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Produced Water Effluents Analysis in an Oil Processing Facility (A Case Study of Nkoro Field in Nigeria)

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Abstract- A study of Produced Water Effluents Analysis in an Oil Processing Facility (A case study of Nkoro Field) was conducted. The Physical, Chemical and Heavy metal parameters were monitored at various treatment stages up to the point of discharge, using in-situ/ laboratory analytical techniques/methods in order to access the impact of the produced water effluents on the receiving surface water quality. The produced water effluents of the Nkoro Field were sampled weekly for twelve (12) weeks in accordance with Environmental Guidelines and Standards for the Petroleum Industries in Nigeria (EGASPIN). The values of the selected parameters were determined In-situ/Laboratory Analytical Techniques/methods such as Photometric and Titrimetric methods, Hanna HI 98129 pH/Temperature/Conductivity/TDS meter, Gravimetric, HACH DR 2400 spectrophotometer and Atomic Absorption Spectrophotometer (AAS) (GBC Avanta Ver.2.02). Temperature, pH, Electrical Conductivity, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Oil and Grease content, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD5), Alkalinity, Phosphate, Sulphate, Ammonium, Dissolved Oxygen (DO), Copper, Zinc, Chromium, Lead, Iron, Manganese, Nickel and Cyanide. All the parameters except Electrical Conductivity, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Alkalinity, Phosphate, Chromium, Lead, Iron and Nickel fall within the recommended limits disposable to surface water ways in Nigeria. The amount of these parameters reflects the quality and efficiency of the produced water treatment plants installed. The appearance was clear and in accessing the effective and efficiency of the produced water effluent treatment process in relationship to design specification, one could conclude that the efficiency is on the average and really needs modifications to reduce the concentrations of the parameters that do not conform to the standard limits.

Keywords- *Produced water effluents, characteristics of produced water, legal (regulatory) and administrative framework, activated sludge process, in-situ/ laboratory analytical techniques/methods*

I. INTRODUCTION

The exploration and exploitation of crude oil have and will continue to be on the rise as long as crude oil remains the most viable and economical source of global energy supply without any credible alternative economically. The production and processing of crude oil into usable products involves the generation of wastes mainly effluents, sanitary wastes, ballast/bilge wastewater etc. In order to avoid polluting the environment these wastes have to be properly handled and treated before discharge into the environment. Globally, there is a lot of concern about the protection and conservation of the environment through efficient and effective check on wastes generated not only from petroleum production activities. It is a common practice the world over for countries to enact legislation and guidelines as well as establish agencies to monitor the operations of oil & gas and other activities. The issue of proper handling and disposal of wastes as effluent wastewaters from oil production facilities cannot be over emphasized as these wastes could pose serious environmental and health risks (Nwankwo and Irechukwu, 1992). They could form sources for local contamination of soil and ground water. Although total prevention of environmental pollution is not feasible (Headworth, 1989), it is increasingly evident that environmental resources and quality management must involve to improved waste disposal practices as well as very good industrial practices.

Environmental pollution is of major concern mainly because of the implications for human health, animals, plants etc. The environmental concern due to the harmful effects of these wastes has led to the separation and treatment of effluents arising from petroleum production and processing activities as well as certification through monitoring before discharging into the environment. In view of the above, the regulatory authorities of the Department of Petroleum Resources and Federal Ministry of Environment have set discharge permissible limits and environmental standards to safeguard the environment. Effluents and drilling waste monitoring have been put in place by the authorities, as a measure to ensure compliance to the set standards before discharge of such wastes into the environment (DPR, 2002) and (FEPA, 1991).

The existence of man is largely dependent in the state of the environment as he depends directly or indirectly on it for the basic necessities of life. Man's food is grown on Land, the air he breaths is from the atmosphere, the water he uses is either from the stream or underground water and so on. Science has not yet provided substitutes for the natural supply of these basic necessities by the environment, though modifications and applications have been made.

This calls for an in –depth knowledge and understanding of the anti –pollution measures and environmental chemistry (Coleman, 1975).

However, in the developed countries, strict adherences to standards are maintained to ensure good and efficient pollution control. Industrial effluents are treated to very low levels of toxicity before discharging into the receiving medium. Meanwhile, in the third world countries like Nigeria, there is very little adherence to anti-pollution standards but with the establishment of the Federal Environmental Protection Agency (FEPA), and now Federal Ministry of Environment (FMENV) by the Federal Government, there is a ray of hope. These possess a treat to human existence if not checked since a pollution effect on the environment and man is cumulative (Connell, 1980).

Meanwhile, pollution varies from air pollution, (poisonous gasses, fumes, mists, vapor, particulate matters, fog, dust), sound pollution, (noise from automobiles and industrial equipment), Land pollution, (when solid, semi –solid and liquid effluents are Discharged in Land) and water pollution (water bodies being the major recipient of industrial (oil / gas) effluents and domestic sewers, seeps from unprotected landfills and sewage pits into the underground water bodies). Thus, there is a great need for proper control of produced water treatment processes to ensure very low toxic levels of pollutants discharged into the natural receptors in the environment. The case of Niger Delta, an essentially industrial area is important. This is particularly so considering the environmental pollution associated with effluents and waste from the various industrial activities, ranging from exploration, development, production and refining of crude oil etc.

II. LEGAL (REGULATORY) AND ADMINISTRATIVE FRAMEWORK:

There are several National Regulations that guide oil and gas exploration and production activities in Nigeria. Below are some legal frameworks relevant to environmental pollution compliance and management.

A. Federal Ministry of Environment Regulations 1991

Decree 59 of 1988 established the Federal Environmental Protection Agency (FEPA) as the chief regulatory body for environmental protection in Nigeria. This decree has the responsibility of ensuring that all industries meet the limits prescribed in the national guidelines and standards and associated regulations for environmental pollution management (e.g. effluent limitation, management of solid hazardous wastes etc.). From time to time, the FMENV updates the National guidelines and standards.

Some of the relevant sections of the regulations and guidelines include:

1. Section I.8 of 1991, National Effluent Limitation Regulation which makes it mandatory for industrial facilities to install anti- pollution equipment, makes provision for effluent treatment and prescribes maximum limits of effluent parameters allowed for contraventions. It also provides that all industries in Nigeria should be operated on the basis of Best Available Technology (BAT).
2. Section I.9 of 1991, Pollution Abatement in Industries and Facilities Generating Wastes. This regulation imposes restrictions on the release of toxic substances and stipulates requirement for monitoring pollution.

B. Environmental Guidelines and Standards for the Petroleum Industry in Nigeria, Revised Edition, 2002.

Some relevant parts of the guidelines and standards are as follows:

i. Part V.B.5.4.1 specifies that waste waters from the Production Platform and Terminal comprising of process/oily water, sanitary water, produced water, spent catalyst, etc., shall not be disposed of directly or indirectly into any inland water, fresh water or reservoir, any swamp, coastal or offshore waters, any flood plains, upland valleys, and any pit or land other than lined or concreted pit, basin or steel tank so designed and utilized that there shall be no overflows, leakages and seepages into adjacent surface and ground waters.

ii. Part V.B.5.4.2 provides that disposal of Production Platform Terminal wastes is prohibited on unsecured land, public drain and sewers, except that the quality and quantity of the discharge shall not cause hazards to human health, harm living organism (fauna and flora), and impair the quality to use adjacent land water.

iii. Part V.B.5.6.1 states that waste water from Production Platform Terminal operations-process water, produced water, oily water, storm water, and sanitary water shall be treated to the satisfaction of the Director of Petroleum Resources (DPR) before disposal.

III. CHARACTERISTICS OF PRODUCED WATER:

Industrial (oil / gas) produced water effluents are not expected to exceed certain values for example, some authorities do not permit oil and grease effluent to exceed 20 ppm (mg/l) (Osibanjo and Ajayi, 1981). For liquids especially fuel and oil effluents, it is desirable also to know the electrical conductivity, since this is the measure of its tendency to pick up static charges. This can lead to high energy spark discharges capable of igniting the flammable liquids e. g fuel / air mixtures (Paulis, 1989) to avoid pollution of water and the environment. Generally, relevant authorities' in-charge of environmental safety should demand the quality of industrial (oil/ gas) produced water. They should also insist that liquid effluent discharged especially from petroleum and chemical associated industries should be monitored at least once a week to ascertain the concentrations of the following parameters in Table 1. As these parameters shown in Table 1, are the minimum required parameters that need monitoring to ascertain the level of pollutants in the produced water effluents.

It is necessary that authorities engaged in oil/gas industry activities should support the crusade against environment degradation by ensuring that either effluent meets the required specifications. For this work, emphasis is placed on water pollution since produced water is in broad sense polluted water. By definition, produced water is water, which due to some contamination or pollution from oil/gas industrial activities cannot be put in much use except when highly treated. Basically, produced water contains water in a very high percentage with a smaller proportion of suspended solids, organic and inorganic matters, micro –organisms and refectories. Most of these materials are harmful to man and are referred to as pollution

(Gordon et al, 1981). They give physical, chemical and biological qualities that are characteristic of domestic and industrial waste waters.

TABLE I. PHYSICO–CHEMICAL PARAMETERS THAT REQUIRE MONITORING

1.	pH	12.	Iron (Fe)
2.	Temperature	13.	Sodium (Na)
3.	Density	14.	Cyanides
4.	Electrical conductivity	15.	Sulphide (as H2S)
5.	Salinity	16.	Sulphate (as SO4)
6.	Oil / Grease content	17.	Ammonia (NH4)
7.	Total suspended solids (TSS)	18.	Total Phosphorus (as PO4)
8.	Total dissolved solids (TDS)	19.	Total Nitrogen (as NO3)
9.	Biochemical Oxygen Demand (BOD5)	20.	Surfactants
10.	Phenols	21.	Total Chromium
11.	Lead (Pb)	22.	Discharge rate (gallons or liters per day) etc.

IV. ACTIVATED SLUDGE PROCESS

The most common suspended growth process is the activated sludge process. The process may be carry out in a completely mixed flow reactor or plug flow reactor. Three basic reactor configurations are commonly used;

1. Completely –mixed reactor with sludge recycles (figure 1).

2. Completely – mixed reactor without sludge recycles

3. Plug flow reactor with sludge recycle.

Recycles sludge consists primarily of micro-organisms, which increases biomass in the reactor and therefore directly affects the biomass production and substrate utilization rates.

The activated sludge process shown in figure 1 consists of the following operations:

1. Mixing of activated sludge: Some portion of the activated sludge settled at the bottom of the secondary settling tank is re-circulated and mixed with the effluent of primary settling tank just before its entry to the aeration tank (reactor).

2. Aeration: Aeration (reactor) is the first equipment in the activated sludge process. Here, the effluent in the primary settling tank and air are brought into intimate contact by agitating with some mechanical devices.

TABLE II. ESTIMATED ANNUAL WASTE ARISING IN THE EUROPE COMMUNITY-PRINCIPLE SOURCES

Sources	Million tones	%
House hold and consumer waste	132	6
Agricultural waste	950	44
Industrial waste	160	7
Sewage sludge	300	14
Extractive waste	250	12
Demolition and Construction wastes.	170	8

Source: Adapted from Haines (1998).

Aeration serves two important purposes; supplying the required oxygen to the organisms to grow and providing optimum contact between the dissolved and suspended organic matter and the micro-organisms. The aeration system consumes approximately 50 to 65% of the net power demand for a typical activated sludge produced water treatment plant; therefore the efficiency of different aeration systems is an important consideration. The time that the mixed liquor is aerated varies from as little as 30 minutes to as much as 36 hours depending upon the treatment process used. Aeration can be performed mechanically or by using a diffused system. Mechanical aerators physically splash the produced water into the atmosphere above the tank and create turbulence assuring effective produced water mixing. Mechanical aerators include brushes, blades or propellers that introduce air from the atmosphere. Surface aerators float at the surface or are mounted on supports in or above the basin. Mechanical aerators tend to incur lower installation and maintenance costs. A diffused air system introduces compressed air through a perforated membrane into the produced water. Diffusers are classified by the physical characteristics of the equipment, or by the size of the air bubble. The choice of bubble size, diffuser type, and diffuse placement can have a great effect on the efficiency of the aeration process.

3. Sludge settlement: The secondary sedimentation tank is the second equipment in activated sludge process. After agitation in the aeration tank, the effluent is taken to the secondary settling tank and detained for a specific period. During this detention period, the sludge is settled at the bottom of the tank. This sludge is re-circulated to aeration tank and the remaining portion is sent to digestion tank.

Thus, the cycle of activated sludge process goes on working. The activated sludge process has the advantage of producing a high quality effluent for a reasonable operating and maintenance costs. The activated sludge process uses micro-organisms to feed on organic contaminants in produced water, producing a high quality effluent. The basic principle behind all activated sludge process is that the micro-organisms grow; they form particles that cluster together. These particles

(Floc) are allowed to settle to the bottom of the tank, leaving a relative clean liquid (effluent) free of organic materials and suspended solids. In activated sludge process, effluent produced water from primary clarifier is mixed with varying amount of recycled liquid containing a high portion of organisms taken from a secondary clarifier, and it becomes a product called mix liquor (Smart, 1997), this mixture is stirred in the aerator and injected with large quantity of air, to provide oxygen and keep solids in suspension. After a period of time, the mixed liquor flows to a clarifier where it is allowed to settle. A portion of the bacteria is allowed as it settles, and the partially cleaned water flow on to further treatment. The resulting settled solid, the activated sludge are returned to the aerator (reactor) to begin the process again. A basic activated sludge process description consists of several inter-related components.

- An aeration tank where the biological reactions occur.
- An aeration source that provides oxygen and mixing
- A tank, known as the clarifier, where the solids settle and are separated from treated wastewater.
- A means of collecting the solid either to return them to the aeration tank, (return activated sludge) or remove them from the process (waste activated sludge).

V. DATA SOURCE

The physico-chemical analyses were carried out using standard test methods such as Photometric Method for Oil and Grease contents, Titrimetric for the determination of Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD_5). Dissolved Oxygen (DO) was done in-situ; Temperature, pH value and Conductivity were determined in-situ using Hanna HI 98129 pH/Temperature/Conductivity/TDS meter, Gravimetric for the determination of Total Dissolved Solids (TDS) and Total Suspended Solids (TSS), Titrimetric for the determination of Hydrogen sulfide and Alkalinity. HACH DR 2400 spectrophotometer was used for the determination of cyanide (CN-), Nitrogen Ammonia (NH_4^+), Phosphate (P) and Sulphate (SO_4^{2-}).

Atomic Absorption Spectrophotometer (AAS) (GBC Avanta Ver.2.02) was used for the determination of Copper (Cu), Zinc (Zn), Iron (Fe) and other Heavy Metal Contents. The above analysis was carried out at the Quality Control Laboratory of ANAL Concept Ltd, Port Harcourt, Specialized in Environmental/Analytical consultancy, and all the data were obtained experimentally.

Field sampling and data collection were done in accordance with Environmental Guidelines and Standards for the Petroleum Industries in Nigeria (EGASPIN). Where this could not be achieved other scientifically proven and acceptable methods were adopted e.g. American Public Health Association (APHA), American Petroleum Institute (API) and American Society of Testing Materials (ASTM).

After in-situ measurements of some of the parameters, samples for the analysis of other physical, chemical and heavy metal parameters were collected using appropriate sampling containers (glass bottles with Teflon covers) and preserved in an ice-cooler box. The bottles (containers) were properly labeled to indicate their content and collection site. They were also well covered to avoid spilling or contamination. Samples were collected when the flow was lamina in order to avoid the flow of debris into the bottles (containers). These samples were collected for each week and for a total of 12 weeks and the analysis carried out each week the sample was collected.

The values shown in Tables 3, 4 and 5 are the means/average set of results gotten from the Physical, Chemical and Heavy Metal parameters analysis carried out in twelve (12) weeks (3 months). The mean set of results is hoped to give a more accurate set of results of the produced water effluents.

The data for each of the Physical, Chemical and Heavy Metal parameters versus time (weeks) plots are shown in Figures 2-20. The analysis of all the results gotten is compared with the Federal Ministry of Environment (FMEMV), Department of Petroleum Resources, World Health Organization (WHO), Great Britain and Western Germany effluent discharge standards or limits. This effluents discharge into surface water, the standard for effluent discharge on land application is not included since our field of collection of the samples discharges its effluent in to surface water.

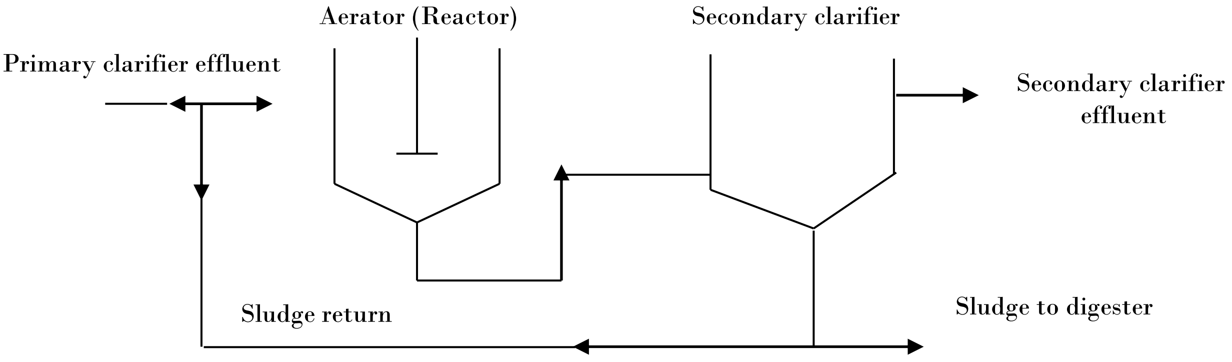

Figure 1. Activated process using completely – mixed reactor with sludge recycle.

TABLE III. Mean/Average values for Physical Pollution parameter

Sampling Stations	Temp. (oC)	pH	Conductivity (μs/cm)	TDS (mg/l)	TSS (mg/l)	Oil/Grease (ppm)
HP Separator	34.0	7.0	48,816.6	24,037	1,335	0.3
LP Separator	36.2	7.3	45,816.6	22,376	1,190	0.6
IP Separator	36.1	7.1	44,872.5	16,652	1,054	0.4
PW Vessel	34.1	7.1	49,209.1	23,657	1,184	0.3
Portside Slop	30.7	7.1	48,062.5	19,313	1,152	0.3
T/Separator	35.7	7.2	40,833.3	19,017	945	0.5
WHO Standard	10-30	7-10	10,000	2,000	30	0.01
West Germany	20-28	5-10	1,500	2,000	20	0 trace
Great Britain	26-32	5-9	2,500	1,800	30	4
DPR	30	6.5- 8.5	1,200	5,000	50	20
FMEMV Limit	<40	6-9	2,500	2,000	30	10

TABLE IV. Mean/Average values for Chemical Pollution Parameter

Sampling Stations	COD (mg/l)	BOD (mg/l)	Alkalinity (mg/l)	PO4 (mg/l)	SO4 (mg/l)	NH4+ (mg/l)	DO (mg/l)
HP Separator	4.41	2.33	1,167	13.3	4.0	0.26	2.3
LP Separator	7.57	4.21	1,342	16.9	30.0	0.39	1.7
IP Separator	3.91	2.80	1,446	26.9	5.7	0.32	2.1
PW Vessel	4.08	2.10	1,058	12.3	6.4	0.28	2.2
Portside Slop	3.31	1.94	1,175	10.1	4.7	0.28	2.2
T/Separator	5.93	2.91	1,179	17.1	10.1	0.30	2.1
WHO Standard	90	40	100	0.1	250	-	5.0
West Germany	<80	<25	100	0.1	250	-	5.0
Great Britain	<80	<25	100	0.1	250	-	<5.0
DPR	125	25	100	-	250	-	5.0
FMEMV Limit	90	<50	100	0.1	250	-	5.0

TABLE V. Mean/Average values for Heavy Metals Compositions

Sampling Stations	Cu (mg/l)	Zn (mg/l)	Cr (mg/l)	Pb (mg/l)	Fe (mg/l)	Mn (mg/l)	Ni (mg/l)	CN-(mg/l)
HP Separator	<0.001	<0.001	2.50	0.70	1.20	0.10	0.20	0.022
LP Separator	<0.001	<0.001	2.40	0.70	0.80	0.20	0.20	0.037
IP Separator	<0.001	<0.001	2.50	0.80	0.90	0.10	0.30	0.021
PW Vessel	<0.001	<0.001	2.40	0.60	1.00	0.10	0.20	0.021
Portside Slop	<0.001	<0.001	2.20	1.01	1.10	0.10	0.20	0.017
T/Separator	<0.001	<0.001	1.70	0.50	0.70	0.20	0.20	0.029
WHO Standard	2.00	<5.00	0.05	0.01	<0.10	0.40	<0.03	0.07
West Germany	3.00	5.00	0.50	3.00	0.50-1.50	0.25-0.50	0.50	0.07
Great Britain	2.00	-	0.50	0.10	0.20	0.01	0.20	0.07
DPR	1.50	5.00	<0.10	0.05	-	0.40	0.02	0.05
FMEMV Limit	<1.00	1.00	0.50	0.05	0.30	0.40	0.02	0.05

VI. DISCUSSION OF RESULTS

Temperature: The mean value temperature recorded for the produced water effluent was 30.7 ^{0}C, (Table 3). The value complied with the FMEMV limit of <40 ^{0}C and slight difference on DPR regulatory limit of 30 ^{0}C and WHO standard of 10-30 ^{0}C. From Figure 2 the weekly values complied with FMEMV limit while weeks 1 and 9 complied with both DPR regulatory limit and WHO standard. The observed temperature values resulted from the production process as shown in the plot.

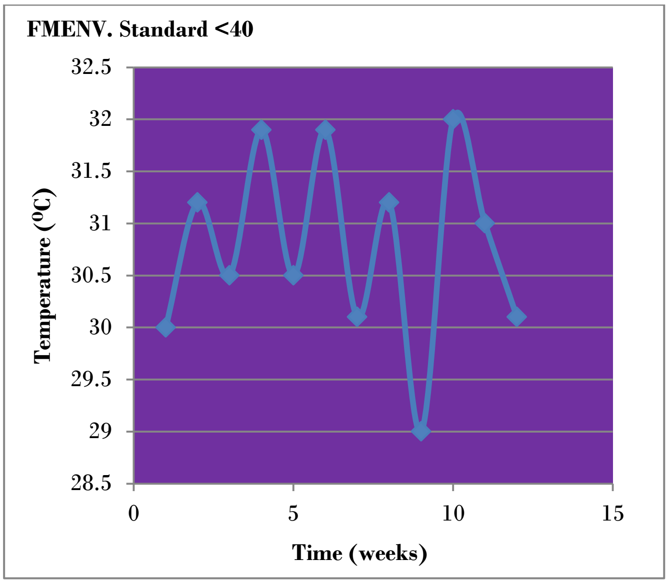

Figure 2. Temperature versus Time plot

VII. HYDROGEN ION (PH-VALUE) CONCENTRATION

The recorded average of Hydrogen Ion (pH value) concentration was 7.1(Table 3), and this complied with FMEMV, DPR and WHO regulatory limits of 6-9, 6.5-8.5 and 7-10, respectively. The weekly pH values recorded all conformed to the regulatory limits as shown in plot of Figure 3. From Figure 3, the pH values of weeks 2, 4, 6, and 9 are on acid side, weeks 3, 10, and 11 are on neutral side while weeks 1, 5, 7, 8 and 12 are on base side because a neutral pH, that of pure water is 7.0, a pH below 7.0 is on acid side and a pH above 7.0 is on basic side.

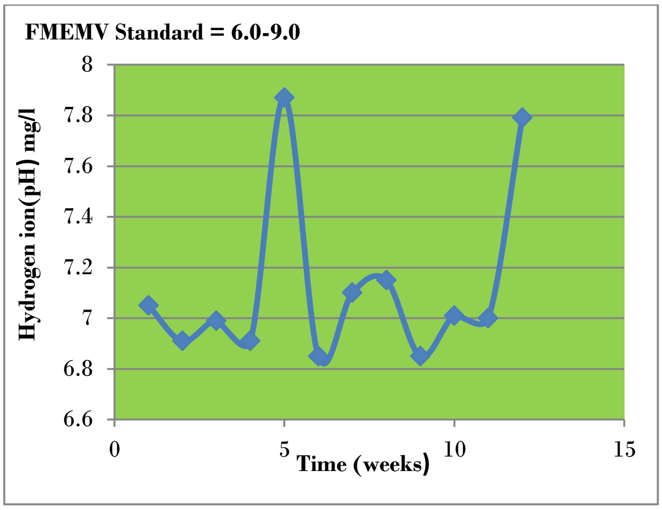

Figure 3. Hydrogen ion (pH) verses Time

Electrical conductivity: The obtained average value of electrical conductivity of the produced water effluent was 48,062.5µs/cm (Table 3), and does not fall within the recommended FMEMV, DPR and WHO standard values of 10,000µs/cm, 2,500µs/cm and 1,200µs/cm specifications. The weekly values recorded were very high as shown in Figure 4, so should be rejected. And that is the sole aim of this thesis as to know those parameters to be given due attention in design specification. Figure 4 shows that the electric current is transported by the ions in solution, the conductivity increases as the concentration of ions increases. This is because in water a net motion of charged ions can occur. This phenomenon produces electric current. Thus the conductivity increases as the water dissolves the ionic species.

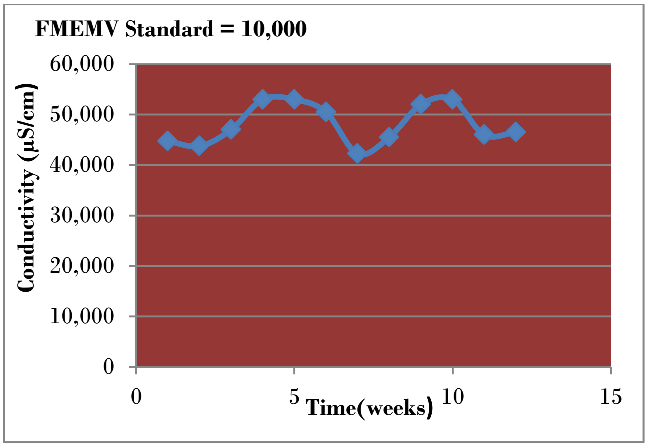

Figure 4. Conductivity versus Time

Total dissolved solids (TDS): The observed mean value of Total Dissolved Solids (TDS) of the produced water effluent was 19,313mg/l (Table 3), and does not fall within the permissible FMEMV, DPR and WHO limits of 2,000mg/l, 5,000mg/l and 2,000mg/l respectively. The weekly recorded values were very high as shown in Figure 5, and should be totally rejected. Figure 5 shows that high Total Dissolved Solids (TDS) is an indication of dissolved solutes in the wastewater, because wastewater contains a variety of minerals or salts, which are mainly composed of carbonates, bicarbonates, chlorides and nitrates. Total Dissolved Solids (TDS) is a measure of the total combination of all these.

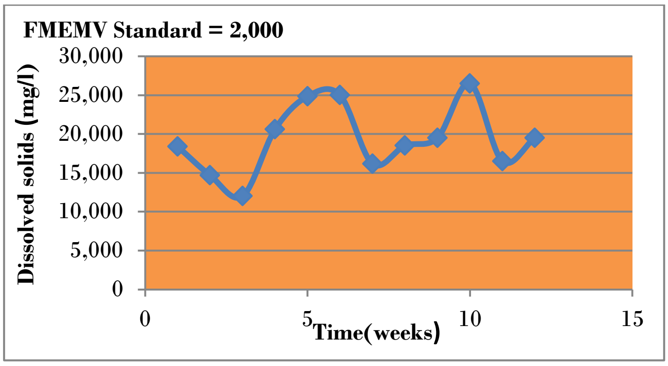

Figure 5. Total Dissolved Solids versus Time

Total suspended solids (TSS): The recorded average value of the Total Suspended Solids (TSS) of the produced water was 1,152mg/l and does not fall within the permissible FMEMV, DPR and WHO standard values of 30mg/l, 50mg/l and 30mg/l, (Table 3). The recorded weekly values ranged between 945mg/l to 1,190mg/l and exceeded the Regulatory compliances as shown in Figure 6.

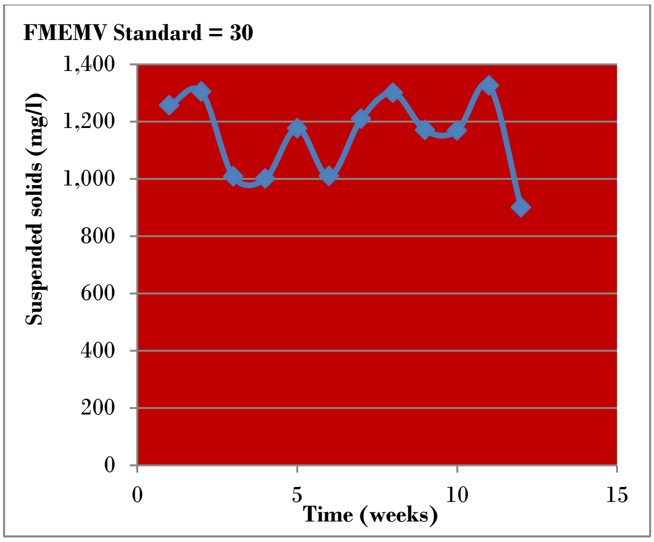

Figure 6. Total suspended solids versus Time

Oil and Grease content: The mean value of oil and grease content of the produced water effluent was 0.3ppm and conformed to the permissible FMEMV and DPR limits of 10ppm and 20ppm respectively, and does not conform to WHO Standard of 0.01ppm, (Table 3). The observed weekly results gave clear conformity of FMEMV and DPR Limits as shown in Figure 7, and as an indication of efficiency of oil and grease content treatment, despite the non-compliance of WHO Standard and should be accepted.

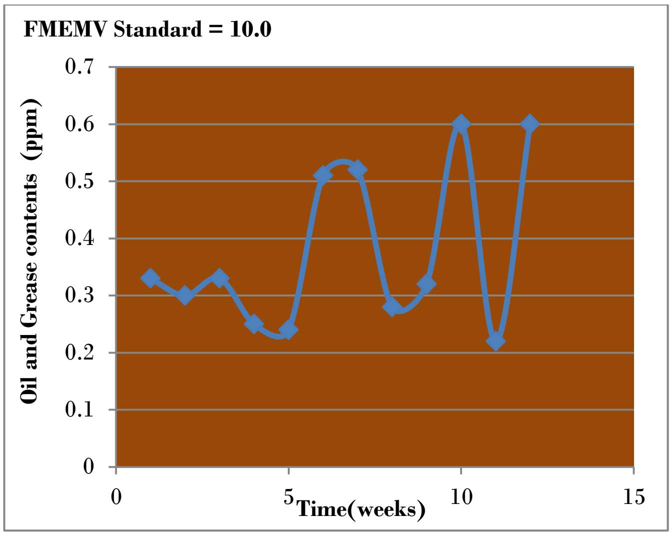

Figure 7. Oil and Grease contents versus Time

Chemical oxygen demand (COD) concentration: The recorded average value of chemical oxygen demand of the produced water effluent was 3.31mg/l and complied with the recommended FMEMV, DPR and WHO Standard limits of 90mg/l, 125mg/l and 90mg/l respectively,(Table 4). The weekly results obtained were in compliance with the regulatory standards as shown in Figure 8, and indicate that there is no presence of organic and inorganic pollutants in the effluent, as COD was used as a measure of the oxygen equivalent of the organic matter content of the sample.

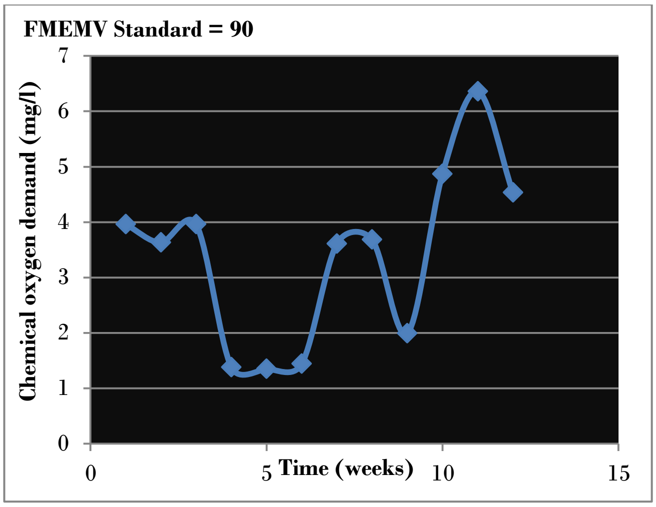

Figure 8. Chemical oxygen demand vs Time

VIII. BIOCHEMICAL OXYGEN DEMAND (BOD$_5$)

The average value of biochemical oxygen demand of the produced water effluent was 1.94mg/l, and is in compliance to FMEMV, DPR, and WHO permissible limits of <50mg/l, 25mg/l and 40mg/l, respectively, (Table 4). The results of the weeks obtained were low and regulatory permitted levels as shown in Figure 9 and indicate that the produced water contains some organic matters and should be accepted, as it was used to measure the amount of oxygen used by bacteria in water.

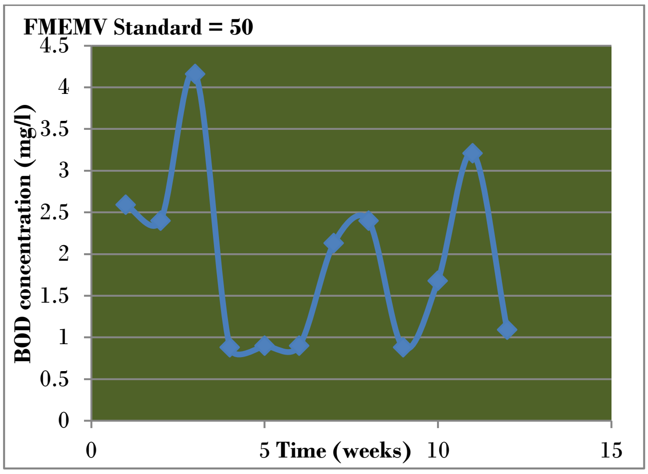

Figure 9. BOD concentration versus Time

Alkalinity concentration: The mean value of alkalinity of the produced water was 1,175mg/l, and does not comply with FMENV, DPR and WHO Standards of 100mg/l, and does not fall within the permissible limits, (Table 4). The weekly results were not conformed to the regulatory standards and weeks 4, 5 and 6 almost gave the same result as shown in Figure 10 and should be totally rejected.

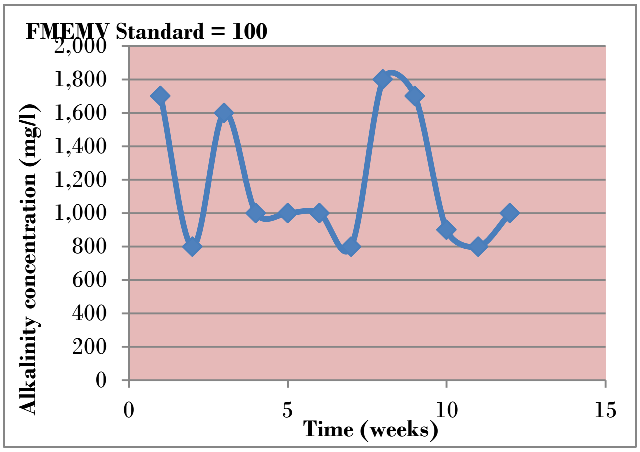

Figure 10. Alkalinity concentration vs Time

Phosphate (PO$_4$): The recorded average value of phosphate of the produced water was 10.1mg/l and does not comply with FMEMV, DPR and WHO specification limit of 0.1mg/l for all the regulatory bodies, (Table 4). From Figure 11, the weekly observed values were high to the regulatory specification limit. The weekly values of Figure 11 also indicate that the produced water does not contain nutrient to sustain aquatic life because of high values obtained. Phosphates are major elemental nutrients needed to sustain aquatic life. Various forms of phosphate have been related to general problem of eutrophication, as concentration within 0.1mg/l indicates excessive enrichment. Above 0.2mg/l is considered nutrient deficient.

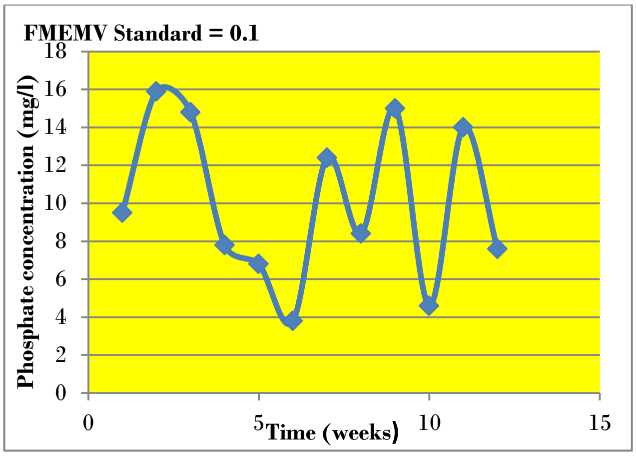

Figure 11. Phosphate concentration vs Time

Sulphate (SO$_4$): The recorded mean value of sulphate of the produced water effluent was 4.7mg/l and conformed with the FMEMV, DPR and WHO specification limit of 250mg/l for all the regulatory bodies and should be accepted, (Table 4). The weekly recorded values, Figure 12 were within the recommended limits. Also, Figure 12 weeks 4, 6 and 10 results were higher than others, despite that still in regulatory limits conformity. Sulphate is also a nutrient.

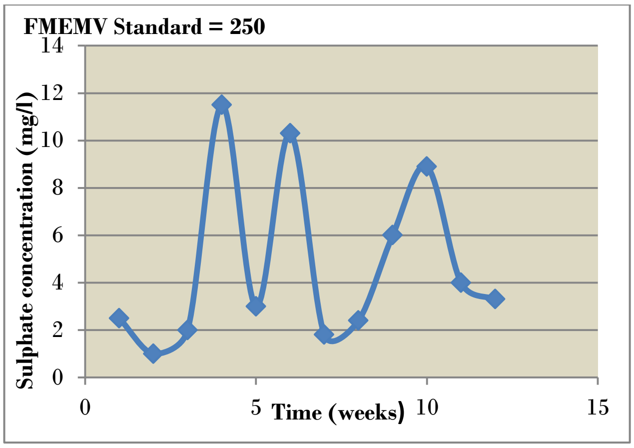

Figure 12. Sulphate concentration vs Time

IX. AMMONIUM CONCENTRATION (NH_4^+):

There is no WHO, GREAT BRITAIN, DPR or FMEMV standards for Ammonium concentration and therefore, cannot tell if the value falls within the permissible limit or not. While average recorded value was 0.28mg/l, (Table 4).

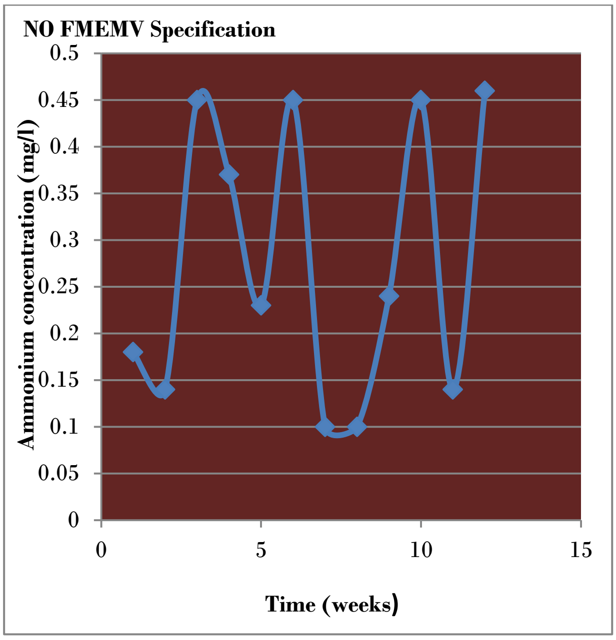

Figure 13. Ammonium concentration vs Time

Dissolved oxygen (DO): The average recorded dissolved oxygen concentration value of the produced water effluent was 2.2mg/l and complied with the FMEMV, DPR and WHO permissible limit of 5.0mg/l for the regulatory agencies, (Table 4). The weekly obtained values, Figure 14 were within the recommended limits. Figure 14 also, week 4 has the list value than other weeks. Dissolve Oxygen is one of the most commonly used parameters of water quality. Certain levels of Dissolve Oxygen (DO) adversely affect fish and other aquatic life, while total absence of DO leads to development of anaerobic conditions with attendant odour and aesthetic problems.

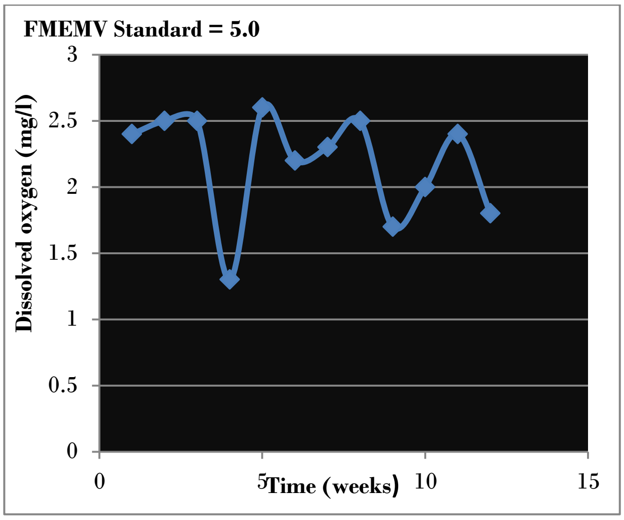

Figure 14. Dissolved oxygen concentration versus Time

Copper (Cu) concentration: The average and weekly values of copper of produced water effluent observed were less than 0.001mg/l, (Table 5) and very infinite compared to the FMEMV, DPR and WHO permissible limits of less than 1.00mg/l, 1.50mg/l and 2.00mg/l respectively and therefore should be accepted.

Zinc (Zn) concentration: The mean value of zinc concentration of the produced water effluent observed also was less than 0.001mg/l (<0.001mg/l), (Table 5) and very small compared to the FMEMV, DPR and WHO permissible limits of 1.00mg/l, 5.00mg/l and less than 5.00mg/l (<5.00mg/l), Table 5 and should be accepted.

Chromium (Cr) concentration: The mean value of chromium concentration of the produced water effluent was 2.20mg/l and does not fall within the FMEMV, DPR and WHO standard limits of 0.50mg/l, less than 0.10mg/l (<0.10mg/l) and 0.05mg/l respectively, (Table 5). The weekly values obtained were not in compliance to the permissible levels, Figure 15 and also, weeks 2, 3, 7 and 8 results were lower than other weeks result, this is as a result of time dependent.

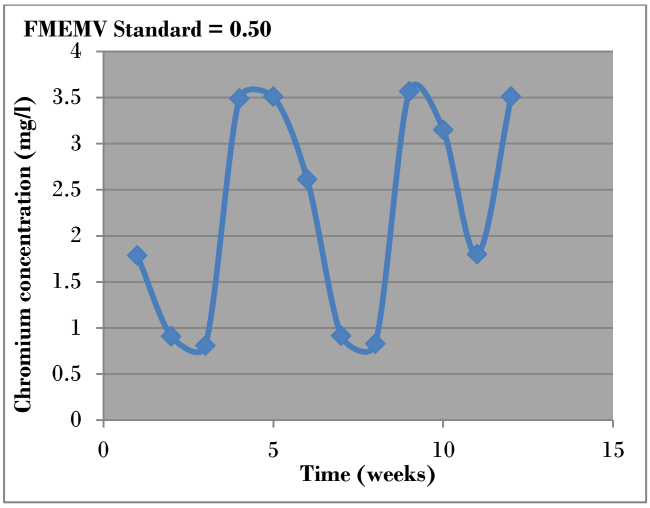

Figure 15. Chromium concentration vs Time

Lead (Pb) concentration: The average value of lead concentration of the produced water was 1.01mg/l and does not conformed within the FMEMV, DPR, and WHO standard limits of 0.05mg/l, 0.05mg/l and 0.01mg/l respectively, (Table 5). The weekly results obtained were not in compliance to the regulatory recommendations, as shown in Figure 16. Heavy metals are regulated in water because they are toxic to humans and animals, from Figure 16 this should be totally rejected.

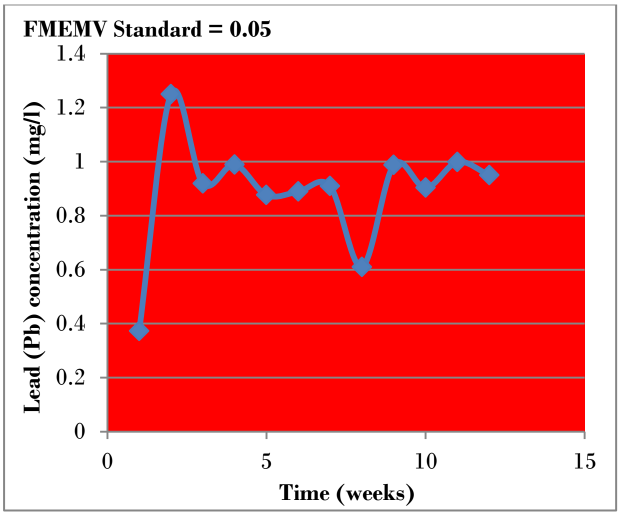

Figure 16. Lead (Pb) concentration vs Time

Iron (Fe) concentration: The mean value of Iron concentration of the produced water effluent was 1.10mg/l and does not fall within the FMEMV and WHO permissible limits of 0.30mg/l and <0.10mg/l respectively, (Table 5). There is no recommended DPR limit for this parameter. From Figure 17, week 1 result was below the limit while other weeks results were above the recommended limits.

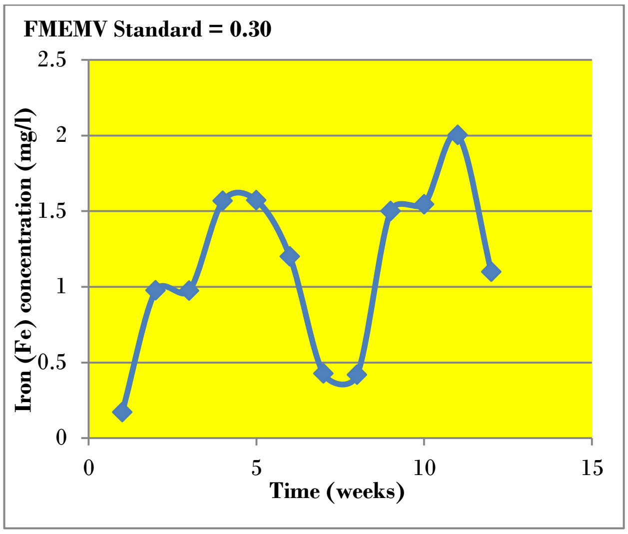

Figure 17. Iron (Fe) concentration vs Time

Manganese (Mn) concentration: The average manganese concentration value of the produced water effluent was 0.10mg/l and complied within the FMEMV, DPR and WHO standard value of 0.40mg/l for the regulatory agencies, (Table 5). The weekly results obtained were conformed the recommended limit, Figure 18.

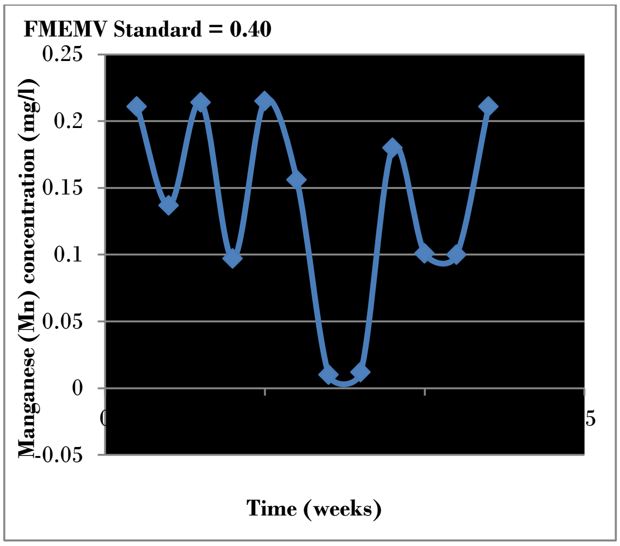

Figure 18. Manganese (Mn) concentration versus Time

Nickel (Ni) concentration: The average value of nickel concentration of the produced water effluent was 0.20mg/l and does not fall within the FMEMV, DPR and WHO specification values of 0.02mg/l, 0.02mg/l and < 0.03mg/l respectively, as shown in (Table 5). The obtained weekly values were above the recommended limits, Figure 19.

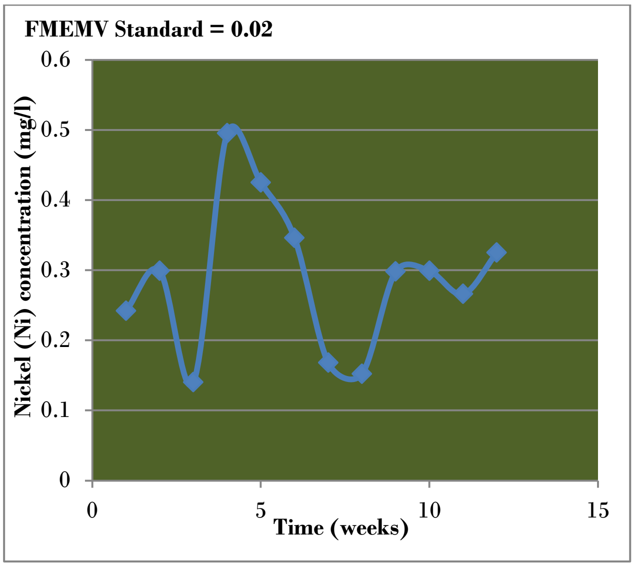

Figure 19. Nickel (Ni) concentration vs Time

Cyanide (CN-) concentration: The average cyanide concentration value of the produced water effluent was 0.017mg/l and falls within the FMEMV, DPR and WHO permissible limits of 0.05mg/l, 0.05mg/l and 0.07mg/l respectively, (Table 5). The weekly values obtained conformed to the recommended values, Figure 20.

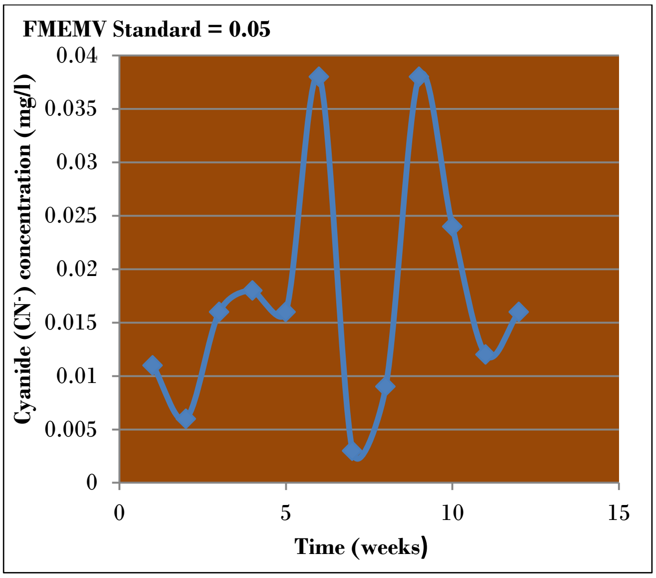

Figure 20. Cyanide (CN-) concentration versus Time

X. CONCLUSIONS

The physico-chemical, biological and heavy metals analysis carried out on samples collected clearly reveal the environmental status and pollution abatement equipment or devices in the Nkoro field.

Based on the mean/average results of the experimental analysis of produced water effluent from Nkoro Field, the following conclusions can be made:

1. The concentrations of the following parameters in the produced water fall within the Federal Ministry of Environment (FMEMV), Department of Petroleum Resources (DPR) and WHO limits for pollution control in Nigeria and standards for other parts of the world: Temperature, pH, Oil/Grease content, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Sulphate (SO4), Dissolved Oxygen (DO), Copper (Cu), Zinc (Zn), Manganese (Mn) and Cyanide (CN-).
2. Electrical Conductivity, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Alkalinity, Phosphate (PO4), Chromium (Cr), Lead (Pb), Iron (Fe) and Nickel (Ni) are above the Federal Ministry of Environment (FMEMV) recommended limits for pollution control in Nigeria.
3. The non-compliance observed in the parameters TDS, TSS and Conductivity values of the samples may have been influenced by the high concentration of dissolved solids in the surrounding recipient water.
4. In accessing the effective and efficiency of the produced water effluents treatment process is on the average and really need modifications to reduce the concentrations of the parameters that do not conform to the standard limits hence, manage it economically and ecologically.

NOMENCLATURE

^{0}C = degree Celsius temperature measurement, mg/l = milligrams per litre, API = American Petroleum Institute, FEPA = Federal Environmental Protection Agency, ASTM = American Standard of Testing Material, APHA = American Public Health Association, pH = hydrogen ion, determine quality of water, acid or base level, FMEMV = Federal Ministry of Environment, TDS = total dissolved solid, PO_4 = Phosphate, $SO_{4=}$ Sulphate, NH_4^+ = Ammonium, Cu = Copper, Pb = Lead, Zn = Zinc, Cr = Chromium, Fe = Iron, DO = dissolved oxygen, Ni = Nickel, CN$^-$ = Cyanide, Mn = Manganese, ppm = parts per million.

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