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Performance evaluation of a produced water treatment plant in a crude oil production facility

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ABSTRACT

The present study which was carried out (on a facility that is located on Latitude 04° 35.52'N and Longitude 08°25.45'E) using standard method of analysis monthly for two years has demonstrated that the treated produced water discharged from the crude oil processing into the near shore environment is 63.6% (each for both years) efficient when compared with the Guideline limits of the Regulatory body (Department of Petroleum Resources [DPR] of Nigeria). Out of the fourteen parameters investigated temperature, salinity as chloride, total suspended solids, turbidity and total dissolved solids were above the regulatory limits. There is therefore need to add additional polishing technologies to further reduce these parameters before discharging into the aquatic environment. Due to cost implications of such high technologies there is need for the operators to routinely clean up their existing produced water treatment plants so as to meet 100% efficiency of the regulatory body to maintain a sustainable environment.

Key words: efficiency, environment, produced water, sustainable, treatment

1. INTRODUCTION

The processes involved in the drilling, stabilization and processing of crude oil among others generate large amount of wastewater, which could be high in salts, inorganic (metals) and organic compounds (EGASPIN, 2002; Veil *et al.*, 2004; Ugochukwu and Leton, 2004; Guerra *et al.,* 2011; Nwokoma and Degde, 2012). The ecological health of many river systems is threatened by the discharge of such waste water with toxic compounds and the accumulation of these contaminants in these aquatic resources (Osuiji *et al*., 2004; Osuji and Onojake 2004; Emoyan *et al*., 2008; Joel *et al*., 2009). Again It has been observed that every aspect of oil operations, though in varying degrees, poses significant negative impacts not only on the environment but also the environmental consequences thereof imposes economic effects on the indigenes of that locality (Orubu *et al*., 2004; Joel *et al*, 2009; Nwokoma and Anene, 2010).

However, the characteristics of produced water vary from one formation to another and are affected by the type of crude produced, total hydrocarbon concentration among other factors (EGASPIN, 2002; Guerra *et al.,* 2011; Nwokoma and Degde, 2012). The continuous discharge of such wastewaters into a seawater environment could alter the physico-chemical characteristics of receiving waters causing damage to aquatic resources besides direct toxic effects on the fauna and flora (Obire and Amusan 2003; Otukunefor and Biukwu 2005; Emoyan *et al*., 2006; Ibigoni *et al*., 2009; Howard *et al*., 2011).

Produced water treatment varies from facility to facility but the objectives are the same. Some of such objectives are de-oiling, removal of dissolved organics, disinfection, removal of suspended particles, sand, turbidity, etc. removal of light hydrocarbon gases, carbon dioxide, hydrogen sulfide, etc. removal of dissolved salts, sulfates, nitrates, contaminants, scaling agents, etc. removal of excess water hardness among others (Arthur *et al*., 2005; Guerra *et al.,* 2011). The vista of treating produced water is, from one viewpoint, an approach to reducing adverse environmental impact; from the other a robust possibility to optimize and increase crude oil production, which means increase profitability (Nwokoma and Degde, 2012). In this part of the globe where best technological practices are not adequately applied or followed prudently were available (Poly- Alens, 2014; Eivind, 2012, Emuedo *et al.,* 2014). We find some untreated and partially treated produced water discharged into the open environment without regard to the regulatory standards. But for those who do have a kind of technology in treating this particular waste how efficient is the process and compliance level to the oil and gas regulatory bodies? In order to safeguard the environment and ensure sustainable development, there is the need therefore to prudently monitor and evaluate how efficient the process put in place complies with specified regulatory limits.

2. MATERIALS AND METHODS

Brief description of the facility and sampling points

The facility is situated at Latitude 04° 35.52’N and Longitude 08°25.45’E. It is an offshore floating production facility that receives and treats hydrocarbon fluids in a multistage multiphase separation train where the incoming well fluids are separated into gas, oil and water, with the gas and water being by-products of the oil production. The water so produced (Produced water) from the separation process is further processed and treated (using the hydrocyclone and hybrid gas flocculation (HGF) technology) before discharging into the open sea.

The well head fluid goes into the first stage separator where the oil is taken up and the water is channeled into the hydrocyclones (first sampling point for this study – inlet of hydrocyclone). The hydrocyclones generate spinning motion of the fluid that creates centrifugal force to push heavier water outward and lighter oil into the middle core of the cones. The water continues down and exits out the tapered end (Arthur *et al.,* 2005) (outlet of hydrocyclone - second sampling point for this study) where it goes to the Hybrid gas flocculation vessel for further treatment before discharging overboard (third sampling point for this study).

Sample collections and preservation

Samples were collected at least twice monthly in line with the regulatory body - Department of Petroleum Resources (DPR) of Nigeria – Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN) (EGASPIN, 2002) from the sampling points indicated above on the facility using glass (500.0ml) for Total hydrocarbon content (THC), 250.0ml (glass) for biochemical oxygen demand, 500.0ml (plastic containers) for physico-chemical parameters and another 500.0ml (plastic container) for metals. The sampling cans were properly washed with detergent and rinsed copiously with tap water and distilled water. Containers for trace metal determinations were later soaked in 1:10 nitric acid for 48 hours after which they were rinsed with deionised/distilled water. Samples for total hydrocarbon were collected in clean glass bottles with screw caps. In order to prevent sample misidentification, specific details on sample identification were entered on a permanent label and attached to each sampling can. Samples were preserved and transported according to the recommended procedures as stated in Part VIII (D) Section 2.0 of EGASPIN (2002) in order to avoid sample degradation and transformation. Samples for the determination of physico-chemical parameters were preserved and transported in iced coolers at 4°C while those collected for the determination of THC, were preserved with 1-ml 1+1 sulphuric acid per liter to pH ≤ 2. Samples for the determination of trace metals were preserved with 1-ml 1+1 nitric acid per liter to pH ≤ 2.

Sample analysis

Temperature, pH, electrical conductivity/TDS and salinity were analysed in-situ in the field using pre-calibrated Wagtech pH/thermometer, conductivity/TDS and salinity meters (Wagtech, 2005) in line with APHA (2005). Results of such analysis were recorded in the field logbook. Turbidity of collected samples were analysed the same day (in the field) using a Wagtech turbidimeter as described in (APHA, 2005).

Total suspended solids were determined with a Hach Spectrophotometer at a wavelength of 810nm. The digital displayed value was recorded in mg/l (APHA, 2005). Chemical oxygen demand (COD) was determined using the closed reflux method (APHA, 2005). For Total organic carbon, the Potassium dichromate method was used (ASTMD 2579 – 2003). Biochemical oxygen demand (BOD_5) was anslysed using the respiromatory method (AP HA 2005, Velp Scientifica, 2003). The heavy metals - Lead, Chromium, Copper, Zinc and Iron were all analyzed using Atomic Absorption Spectrophotometry Buck Scientific 200A (APHA, 2005), after sample digestion with concentrated nitric acid. THC (Oil and Grease) was determined according to ASTM 3921 (2003). The whole sample about 500ml was poured into the separatory funnel and extracted three times with 30ml of the extracting solvent (xylene). The combined extract was filtered through 10g of anhydrous sodium suphate and the spectrophotometer reading taking which gives the Oil and Grease value. Each of the values was then calculated from the calibration graph into mg/l in line with the method.

Data obtained were subjected to statistical analysis using Data tools analysis in Microsoft Excell 2003. Percentage removal as shown in Tables 1 and 2 was calculated using the following equation (Rajasekhar *et al.*, 2013; Sivakumar and Nouri, 2015; Sivakumar, 2015).

$$\%\ removal = \frac{C_1 - C_2}{C_1} \times 100.0\%$$

Where C_1 is influent concentration (Inlet of hydrocylone value) of any parameter in mg/l, and C_2 is effluent concentration (discharge (HGF) value) of any parameter in mg/l. Figures 1 and 2 below were developed by converting the discharge and DPR's values into percentage using the later as reference point. Using temperature as an example –

$$DPR's\ \%Temperature = \frac{30}{30} \times 100.0\% = 100.0\%$$

$$Discharge\ \%Temperature = \frac{49.1}{30} \times 100.0\% = 163.7\%$$

3. RESULTS AND DISCUSSION

A summary of the mean values of the physicochemical parameters in the produced waters of the treatment process and their percentage removal for the two years are presented in Tables 1 and 2, while in Figures 1 and 2, a comparison was made between the finally treated water that was discharged into the open sea and the limit set out (EGASPIN, 2002) by the regulatory body (DPR).

The pH of the Produced water was alkaline from the inlet of the hydrocyclone in nature but the treatment process was able to remove 3.9% and 2.1% of the alkalinity for the first and second year respectively. Comparing this with the pH of aquatic water quality requirement set out by the Federal Ministry of Environment (FMEnv) (FMEnv, 1991) and South African water quality guideline (SAWQG) for Aquatic ecosystem (SAWQG, 1996) this parameter is within limit. Again comparing it with the Oil and Gas regulatory discharge limit of 6.5 –8.5 this parameter is within limit (Figure 1 and 2).

The process temperature is relatively higher than that recommended by the regulatory body (DPR) (30°C) however the treatment process was only able to remove 3.2 and 3.9% of the first and second year, comparing this with the aquatic water quality requirement it is far above the limit, this will definitely affect the fauna and flora (Obire and Amusan, 2003; Otukunefor and Biukwu, 2005). Again the percentage temperature removal recorded in this study is far lower than that reported (52.9% i.e. from 42.0°C to 25.9°C) by Nwokoma and Degde (2012) in a similar study.

The treatment process was only able to remove 0.2 and 0.5% respectively of the first and second year of Salinity as chloride from the produced water. The discharge value is more than four times the DPR limit of 2000mg/l, which means the treatment process is not effective at all in the removal of this parameter.

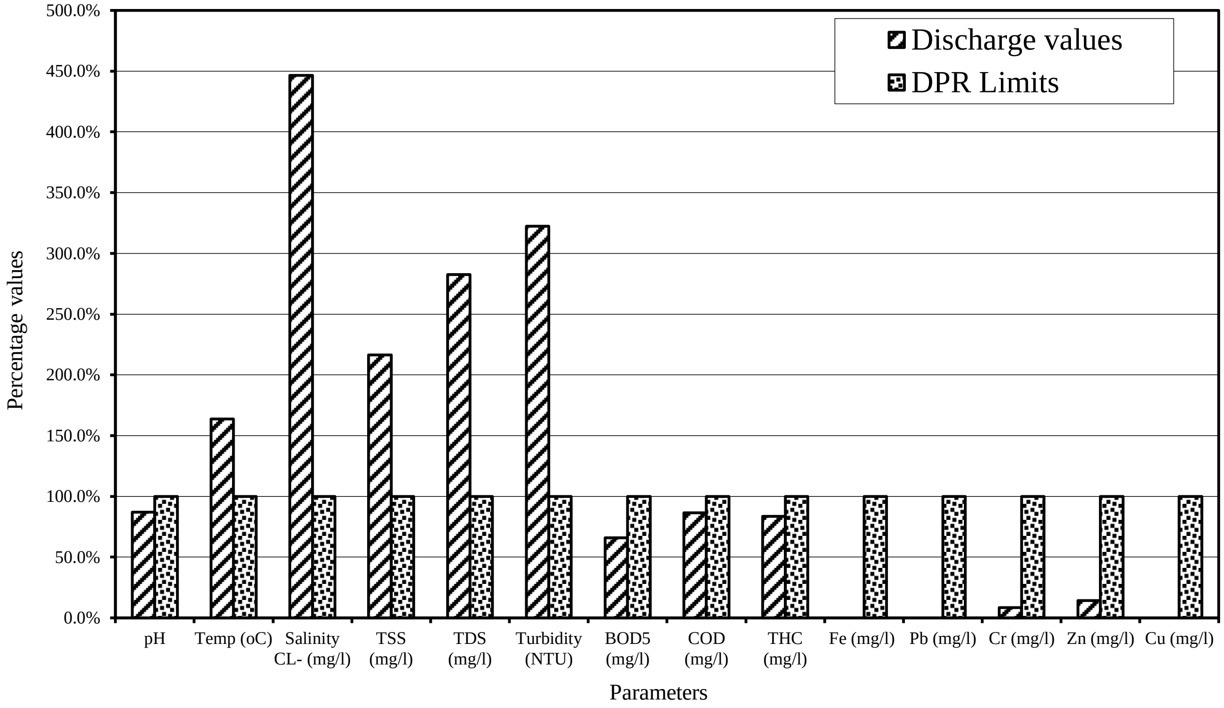

Figure 1
Comparison of the overboard discharge (first year's average) values of the parameters and DPR limits in percentages

Table 1 Summary of the mean values of the physicochemical parameters in the produced waters of the treatment process and their percentage removal for the first year (Mean ± Std)

Physicochemical parameters	Inlet of the hydrocyclone	Outlet of the hydrocyclone	HGF outlet (Overboard discharged)	Percentage removal (%)	Regulatory limit		
					DPR 2002	FMEnv 1991	SAWQG 1996
pH	7.7±0.18	7.5 ±0.13	7.4±0.12	3.9	6.5 –8.5	6.0-9.0	6.5-9.0
Temperature (°C)	50.7±1.66	47.2±12.69	49.1±1.66	3.2	30.0	20.0-30.0	<10% of normal cycle
Salinity as chloride (mg/l)	9124.4± 1553.25	8534.1±3084.68	8898.5± 1518.19	2.5	2000.0	<4520.0	-
Total Suspended Solids (mg/l)	235.5± 209.13	866.4±2649.94	31.4±14.47	86.7	< {50% of receiving medium 32.0) = 16.0	-	<10% of normal cycle
Total Dissolved Solids (TDS) (mg/l)	13262.9± 1505.02	12621.8± 4138.86	14118.6 ±1324.95	-6.5	5000.0	500	<10% of normal cycle
Turbidity (NTU)	264.2±108.57	1315.3±4246.81	24.9±13.32	90.6	<{15% of (receiving medium 21.7) = 3.2	<55	-

Biochemical oxygen demand (BOD_5) (mg/l)	238.0±292.0	164.0±217.2	82.4±82.5	65.4	125	4	-
Chemical oxygen demand (COD) (mg/l)	314.4±72.4	219.6±108.4	108.0±88.9	65.5	125		
Total Hydrocarbon Content (mg/l)	2548.8±1387.65	295.7±404.39	16.7±3.42	99.3	20	0.01	-
Iron (total)	4.555±4.913	35.677±102.761	4.153±3.530	8.8	-		
Lead (mg/l)	0.025±0.009	0.890±1.746	0.016±0.006	36.0	-	0.002	0.001
Chromium (Total)	0.049±0.020	0.033±0.018	0.040±0.023	18.4	0.5		
Zinc (mg/l)	1.130±1.012	0.906±1.093	0.716±1.001	36.6	5.0	0.05	0.002
Copper (mg/l)	0.234±0.285	0.251±0.164	0.253±0.146	-8.1	-	0.002-0.004	0.0012

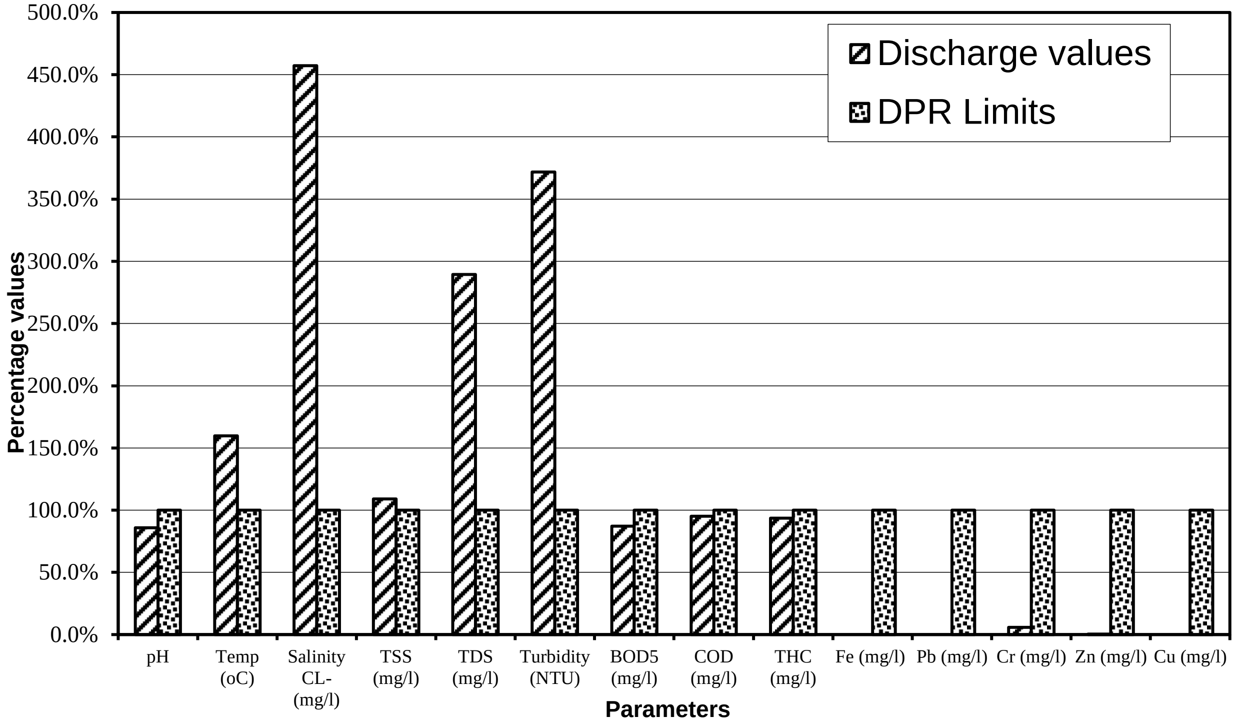

Figure 2

Comparison of the overboard discharge (second year's average) values of the parameters and DPR limits in percentages

Table 2 Summary of the mean values of the physicochemical parameters in the produced waters of the treatment process and their percentage removal for the second year (Mean ±Std)

Physicochemical parameters	Inlet of the hydrocyclone	Outlet of the hydrocyclone	HGF outlet (Overboard discharged)	Percentage removal (%)	Regulatory limit		
					DPR 2002	FMEnv 1991	SAWQG 1996
pH	7.5±0.1	7.4±0.1	7.3± 0.1	2.7	6.5 –8.5	6.0-9.0	6.5-9.0
Temperature (°C)	49.9±1.5	49.7±1.5	47.9±1.5	4.0	30.0	20.0-30.0	<10% of normal

							cycle
Salinity as chloride (mg/l)	9188.8±232.9	9278.0±219.2	9145±202.8	0.5	2000.0	<4520.0	-
Total Suspended Solids (mg/l)	512.7±152.8	363.5±84.4	116.5±43.0	77.3	< {50% of receiving medium 214.0) = 107.0	-	<10% of normal cycle
Total Dissolved Solids (TDS) (mg/l)	13421.1±1468.2	14091.0±321.3	14476±166.0	-7.9	5000.0	500	<10% of normal cycle
Turbidity (NTU)	359.9±95.1	277.0±45.3	78.1±14.2	78.3	<{15% of (receiving medium 140.9) = 21.0	<55	-
Biochemical oxygen demand (BOD_5) (mg/l)	274.5±215.0	257.0±145.7	109.0±62.6	60.3	125	4	-
Chemical oxygen demand (COD) (mg/l)	338.3±48.5	177.8±36.7	118.9±70.0	64.9	125		
Total Hydrocarbon Content (mg/l)	3973.2±1633.2	396.0±357.2	18.7±5.6	99.5	20	0.01	-
Iron (total)	1.920±0.44	2.124±0.82	2.032±0.761	-5.8	-		
Lead (mg/l)	0.004±0.01	0.004±0.00	0.002±0.002	50.0	-	0.002	0.001
Chromium (Total)	0.035±0.01	0.028±0.01	0.029±0.017	17.1	0.5		
Zinc (mg/l)	0.015±0.03	0.024±0.04	0.022±0.041	-46.7	5.0	0.05	0.002
Copper (mg/l)	0.363±0.38	0.438±0.48	0.437±0.408	-20.4	-	0.002-0.004	0.0012

The open sea's salinity as chloride level for the second year was (5956.7±1881.4) (Howard *et al.*, 2012), so discharging such high value of salinity as chloride will definitely alter the quality of the sea water.

The treatment process was able to remove 86.7 and 77.3% of Total Suspended Solids from the produced water. This is not efficient as the discharge values for both years where greater than 50% of the receiving medium, which is the open sea (Howard *et al.*, 2012) and also that of the aquatic water quality of SAWQG (1996). The treatment process could not remove total dissolved solids from the produced water rather more solid particles were added into the water. These additions could be from the treatment chemicals - demulsifiers, water clarifiers etc. When compared to the DPR's limit of 5000(mg/l) the values for each year is more than twice above that and also above the aquatic water quality guidelines. Although turbidity was effectively removed from the produced water in both years - 90.6 and 95.0%, the discharged values did not meet the DPR limit (EGASPIN, 2002) of less than 15% of receiving medium (Howard *et al.*, 2012) as stated in both tables. In terms of the aquatic water life quality for FMEnv (1991) these values are within limit.

There was a considerable reduction of BOD_5 as noticed from the inlet of the hydrocyclone to the HGF outlet given a percentage removal of 65.4 and 60.3 respectively for both years. The discharge values for both years are below the regulatory limit of 125mg/l (EGASPIN, 2002), and are also comparable to that obtained (92.0mg/l) by Nwokoma and Degde (2012) in a related study. However, that of the second year seems to depreciate which could be due to the fouling of the treatment plants and hence with time there will be need to clean up the treatment plants (hydrocyclones and the HGF units). The efficiency of the treatment plant in reducing the high BOD load could be attributed to hydrocarbon utilizing-microorganisms within the sediment of the treatment facility as observed by Nwokoma and Degde (2012).

The removal of Chemical oxygen demand was relatively efficient as we recorded 65.5 and 64.9 percent removal respectively for both years. The average discharge values for both years are also lower than the regulatory limit of 125.0mg/l (EGASPIN, 2002). Just like the BOD_5, that of the second year seems to depreciate which could also be due to the fouling of the treatment plants and hence the need for cleaning. The high value of COD in the outlet hydrocyclone for the second year could be due to the increase of the treatment chemicals such as demulsifiers, water clarifiers etc. that were used in the treatment processes.

Average total hydrocarbon content extraction between the inlet hydrocyclone and the outlet of the hydrocyclone and finally at the HGF was efficient as the percentage removal were below the DPR limit of 20.0mg/l (EGASPIN, 2002) as indicated in Tables 1 and 2. However, that of the second year was relatively higher which implies the need to clean up the plants (hydrocyclones and the HGF units). Nwokoma and Degde (2012) have reported a higher efficient removal of same parameter (98.7% i.e. from 645.3mg/l to 8.2mg/l.) from a similar work in the Niger Delta, which implies the operators of this facility have to embark on clean up operations.

The removal of iron from the produced water between the inlet and outlet of the hydrocyclone is negative for the first year, which means through the process there was addition of iron into the produced water but at the HGF unit this was drastically reduced to give 8.8% removal. For the second year there was a minimal addition of iron from the process into the produced water from the three units - inlet and outlet hydrocylone and HGF units. Lead was added into the produced water through the process – from the inlet to the outlet of the hydrocyclone but it was finally removed at the HGF unit for the first year to give a percentage removal of 36.0. However, the discharge value of 0.016mg/l is above FMEnv (1991) and SAWQG (1996) limits and hence will definitely affect aquatic water quality of the area, whereas in the second year there was a 46.7% removal of lead that makes it to be at par with the FMEnv limit (1991), but higher than that of the SAWQG (1996) limit. Total chromium was removed from the produced water at each unit of the process for both years at 18.4 and 17.1% respectively. In the first year of the treatment, zinc was removed at each stage of the process to arrive at 36.6% removal, however for the second year there was addition of zinc into the produced water as we recorded a negative value of 46.7%. The final discharge values for both years are below DPR recommendation, but higher than that stated by FMEnv (1991) (for the first year) and SAWQG (1996) for aquatic water quality. Unlike all the metals, copper was added into the produced water from the process treatment for both years. That is from inlet to the outlet hydrocylones and then to the HGF unit. The reason could be due to the make of the treatment plant which may be mainly alloys of copper and other metals. The values recorded for both years were all higher than the limits given by FMEnv (1991) and SAWQG (1996) for aquatic water quality guidelines

4. CONCLUSION

The present study has demonstrated that the produced water discharged from the crude oil processing into the near shore environment is within statutory limits except for temperature, salinity as chloride, total suspended solids, turbidity and total dissolved solids. The implication of this is that of the eleven parameters that are regulated by the regulatory body (Department of Petroleum Resources of Nigeria) out of the fourteen investigated, the facility is 63.6% efficient in handling, treating and discharging of effluent (Produced) water that meets environmental standards, though additional polishing technologies are available which could further reduce the dispersed oil contents, and in some cases reduce the level of associated soluble materials. Due to cost implications of such high technologies there is need for the operators to routinely clean up their produced water treatment facility so as to meet 100% efficiency of the regulatory body to maintain a sustainable environment.

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