JASEM ISSN 1119 - 8362

J Appl. Sci. Environ. Mgt. 2003
Vol. 7(1) 61 - 66

The Environmental Impact of Oilfield Formation Water on a Freshwater Stream in Nigeria

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ABSTRACT: A comparative analysis of the physico-chemical parameters of treated oilfield formation water and that of a freshwater stream with no previous history of pollution from oil exploration activities was determined. The environmental impact resulting from the discharge of treated oilfield formation water into freshwater samples collected from this stream with no previous history of pollution from oil exploration activities was assessed in terms of changes in water quality parameters such as Dissolved oxygen (DO), Biochemical oxygen Demand (BOD) and in the microbial populations of the freshwater samples over a period of seven days since oilfield formation water readily mixes with flowing water after discharge. The analyses showed that concentrations of constituents such as chloride, total dissolved solids, total hardness, nitrate nitrogen and ammonium nitrogen alkalinity and silicate of the oilfield formation water were much higher than those of the freshwater source. The oxygen uptake (BOD values) in some stations of the freshwater stream differed significantly only at the 5% level after the treatment. Generally, the microbial populations were also lower after the treatment. Such observations suggest that, there is reduction in the biological activities of the freshwater after the addition of the treated oilfield formation water. @ *JASEM*

Formation water (also called produced water, oilfield brine, oilfield waste waster or connate water) is water that occurs in association with oil and gas in reservoir rocks and is present in the rocks immediately before drilling. The consensus among geologists is that Formation water originated from prehistoric seas (Chilingarian and Yen, 1978). Offshore drilling for oil and gas produces large amounts of Formation water, which is usually discharged into the aquatic environment. Water co-produced with oil and gas and separated for discharged retains up to 50 mg/L^{-1} of separate-phase oil as small droplets and also may contain up to 35 mg L^{-1} of dissolved hydrocarbons (Koons *et al.*, 1977). The relative amount of hydrocarbons contributed to the aquatic environment by oilfield-produced waters is so small that any overall environmental effects from these inputs should be minimal (Koons *et al.*, 1977). However, the numerous inorganic and organic constituents dissolved in the Formation water can be potentially or actually far more hazardous than the crude oil itself (Wardley-Smith, 1979). The ecological health of many river systems is threatened by the discharge of toxic compounds and the accumulation of these contaminants in these aquatic environments (Pruell *et al.*, 1990). In Nigeria, sources of contamination are known to include industrial effluents sewage outfalls, urban runoff, rivers and atmospheric deposition. Many freshwater river systems have been classified as unfit for human consumption by the Federal Environmental Protection Agency (Onu, 1991). The recent introduction of environmental pollution discharge charges by the Lagos State Government is an effort to arrest the continued degradation of the environment through the discharge of untreated industrial wastes (Uwejamomere, 1991). The largest contributors are the petroleum and petrochemical-bases industries. In Nigeria were oil exploration activities are being carried out, Formation water is one of the major pollutants of the aquatic environment, which has now attracted much attention of the public. Unlike oil which forms a slick, Formation water readily mixes with flowing water after discharge, Collins (1975; 1980), Koons *et al.*, (1977) and Hunt (1979) provide extensive data on Formation water from many oilfield locations. Nigeria oilfield Formation waters contain 3,000 to 9,000 mg/L^{-1} chloride ions (Ibiebele, 1985; Oteri, 1985) and the continuous discharge of such wastewaters into a freshwater environment could cause major damage to aquatic and agricultural resources. Courant *et al.* (1985) provide extensive data for water-type classification for the Niger delta river and creek waters. These are areas that have experienced oil exploration activities over the years. The few oil pollution studies that have been carried out were mainly based in the Niger Delta areas (Snowden and Ekweozor, 1987; Obire, 1988; 1990). These areas have experienced oil exploration activities over the past 30 years. Reliable baseline data for use in assessing the impact of oil production activities are thus completely absent. Pollution incidents are generally monitored in a questionable manner involving measurements taken only after the occurrence of the incident (Snowden and Ekweozor, 1987). In recent years, oilfield formation water has

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been regarded as a major pollutant of the aquatic environment in Nigeria (Ibiebele, 1985). To reduce the impact of oilfield formation-water, oil exploration companies now subject the oil field formation-water to some form of treatment before it is discharged into the aquatic environment. In Nigeria however, no information is available which allows for comparison of the constituents of such treated Formation waters and the bodies of waters into which they are usually discharged. In Nigeria also, no information is available which allows comparison of short-term or long-term effects of treated oilfield formation water discharged into surface waters. Microorganisms are useful in predicting the impact of a particular stress on the environment and microorganisms often respond to the introduction of a pollutant through shifts in their numbers (Mckinley *et al.*, 1982; Clark and Patrick, 1987; Obire, 1988). Our objectives therefore were to investigate water quality characteristics of treated formation water and those of a freshwater stream, which has no previous history of pollution with formation water or of contamination by oil exploration activities. The immediate effect of the addition of treated oilfield formation water on the water quality characteristics such as Dissolved oxygen (DO) and Biochemical oxygen demand (BOD) and on the microbial population of the freshwater stream was also investigated. The aim is to provide a comparative analysis of the constituent composition of treated oilfield formation water and those of a freshwater source, and also to provide a baseline against which the impact of future discharge of formation water on freshwater could be assessed.

MATERIALS AND METHODS

Treated oilfield Formation water was collected form an oil field in the delta area of Delta State where oil-water separation and oil-gas pumping operations are being carried out. Freshwater samples were collected from three different stations located on the Awo freshwater stream in Akure, Ondo State, Nigeria. This stream has no history of contamination from oil exploration activities. The treated oilfield formation water used for the studies was filter-sterilized using 0.22μm pore size membrances, type GS (Millipore SA 67 Molsheim, France).

The treated Formation water and freshwater samples were analysed for pH, total dissolved solids, chloride, calcium hardness, magnesium hardness, total hardness, total alkalinity, nitrate, ammonia, phosphate, silicate, and total iron. These tests were carried out in accordance with procedures specified in APHA (1985). Colour was determined using a Lovibond colour comparator and expressed in Hazan units (Hu). The determinations of dissolved oxygen (DO) and Biochemical oxygen demand (BOD) were carried out according to the procedures specified in APHA (1985). The effect of the addition of treated oilfield formation water on the freshwater quality was determined by the addition of sterilized formation water (5% v/v) to the freshwater samples (treatment) and were analysed for DO and BOD at different incubation periods (0, $^1/_2$,1,2,3,4,5,6 and 7 days). Corresponding freshwater samples without treatment oilfield formation water (controls) were also analysed for DO and BOD. The effect of treated oilfield formation water (5%v/v) on the microbial population of the freshwater was determined by bacterial enumeration for a period of 7 days ($^1/_2$,1,2,3,4,5,6, and 7 days). Corresponding control samples were also set up for the bacterial enumeration. The numbers of aerobic heterotrophic bacteria were estimated using the spread plate technique on nutrient agar. All plates were incubated in an incubator (Astell Hearson England, Model JB F040) for 24h when colonies, which developed, were counted as numbers of aerobic heterotrophic bacteria (colonies forming units-cfu) estimated from averages of three replicate 0.1ml spreads of 10^{-4} dilutions. Values obtained were expressed in x10^4 cfu $100mL^{-1}$.

RESULTS AND DISCUSSION

The average data obtained for triplicate samples for the constituent concentrations of the treated formation water and the freshwater is shown in Table 1. The result of the investigation showed that except for silicate, colour, phosphate and total iron, the concentrations of the constituents of the treated oilfield Formation water were higher than those of freshwater samples. Both water samples had equal amounts ($20mg/L^{-1}$) of silicate. This is probably due to the geological formation of the freshwater stream, which like the Formation water has its source from rocks and flows over rocks and sandstones. The colour of the freshwater and treated Formation water was 80 Hu and 40 Hu units respectively. The colour of the freshwater may have been the result of extraction of colouring material from humans and vegetation around the stream. The colour of the treated Formation water may have been imparted by marine plants and animal life which were transformed into crude oil that occurs in association with Formation water (Chilingerian and Yen, 1978). Phosphorus is a nutrient found typically as phosphate. Continuous discharge of treated Formation water with diminished concentration of phosphate into the freshwater body may result in the dilution or reduction of the nutrient supply in the aquatic ecosystem.

Table 1. Concentrations of Some Constituents of Treated Oilfield Formation Water and Freshwater

Constituents	Treated Oilfield Formation Water	Freshwater
Colour (Hu)	40	80
pH	8.3	6.9
Total dissolved solids mgl^{-1}	12,800	200
Chloride mgl^{-1}	688	0.043
Calcium hardness mgl^{-1}	73.9	54.41
Magnesium hardness mgl^{-1}	216	44.46
Total hardness as $CaCO_3$ mgl^{-1}	289.96	97.7
Total Phenolphthalein alkalinity as $CaCO_3$ mgl^{-1}	158	18
Total methyl orange alkalinity as $CaCO_3$ Mgl^{-1}	1052	114
Nitrate-Nitrogen mgl^{-1}	200	20
Ammonium-Nitrogen mgl^{-1}	10.0	0.4
Phosphate-phosphorus mgl^{-1}	0.07	0.24
Silicate-Silicon mgl^{-1}	20	20
Total iron mgl^{-1}	4.0	5.0

All other physico-chemical parameters such as pH, total dissolved solids, chloride, calcium hardness, magnesium hardness, total hardness, total alkalinity, nitrate – nitrogen and ammonia-nitrogen of the freshwater samples were less than their corresponding concentrations in treated Formation water whose constituent concentrations were in turn less than concentrations reported for typical non-treated oilfield produced waters (Collins. 1975, 1980; Koons *et al.,* 1977; Junt, 1979). The concentrations of total dissolved solids, total hardness, total nitrate-nitrogen and ammonium-nitrogen for treated Formation water in this study were also greater than their corresponding concentrations reported for untreated and treated sewage mixed with industrial effluent (Tripathi and Suresh, 1991). The effect of the addition of treated oilfield formation water on the BOD in the different stations of the freshwater stream is shown in Table 2.

Table 2: Oxygen Uptake of the Freshwater

Incubation Period (Days)	BOD Value ($mg\ l^{-1}$) Stations					
	A		B		C	
	Control	Treatment	Control	Treatment	Control	Treatment
1/2	17.5	16.0	17.9	0.4	1.10	0.2
1	21.0	12.8	20.05	1.0	1.30	2.1
2	17.6	4.8	19.4	0.6	1.20	1.3
3	11.9	2.8	19.8	1.0	1.15	0.4
4	14.5	2.8	21.4	1.0	1.35	0.9
5	19.6	2.5	21.0	0.6	1.20	1.1
6	19.6	2.7	19.5	0.7	1.21	1.1
7	18.9	2.5	19.5	0.7	1.20	1.0

The BOD values for stations A,B and C of the freshwater (control) ranged from $11.9mgL^{-1}$ - $21.0mgl^{-1}$; $17.9mgL^{-1}$ - $21.4\ mgL^{-1}$; and $1.10\ mgL^{-1}$ - $1.35\ mgL^{-1}$ respectively while the BOD values for the stations after treatment ranged from $2.5\ mgL^{-1}$ - $16.0mgL^{-1}$; $0.4\ mgL^{-1}$ - $1.0\ mgL^{-1}$ and $0.2\ mgL^{-1}$ - $2.1\ mgL^{-1}$ respectively. The present study provides evidence that the addition of treated oilfield formation water changes the dissolved oxygen (DO) and hence the biochemical oxygen demand (BOD) and on the microbial population of the freshwater systems. Statistical analysis using the paired t-test (two-tailed test) of the BOD values obtained showed that there is significant difference over the control at stations A and B at the 5% level after the treatment. There was however no significant difference in BOD values at Station C after the treatment. This may be due to the use of station C for domestic activities such as washing of household utensils; farm implements and farm produce by the inhabitants of the area. Generally, the BOD in the different stations of the freshwater stream were lower after the addition of (5% v/v) the treated oilfield formation water. BOD of the water is an indication of the amount of DO that will be depleted from water during the natural biological assimilation of organic matter. Increased biological activity therefore increases the rate of DO utilization (BOD) from natural water (Dobbins, 1964;

Pavoni and Hagerty, 1975). The addition of treated oilfield formation water with high concentrations of chloride, ammonia, total hardness, total dissolved solids and high alkalinity to the freshwater (treatment samples) may have reduced the extent to which the aquatic organisms utilized available oxygen. This in turn may have lowered the biological activity of the organisms in the treatment samples. Thus the addition of the treated oilfield formation water had direct effect on the biological activity of the freshwater. This explains why the BOD values of the freshwater in the present investigation were higher in the controls than in the treatment samples. The present investigation also provides evidence that the addition of the treated oilfield formation water has effect on the microbial population of the freshwater. Stastistical analysis showed that there is a significant difference in microbial population over the controls in all the stations of the freshwater stream at 5% level after the treatment. In general, the microbial populations in the different stations of the freshwater stream were lower after treatment. Microbial population is a measure of biological activity in a system (Dobbins, 1964; Pavoni *et al.*, 1975; Dow *et al.*, 1990). Thus in this study, the biological activity of the controls were higher than in the treatment samples. This explains why the oxygen uptake (BOD) were higher in the controls than in the treatment samples. Bacteria are less resistant to external influences such as fluctuations in osmotic pressure than higher microorganisms such as protozoa, fungi, lower algae and yeast (Nelso-Smith, 1973). The observed difference in microbial population of the treatment samples may have been caused by the direct toxicity or inhibitory effect of the added oilfield formation water on the microbial populations of the freshwater. This could be as a result of " Osmotic Shock" on the microorganisms because of the high salinity of the added formation water. The high ammonium concentrations of the formation water may also have had a deleterious effect on the microbial population and its high alkalinity may have reduced the extent to which the microorganisms in the treatment samples utilized available oxygen. Thus, there is a reduction in the biological activity in the treatment samples, which may have resulted in the observed lower BOD values in treatment samples. It has also been reported that the chemicals in the water-soluble extracts of crude oil inhibited the growth of certain marine organisms (Lacaze, 1969; Nuzzi, 1973) and may also affect microbial communities as a result of direct toxic effect (Oppenheimer *et al.*, 1980; Clark and Patrick, 1987). The present study shows that there is no significant difference at the 5% level in the BOD values of station C where there is significant difference in the microbial population of the station after the treatment. Oppenheimer *et al.*, (1980) reported that some stations in their study exemplified repression relative to the control oxygen uptake value (BOD), which may have been caused by the added pollutant. They also argued that numerical data and not statistical analysis should be used to indicate that a pollutant had adverse effect in an aquatic environment. The variations in the BOD data between stations in this study may have been caused by the distribution of specific microorganisms in the samples from the different stations or by their initial numbers. These variations are a result of the inherent variability of biological systems (Oppenheimer *et al.*, 1980; Kamath *et al.*, 1991). The effect of the addition of treated oilfield formation water on the microbial population in the different stations of the freshwater stream is shown in Table 3.

Table 3. Microbial Population of the Freshwater (x 10^4 Cfu $100ml^{-1}$)

Incubation Period (Days)	Stations					
	A		B		C	
	Control	Treatment	Control	Treatment	Control	Treatment
½	1.36	0.75	1.36	0.84	0.69	0.56
1	0.97	0.72	1.71	0.68	0.64	0.40
2	0.49	0.28	0.88	0.41	0.45	0.39
3	0.80	0.38	1.93	0.72	0.15	0.10
4	1.30	0.60	4.31	1.21	0.81	0.27
5	1.59	0.63	2.10	1.00	1.15	0.25
6	1.42	0.65	3.32	0.96	1.35	0.48
7	1.60	0.72	4.91	0.96	1.01	0.54

The microbial populations for Stations A, B and C of the freshwater (controls) ranged form 0.36 x 10^4 cfu 100 ml^{-1} to 1.6 x 10^4 cfu 100 ml^{-1}; 0.60 x 10^4cfu 100 ml^{-1} to 4.91 x 10^4 cfu 100ml^{-1}; and 0.15 x 10^4 cfu 100 ml^{-1} to 1.35 x 10^4 cfu 100 ml^{-1} respectively while microbial populations for the stations after treatment ranged from 0.20 x 10^4 cfu 100 ml^{-1} to 0.75 x 10^4 cfu 100 ml^{-1}; 0.24 x 10^4 cfu 100 ml^{-1}; and 0.10 x 10^4 cfu 100 ml^{-1} to 0.56 x 10^4 cfu 100 ml^{-1} respectively. The results of the present study indicate that there were more active microorganisms in the freshwater (controls) than there were in the treatment samples. The reduction in the microbial population in the treatment samples has demonstrated how severe the effect of relatively small amounts of the treated oilfield formation water used in this study can be on a freshwater system. The continuous discharge of such treated oilfield formation water will have a deleterious effect on the proper functioning of the freshwater aquatic ecosystem thereby affecting aquatic and agricultural resources that are of economic importance.

Mckinley *et al.*, (1982). Clark and Patrick (1987) argued that in assessing the potential for adverse environmental effect of pollutants on living resources, it is the population of a representative species and not an individual that is important and that unless an effect has consequences at the population level, it is insignificant. The present investigation showed that concentrations of constituents such as chloride, total dissolved solids, total hardness, nitrate nitrogen and ammonium nitrogen of treated oilfield formation water were much higher than those of the freshwater source. They were also higher than the maximum allowable concentrations for potable water (Cox, 1969). The high concentrations of inorganic and organic constituents present in the treated oilfield formation water can be potentially or actually hazardous. The discharge of wastewater high in chloride, hardness, total dissolved solids, alkalinity and various forms of nitrogen into the aquatic environment is a matter of great concern. High concentrations of these constituents have direct effect on the biochemical oxygen demand (BOD) of aquatic systems and reduce the extent to which aquatic organisms can utilize available oxygen. Nitrate causes methaemoglobinaemia, disease-affecting infants while nitrous acid formed from nitrite in acidic solution can react with amines to form nitrosamines, many of which are known to be carcinogens (Kamath *et al.*, 1991). Since the present investigation has shown that the constituent concentrations of the treated formation water are higher than those of the freshwater stream; and also that the treated formation water has potential for adverse environmental effect on a freshwater system, further treatment of the treated formation water such as that used in this study is necessary if such formation water is to be discharge into freshwater environments.

Acknowledgement: We would like to express our appreciation to the Staff of the Ondo State Water Corporation Laboratory

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