Mobr's method. 50ml of the sample was measured into a beaker and the dilution factor was noted. The sample was adjusted to a pH of 8.3 by the use of standard sodium hydroxide. 5% of potassium chromate was also added to the sample. The burette was then filled with 0.01ml silver nitrate to zero point, and titrated against the sample. When the endpoint was reached, chlorine ion concentration was obtained from the formula:

$$Cl^-\ (mg/L) = \frac{(M1 \times N)\ AgNO_3 \times 35500 \times 10}{M1\ \text{sample}}$$

For iron content determination, 100ml of sample was measured into a beaker. The reagent was then gently injected into the sample with the aid of a syringe. The colour of the sample was observed until the colour change was fixed even with the injection of more orthophenanthroline. A standard colour chart was then used to determine the concentration of Iron in the sample.

Concentrations of heavy metal ions were determined using the Atomic Absorption Spectrophotometer (Perkin Elmer 5100PC). The summary of various parameters and the methods used for analyses are as shown in Table-3.

Table-3. Methods of chemical analysis.

Parameter	Method of analysis
pH	pH meter
Turbidity, copper, lead, nickel	Turbidimetry
Specific gravity	Hydrometer
Oil and grease content, sodium,	Gravimetry
Potassium, calcium, iron, zinc, magnesium, chloride, sulphate, carbonate, bicarbonate ions	Titration
Barium, strontium	Atomic absorption spectro-photometry
Suspended solid	Gravimeter (Membrane Filter)
Dissolved solid	Titration
Particle shape	Electron microscope
Temperature	Thermometer

RESULTS AND DISCUSSIONS

Results of the effluent water analysis in Table-4 show that the pH of the effluents from the terminals and flowstations are all within the limit of 6.5-8.5. Similarly, the iron concentration in the effluents from the terminals and flowstations X and Y is within limits. The iron concentration of the effluent from Z is high and suggests possible corrosion in the system.

However, oil and grease contents of the effluents from all the terminals and flowstations are all above the recommended discharge limit. This is particularly worrisome considering the effects of oil or grease on the environment. Similarly, the Chloride ion, total dissolved solids and total suspended solids in all the effluents exceed set limits. The concentration of the total dissolved solids which include heavy metals and dissolved salts, might have been reduced by the installation of proper treating facilities. The high total suspended solid concentrations suggest that the floatation units are not very effective in handling the high volumes of effluent water at the terminals. At the flow stations there were no flocculation units for treating water.

Tables 5 and 6 show the comparison of oil/grease and metals respectively in effluent waters disposed from fields in Europe and the Niger-Delta. It is evident that oil and grease content, as well as Barium and Zinc concentrations are higher in discharged waters in the Niger Delta.

Similarly, the concentration of Barium, Sodium and Zinc ions in discharge effluents from Europe are lower than in the Niger-Delta. This suggests a higher level of toxicity of Produced water in the Niger-Delta.

The regulations governing produced water management in Nigeria were published by the DPR in 1991 and were adequate for maintaining the standards of the 90s. However, there are no medium and long term strategies and guidelines in place to achieve continuous reduction in permissible discharges until zero discharge is achieved. Dehydration units for the treatment of produced water are available at the terminals and disposal is mainly by the principle of dilution. All the flow stations and terminals however lacked equipment to specially treat dissolved solids.

Table-4. Chemical analysis of produced water in selected Niger delta oil fields.

Parameter	Allowed limit	Terminals		Flow stations		
		A	B	X	Y	Z
pH @75°F	6.5-8.5	8.12	8.53	7.88	8.10	8.43
Resistivity @69°F		0.45	0.68	1.58	0.37	8.40
Oil/Grease content (Mg/l)	10	55.0	42.0	64	80	40
Copper Mg/l	1	0.25	0.01	0.37	0.44	0.08
lead Mg/l	0.05	0.05	0.03	ND	ND	0.04
Iron, Mg/l	1	0.40	0.15	0.35	0.17	1.13
Nickel Mg/l	1	0.50	0.49	0.54	0.33	0.65
Barium Mg/l	-	16.0	8.00	5	20	11
Zinc Mg/l	1	0.10	1.80	0.98	0.09	0.85
Magnesium Mg/l	-	56.0	34.4	165	4.86	14.75
Chloride Mg/l	600	5100	2583	3589	4678	3970
Sulphate Mg/l	200	12.0	2.0	-	-	38
Carbonate	-	16.0	220	200	180	110
Bicarbonate Mg/1	-	2000	980	4720	1036	710
Total dissolved solid	2000	9000	3978	5300	6850	6440
Total suspended solid	30	60	80	138	104	94
BOD (mg/l)	10	500	8.5	4.5	8.68	5.33
Discharge Temp. °F		85	84	92	85	82

Table-5. Oil/grease content of water effluents from selected regions.

Oil fields	Average oil/grease concentration (mg/1)
Brent	3.9
Central North Sea	24.1
Other Northern fields	24.8
Niger delta	47.2

Table-6. Average metal composition from selected regions.

Element	Brent	UK sector	Dutch sector	Niger delta
Ba	1.27	0.66	6.60	8.0
Ca	1,167	5,560	7,240	42
Cu	<0.60	0.60	0.01	<0.01
Na	8,611	8,183	35,484	4,908
Pb	<0.02	<0.05	<0.05	<0.03
Zn	0.49	0.20	-	1.80

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CONCLUSIONS

Based on this study, it can be concluded that:

a) Produced water discharged into the environment in the Niger Delta is yet to meet set standards for disposal as concentration of oil/grease content, total dissolved solids, total suspended solids and some other parameters are still very high;
b) There are laws, guidelines and regulations for the management of produced water in Nigerian oil and gas operations. However, they do not include regulations aimed at further reducing discharges in an on-going basis until zero discharge is achieved in the long term;
c) The disposal guidelines and limits set by the regulatory agencies are not properly monitored and effectively enforced; and
d) Facilities that were investigated handle high volumes of produced water. This suggests that there is need promote minimization and recycling of produced water in the Niger Delta.

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