# EVALUATION OF TREATMENT EFFICIENCY OF DRILLING WASTE WITH THERMAL DESORPTION TECHNIQUE

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## ABSTRACT

*This study investigated the treatment efficiency of oil-based mud contaminated drilling waste using the Thermal Desorption Unit (TDU) technique, and also monitored pollutant gas emissions associated with the process. Composite drilling waste feedstock samples were characterized. Heavy metals were determined spectrophotometrically while total petroleum hydrocarbons (TPHs) (benzene, ethyl benzene, toluene, naphthalene and xylene) were determined chromatographically. Digital air monitors and a high volume gravimetric air filter sampler were used to monitor gaseous emissions. Variation plots and Sudent's t-test were used to analyze data. The concentrations of the contaminants decreased significantly after treatment (t=0.032) at P<0.05 from 21520.00 to 71.61 mg/kg (TPHs), 0.001 to 0.0005 mg/kg (benzene), 7.55 to 0.001 mg/kg (toluene), 3.64 to 0.001 mg/kg (xylene) and 5.80 to 0.001 mg/kg (naphthalene). Very high treatment efficiencies of 99.67, 99.99, 99.97, 99.98, 99.47, 97.48 and 87.13% were recorded for TPHs, toluene, xylene, naphthalene, V, moisture contents and electrical conductivity. Gaseous emission levels were below regulatory limits, even as relatively highest emissions were recorded for suspended particulate matter (15.0 ± 0.2 mg/$m^3$), and least emissions for $CH_4$ (0.39 ± 0.1 mg/$m^3$).*

Keywords: Drilling waste, Gaseous emissions, Heavy metals, Organic pollutants, Thermal desorption unit.

## 1.0. INTRODUCTION

Contamination of drilling fluids with drill cuttings is an unavoidable consequence of successful drilling operation. If the drilling fluid does not carry cuttings and cavings to the surface, Bauder (2005) and Goodarznia and Esmaeilzadeh (2006) observed that the rig either is not making hole or will soon be stuck in the hole it is making. According to Okeke and Obi (2013), drill cuttings consist of various rock particulates and liquid released from geologic formations in the drill hole, and they come out coated with drilling fluids.

Although the drilling fluid from the well discharges into a rig shale shaker where the cuttings are separated from the drilling fluid, this separation step does not completely remove drilling fluid and additives from cuttings (JWSL, 2009). Consequently, the composition of the cuttings will be similar to the drilling fluid, except for down-hole formation particles, particle size distribution, and the relative amounts of various drilling fluid constituents.

Considerable concern has been expressed about the effect of drilling fluids and its constituents on the environment (Neff, 1987). For example, bentonite and barite, which are practically inert toxicologically may in some cases cause physical damage to organisms (Kinigoma, 2001). Impurities in bentonite and barite can contain metals that are not readily mobilized in water, so they have limited bioavailability to marine organisms. Additionally, it has been established that a discharge of bentonite and barite dumped on the ground will prevent plant growth, until other natural processes develope a new topsoil (Murphy and Kehe, 1984). In water, these materials may disperse or sink and may locally kill benthic organisms by burying them. In freshwater, bentonite clays form a viscous gel, which kills fish by preventing or inhibiting their action if they are not caught or trapped in discharge before dilution through dispersion (Moseley, 1983). Cr, which is also found in many drilling fluids is present mostly in tetravalent form and is significantly less toxic than the hexavalent form.

Gaseous emissions from thermal desorption systems also occur and are likely to be combustion gases from the heating system. According to Cole and Mark (2000), they include $SO_2$, oxides of nitrogen (NOx), CO, $CO_2$, Volatile Organic Compounds (VOCs) and particulates from the treatment chamber. The off-gas from the process could also contain concentrations of metals in particulate and/or volatilized forms and persistent organic compounds, such as Poly-chlorinated Biphenyls (PCBs), dioxins and furans, depending on the operating temperature of the TDU chamber.

Drill cuttings treatment performance based on information received from two major operators on the Canadian East Coast from 2002 to 2007 indicate that on a whole well basis, the 6.9% Synthetic Oil on Cuttings (SOC) standard is seldom achieved (JWSL, 2009). For example, only one out of 15 wells in the Eastern Canada examples that were studied achieved 6.9% SOC between 2002 and 2007 period. It was found that the per well mass average percentage SOC was rather 8.46%. Four equipment configurations discharged the greatest weight of cuttings. Of these top four, the average percent synthetic on cuttings ranged from 7.09 to 9.55. Only during specific periods of treatment was a 6.9% SOC achieved. However, the associated treated mass of cuttings discharged (less than 6.9% SOC) represented less than 10% of the total treated mass of 15 assessed wells. Another operator reported that drilling operations conducted in the Nova Scotia Offshore in 2002 were able to achieve the 6.9% SOC through the use of a Verti-G cuttings dryer, combined with ship-to-shore transport of some drilling wastes.

The Directorate of Petroleum Resources (DPR) in Nigeria has also formulated certain guidelines and standards for more effective treatment, recovery and disposal of oily sludge in Part IV Section D 2.0 and 4.0 of the DPR Guidelines. In line with this, the current study evaluated the efficiency of a Thermal Desorption Unit (TDU) facility in the treatment of oily contaminants arising from oil exploration activity in the Niger Delta. The study characterized and determined the levels of contaminants in drilling waste stream before and after treatment, as well as the treatment efficiency of the TDU used. It also identified pollutant gases emissions associated with the treatment process.

## 2.0. MATERIALS AND METHODS

### 2.1. The Thermal Desorption Unit (TDU) Facility

The anaerobic TDU employed in the study was designed to remediate and treat hydrocarbon-contaminated materials and other oilfield wastes. The system consists of an inlet tipping valve and feed screw conveyor, a rotary drum in which the contaminants are desorbed from the soil, a treated soil discharge auger and rehydration pugmill, a vapour recovery unit consisting of Venturi wet scrubber for gas quenching, particulate removal and acid gas neutralizer, an oil water separating system, a water treatment unit, a recovered oil unit, and a control and operation center for electrical, instrumentation and process monitoring.

The TDU operational treatment ranges used were as follows: rotary drum (kiln) in-feed temperature of 400-550°C, residence time of 10-40 minutes, treated material exit temperature of 350-400°C, and final material discharge temperature of less than 100°C from the pugmill chamber.

### 2.2. Waste Treatment Procedure

The waste (drill cuttings) obtained from an ongoing oilfield drilling site in the Niger Delta was analytically characterized to ascertain the operating conditions to be used in the TDU treatment procedure and in keeping with the DPR requirements. The TDU then treated the oily contaminated cuttings by first desorbing the hydrocarbons, which are the principal contaminants in the waste. Thereafter, hydrocarbons were separated from the cuttings and thermally destroyed, leaving the residues (soil) in a benign condition.

**2.3. Chemical Characterization of Waste**

Chemical characterization of waste was done before and after treatment. A representative feedstock sample of drilling waste was collected at each stage from two different mixing tanks with auger and cups. Composite samples were made in each case from the grab samples and samples were thereafter transferred into 500mL Teflon-capped borosilicate glass bottles. The parameters determined include pH, electrical conductivity (EC), moisture contents (MC), heavy metals (As, Cd, Cr, Cu, Pb, Ba, Hg, Ni, V, Zn and Mn), and organics (benzene, toluene, ethyl benzene, naphthalene and total petroleum hydrocarbons).

The method of Pansu and Gautheyrou (2006) was used in the determination of pH and EC. Values were read off a Corning pH meter (Model 7) and the Beribboned conductivity meter (Model cm-21 Bridge) respectively. The oven-dry method was used to determine MC, while heavy metals were determined spectrophotometrically with a Varian Spectr-AA 600 Atomic Absorption Spectrophotometer (AAS). The organic contaminants were determined with a Gas Chromatograph interfaced with the Flame Ionization Detector (GC-FID).

**2.4. Pollutant Gas Emissions**

Gas emissions from the stack were monitored with the TESTO 350XL digital air monitor, while a High Volume Gravimetric Air Filter (HVGAF) sampler was used to measure the Suspended Particulate Matter ($SPM_{10}$).

**2.5. Statistical analysis**

The SPSS v.22.0 and MS Excel© v. 2007 were used to analyze data. Variation plots were used to represent the levels of the contaminants and Student's t-test was used to compare levels of contaminants in the waste before and after treatment at $P<0.05$.

## 3.0. RESULTS

**3.1. Characteristics of Drill Cuttings**

TPH, benzene, toluene, ethyl benzene, xylene and naphthalene decreased from 21520.00 to 71.61, 0.001 to 0.0005, 7.55 to 0.001, 0.001 to 0.0007, 3.64 to 0.001 and 5.80 to 0.001 mg/kg before and after treatment respectively. The trace elements- As, Cd, Cr, Cu, Pb, Hg, Ni, V, Zn and Ba decreased from 0.0009 to 0.0006, 4.83 to 3.03, 3.91 to 2.98, 11.06 to 9.53, 3.97 to 3.03, 0.0008 to 0.0004, 10.84 to 8.74, 0.19 to 0.001, 39.62 to 31.70 and 69.26 to 53.46 mg/kg before and after treatment respectively.

pH increased from 8.86 before treatment to 9.13 after treatment, EC decreased from 8.78 µS/cm before treatment to 1.13 µS/cm after treatment, and MC decreased from 49.61 % before treatment to 1.25 % after treatment.

The Student's t-test confirmed that the concentrations of the contaminants monitored decreased significantly after TDU treatment ($t=0.032$) at $P<0.05$.

**3.2. Efficiency of Treatment of Drill Cuttings**

After treatment (AT), TPH recorded 99.67% treatment efficiency (TE), benzene recorded 50.00% TE, toluene recorded 99.99% TE, ethyl benzene recorded 30.00% TE, xylene recorded 99.97% TE, and naphthalene recorded 99.98% TE (Fig. 1). The trace elements, As, Cd, Cr, Cu, Pb, Hg, Ni, V, Zn and Ba recorded 33.33, 37.27, 23.79, 13.83, 23.68, 50.00, 19.37, 99.47, 19.99 and 22.81% TEs respectively (Fig. 2). However, pH, EC and MC recorded 3.05, 87.13 and 97.48% TEs respectively (Fig. 3).

### 3.3. Gaseous Pollutant Emissions during Treatment

Table 1 shows that mean heat, Suspended Particulate Matter ($SPM_{10}$), carbon (II) oxide, carbon (IV) oxide and HCl vapour emissions were 90.0 ± 0.1 °C, 15.0 ± 0.2 mg/m$^3$, 1.01 ± 0.30 mg/m$^3$, 3.23 ± 0.70 mg/m$^3$ and 0.46 ± 0.30 mg/m$^3$ respectively. However, the other emissions were as follows: methane 0.39 ± 0.10 mg/m$^3$, NOx 9.52 ± 0.34 mg/m$^3$, sulphur (IV) oxide 2.03 ± 0.50 mg/m$^3$, water vapour 6.94 ± 0.81 % and hydrocarbon contents (HCs) 0.81 ± 0.63 mg/m$^3$.

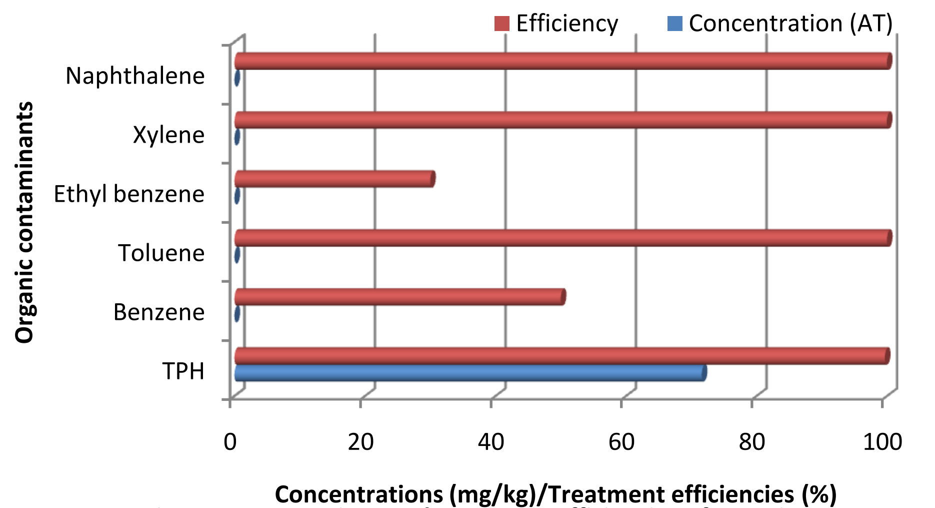


**Fig. 1. Concentrations and treatment efficiencies of organic contaminants after TDU treatment**

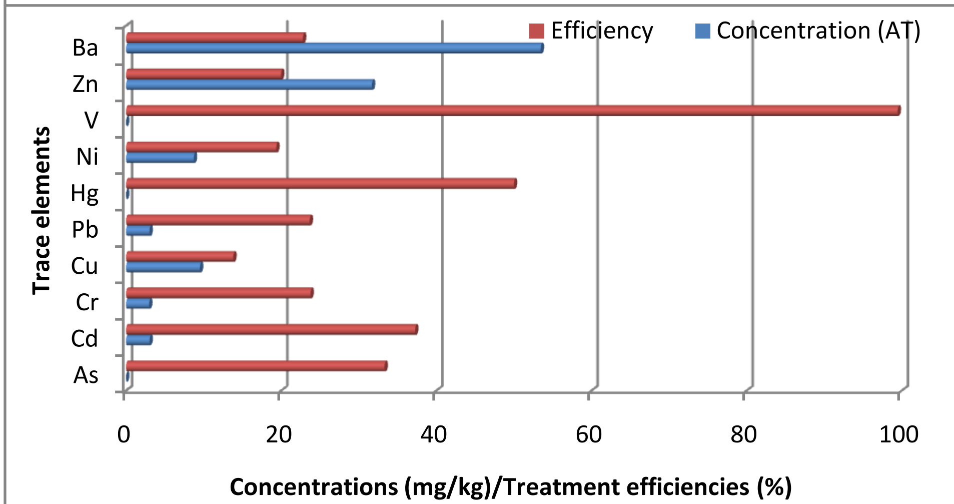


**Fig. 2. Concentrations and treatment efficiencies of trace elements after TDU treatment**

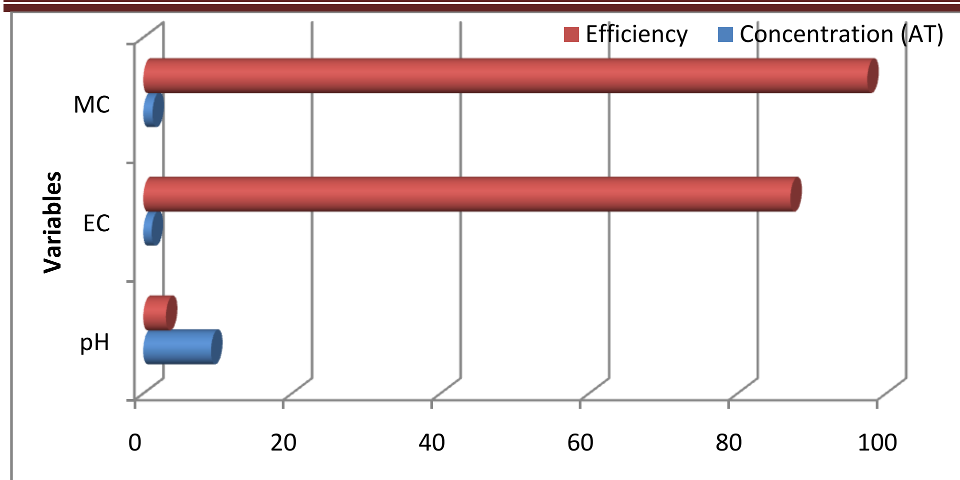


**Fig. 3. Concentrations and treatment efficiencies of pH, EC and MC after TDU treatment**

**Table 1. Maximum stack gas emissions from the TDU facility during Treatment**

| Parameters | Emissions Maximum | Emissions Average ± SE | FEPA limit |
|---|---|---|---|
| Heat (°C) | 90.1 | 90.0 ± 0.1 | 120.0 |
| SPM (mg/m$^3$) | 16.0 | 15.0 ± 0.2 | 100-500 |
| CO (mg/m$^3$) | 1.16 | 1.01 ± 0.30 | NA |
| CO2 (mg/m$^3$) | 4.22 | 3.23 ± 0.70 | 300.00 |
| HCl (mg/m$^3$) | 0.47 | 0.46 ± 0.30 | NA |
| CH4 (mg/m$^3$) | 0.40 | 0.39 ± 0.10 | 800.00 |
| NOx (mg/m$^3$) | 9.76 | 9.52 ± 0.34 | 350-1000 |
| SO2 (mg/m$^3$) | 2.11 | 2.03 ± 0.50 | 30-3000 |
| H2O (vapour) (%) | 7.02 | 6.94 ±0.81 | 50.00 |
| HCs (mg/m$^3$) | 0.89 | 0.81 ± 0.63 | 50.00 |

**SPM=Suspended Particulate Matter, FEPA=Federal Environmental Protection Agency, SE=Standard Error of mean, NA=Not Available, NOx=Oxides of nitrogen**

## 4.0. DISCUSSION

The treatment of drilling waste is very important because of the potential threat they could pose to the environment and by extension, human health on disposal. In the current study, the TDU used gave a satisfactory treatment of the wastes from oil exploitation activity. Virtually all high levels of the contaminants in the waste were drastically reduced after treatment, with over 90% treatment efficiencies in total petroleum hydrocarbons, toluene, xylene, naphthalene, vanadium and moisture contents.

Average treatment efficiencies were recorded for benzene and mercury, while low treatment efficiencies were recorded for ethyl benzene and the recalcitrant trace elements- arsenic, cadmium,

chromium, copper, lead, nickel, zinc and barium. The recalcitrant elements have already been identified by Ogbuagu and Dinney (2014) as persistent in an environmental segment.
The observed decrease in electrical conductivity and increase in pH after treatment implies that the concentrations of the ions capable of conducting electricity in the treated waste stream decreased even as they became less acidic. Okeke and Obi (2013) had made similar observations in pH of drill cuttings after TDU treatment. The reduced electrical conductivity could be associated with decreased moisture content capable of aiding ionization in solution.

However, the levels of the contaminants after treatment were all below the maximum permissible limits of the Federal Environmental Protection Agency. Highest emissions were of the suspended particulate matter, which could comprise of several air-borne particulate pollutant species. The TDU operations generated heat, especially around the combustion emission stacks. Temperature could influence the dispersion of air-borne particulate pollutants. Ogwejifor (2000) had observed that incomplete combustion could produce greenhouse gases (such as methane), other gaseous pollutants (such as carbon (II) oxide), and organic elemental particulates. Neff (1987) had observed that particulate outfalls from TDUs treating oily drill cuttings contain polynuclear aromatic hydrocarbons, acids and trace metals, which have been associated with lung cancer, cardiovascular and respiratory tract diseases. Other possible effects of gaseous air pollution includes deterioration of ecological conditions (Tripathi and Gautam, 2007), vegetation injury and crop yield loses (Joshi and Swami, 2007), addition of toxic gases and other substances to the environment (Seyyednejab *et al.* 2011).

## 5.0. SUMMARY

The Thermal Desorption Unit used in this study treated the oily drilling waste well, with very high treatment efficiencies of especially the organic contaminants. However, the trace elements showed low treatment efficiencies. Air pollutant emissions were low and within regulatory limits.

## 6.0. CONCLUSION

High treatment efficiencies of oily drill cuttings and low air pollutants emissions were associated with the thermal desorption treatment technique used.

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