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ORIGINAL ARTICLE

Assessment of the Toxic Effects of Oil-based Drilling Mud (drilling waste) on Brackish Water Shrimp (*Palaemonetes africanus*)

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ABSTRACT
The toxic stress of drilling mud (drilling wastes) from operations in an oil drilling industry in the Niger Delta area of Nigeria was assessed using standard laboratory toxicity test. The experimental shrimp used was Palaemonetes africanus obtained from a brackish water environment. The concentrations of the drilling wastes used for the definitive experiment was 31250, 62500, 125000, 250000, 500000 ppm SPP (equal to 3.125, 6.25, 12.5, 25 and 50%) after a range finding test was conducted for 24 h. The mean % mortality obtained for the 96 h experimental duration for the five concentrations used were 0, 13, 50, 100 and 100% respectively. The 96 h median lethal concentration (LC_{50}) was estimated using the Finney Probit method of analysis and was found to be 131833 ± 6870% ppm SPP (13.18 ± 0.7%) with a 95% confidence limit of 9.56 - 18.81. There was significant difference between mortality of organisms exposed to the drilling mud waste and the controls at levels of $p < 0.05$. The release of drilling mud waste into water bodies in the Niger Delta could adversely affect bottom dwelling organisms inhabiting such environment due to the toxic effects of the chemical components in the drilling mud. This study provides the impetus to regulate the disposal of drilling mud waste into the environment so as to safe guard the important but fragile aquatic bottom biota.
Key Words: *Oil-based drilling mud; Toxicity; Palaemonetes africanus; Shrimp; brackish water.*

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INTRODUCTION

Crude oil and natural gas are fossil fuels that come from dead animals and plants which have been covered by layers of sedimentary rock, and heated under pressure in the absence of air over millions of years. Crude oil is obtained from the earth crust and since oil and gas are less dense than water, they rise to the top of porous rock layers. They may then become trapped below a layer of non-porous rock and the trapped gas or oil can only be obtained by drilling through the non-porous layer. Oil exploration, drilling, and extraction are the first phase or what the oil industry calls the "upstream" phase in the long life cycle of oil [1].
The physical alteration of the environment from exploration, drilling, and extraction activities include deforestation, ecosystem destruction, chemical contamination of land and water, long-term harm to animal populations and human health amongst others. Oil exploration, drilling, and extraction activities involve the use of water-based muds (WBMs), oil-based muds (OBMs) and synthetic-based muds (SBMs) to:

- cool and clean the bit
- maintain pressure balance between the geological formation and the borehole
- lubricate the bit
- reduce friction in the borehole
- seal permeable formations
- stabilize the borehole and;
- carry cuttings to the surface for disposal [2]

Water-based muds (WBMs) are by far the most commonly used mud, both onshore and offshore. They are widely used in shallow wells and shallower portions of deeper wells, but are not very effective in deeper wells. The use of WBMs sometimes generate 7000 to 13000 bbl of waste per well and about 1400 to 2800 bbl of that amount are drill cuttings depending on the depth and diameter of the well. WBMs use water as their base fluid and do not contain any oil, but are economical and easy to dispose of because of their relative biodegradability and low toxicity [3]. However, due to some limitations of WBMs, oil-based muds (OBMs) have been developed to overcome the problems associated with WBMs and are effective for a wide range of special situations, which include high temperatures, hydratable shales, high angle and extended-reach well, high density mud and drilling trough to salt. Lower waste volume is produced from wells drilled with OBMs, this is due to the fact that very little slumping or caving in of the walls of the hole can occur. Similarly, OBMs can be reconditioned and reused rather than been discharged at the end of the well and it is only the drill cuttings that will be disposed to the ocean. The average volume of OBM waste is estimated at 2000 to 8000 bbl per well as compared to WBMs [3]. OBMs use either diesel or mineral oil as the base fluid and since they contain oil, their waste cannot be discharged on site without complying with the regulatory standards of many countries [1].

Drilling mud (drilling wastes) are sometimes unintentionally or intentionally released into water bodies and can damage the gills of prawn, shrimp and other bottom dwellers at post larvae stages. For most aquatic animals, the gills are major sites through which waterborne pollutants can enter the body and are often affected by such substances [4,5,6,7]. The toxic effect could be due to the paraformaldehyde biocides and heavy metals included in the different mud formulations / composition, which increases the toxicity to aquatic species especially bottom dwellers [8,9]. Acute (short-term) and chronic (long-term) health impacts can occur through bioaccumulation of oil, metals and other products in aquatic species that are consumed by humans.

In many countries, muds and cuttings are discharged on site into the ocean. However, the regulators in Nigeria [Federal Ministry of Environment (FME) and Department of Petroleum Resources (DPR)] require that a toxicity test be conducted on any drilling mud to ascertain their safety before release into the environment or deep wells [10,11]. The lethal concentration (LC_{50}) is a standard toxicity test to determine the concentration of the substance which will prove lethal to 50% of a test population of the organism in a specified duration [12,13].

The aim of this study was to estimate the short-term toxicity of oil-based drilling mud (drilling wastes) on shrimp (*Palaemonetes africanus*) in the brackish water environment. These organisms were chosen because they produce consistent and reproducible response to toxicants and could be transported and maintained in the laboratory with relative ease. They are also principle prey of many larger vertebrates [14].

MATERIALS AND METHODS

Test chemical (*drilling wastes*)

The test chemical used for this study was spent oil-based drilling mud (drilling wastes). The drilling mud (toxicant) used was provided courtesy of the Nigerian Petroleum Development Company Limited in sterilized glass containers. After collection, the test chemical was immediately stored at $4^{o}C$ prior to the commencement of the test. The test chemical was brought to room temperature before the test solutions were prepared. The methods used for preparation of waste drilling fluid suspensions were based on procedures outlined in Standard Methods for the Examination of Water and Wastewater and EPA Protocol 660/3-75-009 [15].

Test organisms

The test species (shrimp; *Palaemonetes africanus*) from brackish water environment used for this study were collected from Abua in Rivers State (4°34′04.208′′ N, 7°21′56.471′′ E). The shrimp were collected with dip nets and transferred into polythene bags filled midway with water from the shrimp habitat. The bags were later inflated with air to provide oxygen and to reduce stress on the test species during transportation to the laboratory.

The stock population of the test species was acclimatized in a large glass (amber-coloured) holding tanks. The holding tanks were aerated with low whisper aerators equipped with air stones. The shrimp were fed daily during the period of acclimatization with prepared commercial shrimp meal to avoid or prevent starvation. The water in the tank was changed every other day to prevent accumulation of metabolites. The shrimp were acclimated for seven days.

Short-term toxicity test of drilling wastes

The short-term toxicity bioassay began with a 24 h range-finding otherwise called exploratory test to determine the range of concentrations to be used in the definitive experiment. A subsample of the mud was mixed with filtered test dilution water in a volumetric flask, mud-to-water ratio of 1 to 9. The mud-water slurry was mixed with magnetic stirrers for 5 minutes and allowed to settle for 1 hour. At the end of the settling period, the suspended particulate phase (SPP) was carefully decanted into an appropriate container. The decanted solution is defined to be 100% SPP (equal to 1000000 ppm SPP). Any other concentration of SPP refers to a percentage of SPP that was obtained by volumetrically mixing 100% SPP with the dilution water. The concentrations of the test solutions used were 3.125, 6.25, 12.5, 25 and 50%

(equal to 31250, 62500, 125000, 250000, 500000 ppm SPP). A negative control without the toxicant was included to ensure the reliability of the experimental procedures.

In the definitive test, ten (10) shrimp per test tank was prepared in triplicate for the five (5) concentrations of the drilling waste and two controls. The test media was aerated and maintained at 28±1°C. The test organisms were exposed to fresh solutions of the various concentrations of the test chemical (drilling waste) every twenty four (24) h. Mortality was recorded during the 96 hour exposure period according to the time schedule at 24, 48, 72 and 96 h and the dead organisms were removed immediately on detection. The criteria for death were total lack of movement, immobility and lack of response after repeated prodding with a probe [16].

The percentage (%) mortality in the three replicate tanks for each concentration at different intervals of time were calculated separately using the formula.

$$\text{Mortality (\%)} = \frac{\text{No dead}}{\text{Total number tested}} \times 100\%$$

Statistical Analysis

The median lethal concentration LC_{50} is the concentration of test chemical or substance that is estimated to kill 50% of a test population during continuous exposure over a specified period of time [13]. This median level concentration is a standard measure of toxicity. The LC_{50} and its 95% confidence limits are usually derived by statistical analysis of mortalities in several test concentrations, after a fixed period of exposure. Median lethal concentrations (LC_{50}) and 95% confidence intervals were calculated with a computer program based on the probit analysis [17]. Mortalities recorded in the three test chambers for the drilling waste was used to determine the LC_{50} for the test organisms. Significant analysis between test treatments and controls at levels of $p < 0.05$ was done using the analysis of variance (ANOVA) in Statistical Package for Social Science (SPSS) statistical software in Version 16.0.

RESULTS

Short-term toxicity of drilling wastes to shrimp

The short-term toxicity of the drilling mud wastes to brackish water shrimp was estimated using the probit method of analysis. The results for the definitive test of the drilling mud and control are shown in Table 1. At the end of the 24-h bioassay, no mortality was recorded in the lowest test concentration of 31250 ppm (3.125%) and 62500 ppm (6.25%) except in the high test concentrations (125000, 250000 and 500000 ppm SPP), which recorded a mean % mortality of 10, 57 and 77 respectively.

The mean % mortality recorded at the end of the 48 h test duration for concentrations 3.125, 6.25, 12.5, 25 and 50% were 0, 0, 23, 77 and 100 respectively. At 72 h, the mean mortality values were 0, 0, 33, 100 and 100% respectively. At this time, most of the organisms were showing signs of stress and their movement became erratic. At 96 h experimental period, the mean mortality values recorded for the varying concentrations of the drilling mud wastes were 0, 13, 50, 100 and 100% respectively (Table 1).

The mean 96 h LC_{50} obtained from the experiment was 131833 ± 6870% ppm SPP (13.18 ± 0.7%). The 95% confidence limit was estimated at 9.56 - 18.81.

Physico-chemical tests were performed on the test solutions at the beginning (24 h) and at the end (96 h) of the duration of the experiment. Parameters analyzed include: pH, TDS, Total Hardness and TSS, which recorded concentrations that varied from (6.58 to 8.35), (4890 mg/L to 5886 mg/L), and (126.0 to 178 mg $CaCO_3$/L) and (25 mg/L to 305 mg/L) respectively.

DISCUSSION

The mortality of *Palaemonetes africanus* in different concentration of drilling wastes is presented in Table 1. Variability in percentage mortality among treatments (drilling wastes) was relatively high. In general, mortality was concentration dependent i.e. there was a progression of effect from low mortality to high mortality rate with increase in toxicant concentrations in the toxicity test of the drilling mud wastes. There was no mortality in the control tank for the 96 h duration of the test, which indicates that the test conditions were appropriate and thus mortality recorded in the test solutions could have been induced from the effect of the drilling mud wastes.

Some observations made include disemboweling of organism at the high concentrations of the drilling mud wastes (250000 ppm and 500000 ppm SPP i.e. 25% and 50% respectively). The cephalothoraxes of most of the organisms were broken from the abdomen at the highest concentrations. The dead organisms at high concentrations were noticed floating in the test solutions. This indicates that the experimental tests organisms were sensitive to the test toxicant since the control group recorded no mortality in all triplicate test vessels [4,18].

Table 1: Short-term toxicity profile of brackish water shrimp exposed to drilling mud wastes

			Mean % Mortality			LC_{50} (%)	SD
Test Duration/Conc	**3.125**	**6.25**	**12.5**	**25**	**50**		
24	0	0	10	57	77	30.16	3.0
48	0	0	23	77	100	19.51	1.5
72	0	0	33	100	100	15.25	0.9
96	0	13	50	100	100	13.18	0.7

LC_{50}= Lethal concentration
SD= Standard deviation

Alterations of the gill filaments seemed to be responsible for the mortality of shrimp observed in this study [7]. The drilling mud waste was toxic and resulted in the death of the test organisms mainly at high concentrations. This could be attributed to the presence of some dissolved compounds in the drilling mud wastes (e.g. chrome salt, surfactants, paraformaldehyde biocide, metals, and oil). Hydrocarbon oils, one of the components of oil-based mud, enter through the gills and disturb the main functional systems such as respiration, nervous system, blood formation and enzyme activity [3].

The values obtained from the toxicity test are an indication that the drilling mud has a potential to cause short-term lethal toxicity. It is also a prediction of likely adverse effect on shrimp populations in benthic sediment of the Niger Delta ecological zone if continuously exposed to oil-based mud wastes. Drilling mud pollution on bottom dwellers could be more detrimental since these organisms remain in their habitat and have no means of burrowing out completely and moving away from the site of pollution like pelagic organisms (fish), which can swim to other directions on sensing pollution in its habitat.

CONCLUSION

This study revealed that accidental and intentional release of drilling mud wastes constitutes a potential threat to environmental sustainability and human health. This is due to the fact that most of the drilling mud wastes released into the environment sorbs to sediment particles where they cause harm to organisms in the sediment and overlying waters. The chemical compounds in the mud could also bioaccumulate in the shrimp and cause adverse health conditions in man when consumed. There is therefore the need to adequately protect the delicate and rich biodiversity of the Niger Delta ecosystem.

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