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Oily Sludge Bioremediation Pilot Plant Project, Nigeria

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***Abstract*—**Brass terminal, one of the several crude oil and petroleum products storage/handling facilities in the Niger Delta was built in the 1980s. Activities at this site, over the years, released crude oil into this 3 m-deep, 1500 m-long canal lying adjacent to the terminal with oil floating on it and its sediment heavily polluted. To ensure effective clean-up, three major activities were planned: site characterization, bioremediation pilot plant construction and testing and full-scale bioremediation of contaminated sediment / bank soil by land farming. The canal was delineated into 12 lots and each characterized, with reference to the floating oily phase, contaminated sediment and canal bank soil. As a result of site characterization, a pilot plant for on-site bioremediation was designed and a treatment basin constructed for carrying out pilot bioremediation test. Following a designed sampling protocol, samples from this pilot plant were collected for analysis at two laboratories as a quality assurance / quality control check. Results showed that Brass Canal upstream is contaminated with dark, thick and viscous oily film with characteristic hydrocarbon smell while downstream, thin oily film interspersed with water was observed. Sediments were observed to be dark with mixture of brownish sandy soil with TPH ranging from 17,800 mg/kg in Lot 1 to 88,500 mg/kg in Lot 12 samples. Brass Canal bank soil was observed to be sandy from ground surface to 3m, below ground surface (bgs) it was silty-sandy and brownish while subsurface soil (4-10m bgs) was sandy-clayey and whitish/grayish with typical hydrocarbon smell. Preliminary results obtained so far have been very promising but were proprietary. This project is considered, to the best of technical literature knowledge, the first large-scale on-site bioremediation project in the Niger Delta region, Nigeria.

***Keywords*—**Bioremediation, Contaminated sediment, Land farming, Oily sludge, Oil Terminal.

I. Introduction

OIL and gas exploration and production (O&G E&P) activities had gone on in the Niger Delta region of Nigeria since 1950s resulting in the installation of O&G E&P facilities like Oil terminals, tank farms, depots, etc. in the region [1]. One of such oil facilities is the Brass Terminal (Fig. 1), about 70ha expanse of oil installations built in the 1980s which is owned and operated by Nigerian Agip Oil Company Ltd (NAOC) in joint venture (JV) partnership with Nigerian National Petroleum Corporation (NNPC) in Brass, Bayelsa State.

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Fig. 1 Aerial view of Brass Terminal & Adjacent Brass Canal

At this terminal and other O&G E&P facilities, during daily activities like loading & offloading of oil to Oil tankers, dehydration of crude, disposal of produced water, etc, substantial volumes of oil spill into the environment through pump / equipment failure, pipe / hose burst, etc. Besides, produced water, oily sludge and other oily wastes could be released into the environment leading to the pollution of the environment. These and other terminal activities performed at this terminal over the years have generated a rather critical situation regarding the quality of the site, with particular reference to the channel and canal bank soil and sediment being contaminated by hydrocarbon substances [2].

It is the O&G E&P industry's best practice, in line with the Oil Company's Environmental policy of pollution prevention and good housekeeping, to clean up any oil spill within her facilities [3]. In view of this, the proponent planned to clean up the canal and thus comply with industry's best practices. This study was therefore designed, as a preliminary stage, to ensure effective clean up by carrying out site characterization, bioremediation pilot plant construction and testing and full-scale bioremediation of contaminated sediment / bank soil by land farming.

II. Materials and Methods

A. Study Area

Brass is a Local Government Area in Bayelsa State, Nigeria with geographical coordinates of 4° 19' 1" North and 6° 14' 34" East. It has an area of about 1,404 km² and a population of 185,049 as at the 2006 National Population Census [4] with its headquarters in Twon-Brass located on the coast. Brass has a coastline of approximately 90 km on the Bight of Bonny. Much of the area of the LGA is occupied by the Edumanom National Forest [5].

Brass terminal, a crude oil and petroleum products storage/handling facility covering about 70 ha and owned by

Nigerian Agip Oil Company (NAOC) was built in the 1980s and is located south of the city of Brass along the Niger Delta coastline.

B. Planned Activities

Three major activities were planned for this project; namely:

(i) Site characterization,
(ii) bioremediation pilot plant construction and testing, and
(iii) final full-scale bioremediation of contaminated sediment / bank soil by land farming.

1. Site Characterization

Samples and Sampling Protocol

For the purpose of site characterization, the Canal was delineated into 12 lots (Lot 1 – Lot 12). Samples taken were the Canal sediment and bank soil as well as a mixture of both (Canal sediment + Canal bank soil). Following a designed sampling protocol (Table I), samples from Brass Canal were collected, as follows:

TABLE I
DESIGNED SAMPLING PROTOCOL FOR THE PROJECT

S/N	SAMPLES	PARAMETERS
1	Sediment from Canal	Anaerobic condition (to evaluate the chemical stability of compounds)
2		Aerobic condition (to evaluate natural attenuation)
3		Aerobic condition with adjustment of moisture
4		Aerobic condition with nutrients adjustment
5		Aerobic condition with moisture & nutrients adjustment
6	Sand from Canal bank	Anaerobic condition (to evaluate the chemical stability of compounds)
7		Aerobic condition (to evaluate natural attenuation)
8		Aerobic condition with adjustment of moisture
9		Aerobic condition with nutrients adjustment
10		Aerobic condition with moisture & nutrients adjustment
11	Mixture	Anaerobic condition (to evaluate the chemical stability of compounds)
12		Aerobic condition (to evaluate natural attenuation)
13		Aerobic condition with adjustment of moisture
14		Aerobic condition with nutrients adjustment
15		Aerobic condition with moisture & nutrients adjustment

A total of 15 sets of samples were collected for analyses in order to define the best land farming treatment of the contaminated Brass Canal sediments and bank soil for the remediation.

Laboratory Analyses

Samples from each of the delineated lots were characterized with reference to the floating oily phase, contaminated sediment and canal bank soil.

Fig. 2 Bank Soil Samples from Some of the Lots Sampled

Standard methods of the Association of Official Analytical Chemists, AOAC [6] and standard methods of American Public Health Association, APHA [7] and [8] were employed for determination of the physico-chemical and microbiological parameters, respectively as shown in Table II. Each of the samples was analyzed for all the parameters at two laboratories (one in Nigeria and the other in Europe) as a quality assurance / quality control (QA/QC) check. It was ensured that the analytical protocols in each of the laboratories complied with Nigeria's statutory methods for spilled oil fingerprinting [9].

TABLE II
ANALYTICAL PARAMETERS AND FREQUENCY

ITEM	ANALYTICAL PARAMETERS	FREQUENCY
1	**General Parameters**	
1.1	Particle size	At the beginning
1.2	pH, %Humidity, Temp; O_2	Once a week
2	**Organic Compounds**	
2.1	Total hydrocarbon - Hydrocarbon C>12 & C<12	Once a week
2.2	BTEXs, PAH	Once a week
2.3	Any Specific organic compound of interest	At beginning & at the end
3	**Nutrients**	
3.1	N^+, NO_4, SO_4, PO_4	Once a week
4	**Microbiological Analyses**	
4.1	THBC & HUB	Once a week

Activities	Days														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Site preparation															
Concrete basin construction															
Drainage system construction															
Water-trap system construction															
Irrigation system installation															
Filling of the basin															
Area Restoration															

Fig. 3 Pilot Bioremediation Plant Construction Schedule

2. Bioremediation Pilot Plant Construction and Testing

As a result of site characterization, a pilot plant for on-site bioremediation was designed and a treatment basin constructed within 15 days (Fig. 3) for carrying out the pilot bioremediation test.

The approximately 10m by 10m bioremediation pilot plant was constructed above a concrete surface in order to minimize the risk of the leachate contaminating underground water and/or soil spreading. The walls were made of concrete barriers (New Jersey elements), 1.4m high.

At the bottom, a waterproof and drainage system was installed. It was built as follows (from the bottom):

- uncontaminated soil layer with a 1% slope toward two sides for rain and irrigation water drainage;
- a high-density polyethylene (HDPE) layer (2mm thick) with a permeability coefficient of $2x10^{-14}$ m/s or lower;
- two lateral logline with a 0.2% slope to allocate two drainpipes for bringing the leachate drained towards the catch basins.
- two drainpipes laid in the gravel layer and made of HDPE with micro-slotted, Ø 4" and PN20;
- each drainpipe tied in with a vertical cleaning tool up gradient and connected to the HDPE traps down gradient;
- a drainage system composed of 40cm of rounded siliceous gravel (2-3cm) and 15 cm of medium/coarse sand separated by a geotextile fabric.

This plant was replicated into five (5) of this 10m x 10m unit with a 2m wide grid / ramp between each treatment basin to allow for the 5 different treatments as designed.

3. Pilot Plant Bioremediation by Land Farming

After the pilot Bioremediation plants were constructed, they were loaded with the oily wastes mixture at the pre-determined wastes loading rate, preparatory for treatment as shown below:

Treatment 1: Mixture of Canal sediment and bank sand treated in an anaerobic condition (to evaluate the chemical stability of compounds);

Treatment 2: Mixture of Canal sediment and bank sand treated in an aerobic condition (to evaluate natural attenuation potentials)

Treatment 3: Aerobic condition with adjustment of moisture

Treatment 4: Aerobic condition with adjustment of nutrients

Treatment 5: Aerobic condition with adjustment of both nutrients and moisture

At the end of the pilot bioremediation tests, the cured wastes were released for preliminary land farming trials.

Fig. 4 (a) Thick Viscous Oily Film (Upstream)

Fig. 4 (b) Thin Oil Slick (Downstream)

III. Results and Discussion

A. Site Characterization

a. Physical Characteristics of the Canal

Thick viscous oily film was observed on the surface of Brass canal upstream (Fig. 4 (a)) while thin oily film interspersed with water (Fig. 4 (b)) was observe at the downstream.

The thick viscous oily film was observed to be dark in colour and had a characteristic hydrocarbon smell. Sediment samples from the canal were observed to be dark with mixture of brownish sandy soil with TPH ranging from 17,800 mg/kg

in Lot 1 to 88,500 mg/kg in Lot 12 samples. Soil samples at the Canal bank (Figs. 5 (a), (b)) was observed to be sandy from ground surface to 3m, below ground surface (bgs) was silty-sandy and brownish while subsurface soil (4-10m bgs) was sandy-clayey and whitish/grayish with typical hydrocarbon smell.

Fig. 5 (a) Canal Bank Grossly Contaminated with Crude Oil (right)

Fig. 5 (b) Canal Bank Grossly Contaminated with Crude Oil (left)

Based on the physico-chemical results obtained from the site characterization, it was observed that there was the need for the sediment and the bank soil to be mixed together for the total petroleum hydrocarbon (TPH) in the mixture to be reduced to enhance bioremediation. It has been reported that at high TPH, indigenous microorganisms in the samples will not be able to carry out bioremediation [10], [11].

Following the results of the protocol samples, the results of the mixture of canal sediment and bank soil under aerobic condition with moisture and nutrients adjustment was much more promising as the most likely conditions for the envisaged pilot bioremediation project.

B. Pilot Plant Bioremediation by Land Farming

Land farming, also known as land treatment or land application, is an above-ground remediation technology for soils and sediments that reduces the concentration of petroleum compounds, and in general organic pollution, by means of biodegradation phenomena. This technology commonly involves the laying of polluted soil (with a thickness of about 50-70 cm) on a proper surface and stimulating aerobic microbial activity through the aeration and/or the addition of nutrients, mineral and humidity. The enhanced microbial activity results in degradation of adsorbed petroleum compounds by aerobic respiration.

The results of microbiological and physico-chemical analyses of the wastes after pilot bioremediation test with treatment 5 (aerobic treatment with adjustment of both nutrients and moisture) are as presented in Table III.

While the value of $3.1x10^2$ CFU $g^{-1}$was obtained as the hydrocarbonoclastic microbial count in the oily wastes mixture (Canal sediment + Canal bank soil), no growth was observed in the Canal sediment and Canal bank soil wastes. This may probably be because of the high concentrations of crude oil in these media (Canal soil, 148.56mg/Kg; Canal sediment, 157.85mg/Kg). According to [11], one disadvantage of bioremediation over other conventional methods of oil polluted sites remediation is that bioremediation cannot proceed at a high concentration of the pollutant.

TABLE III
RESULTS OF MICROBIOLOGICAL AND PHYSICO-CHEMICAL ANALYSES OF WASTES SOIL AFTER BIOREMEDIATION

Parameters	Soil	Sediment	Mixture of Soil + Sediment
THBC ($x10^2$cfu/g)	3.4	4.3	4.5
HUB ($x10^2$cfu/g)	--	--	3.1
pH	5.96	5.93	5.54
THC (mg/Kg)	148.56	157.85	85.86
Phosphate (mg/g)	0.11	0.10	0.13
Sulphate (mg/g)	2.27	1.76	2.05
Nitrate (mg/g)	7.08	5.62	12.93

Detailed results obtained so far from all the treatments of the five (5) pilot bioremediation test plots have been very promising but were proprietary. This project is considered, to the best of technical literature knowledge, the first large-scale on-site bioremediation project in the Niger Delta, Nigeria.

IV. CONCLUSION

Land farming of oily sludge is an acceptable management technique in Nigeria [12]. The results obtained from the preliminary pilot bioremediation tests of the Brass Canal project were quite encouraging and promising; hence land farming of the oily sludge from the Canal will be a feasible management option. As earlier reported [13], there is need to comply with statutory provisions.

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