Drilling Wastes Generation and Management Approach

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***Abstract*—Waste management is one of the problems facing the oil and gas industry. This has often thrown the industry into numerous challenges ranging from technological development to ensuring a clean and safe environment. Oil and gas well drilling processes generate large volume of drill cuttings and spent mud. Onshore and offshore operators have used a variety of methods to manage these drilling wastes. This paper discusses the basic concepts for managing waste generated during drilling operations and provides systematic approach for pro-active waste management practices. It addresses the various stages in drilling waste management, and emphasizes the phases of waste identification, minimization, treatment and disposal as integral parts of waste management process.**

***Index Terms*—Drilling fluid, mud additives, waste management, minimization, recycle, and treatment.**

I. Introduction

The process of drilling oil and gas wells generates two primary types of wastes - used drilling fluids and drill cuttings. Drilling fluids (also known as muds) are used to aid the drilling process; the fluid phase can be water, synthetic or natural oils, air, gas, or a mixture of these components. Muds are circulated through the drill bit to lubricate and cool the bit, control the formation fluid pressures and to aid in carrying the drill cuttings to the surface, where the muds and cuttings are separated by mechanical means.

Muds consist of a base fluid and various solid and liquid additives to allow for good drilling performance. Some of the additives introduce potentially toxic compounds into the fluids, which must be considered when the resulting wastes are managed. The main pollution of spent muds are caused by: biocides, oil, completion or stimulation fluid components, corrosion inhibitors, reservoir fluids (crude oil, brine), and drilling mud chemical components [1].

Drilling wastes are the second largest volume of waste, behind produced water, generated by the E&P industry [2]. API estimated that in 1995 about 150 million barrels of drilling waste was generated from onshore wells in the United States alone [3]. Operators have employed a variety of methods for managing these drilling wastes depending on what federal regulations allow and how costly those options are for the well in question. Onshore operations have a wider range of management options than offshore operations. These include land application, underground injection, thermal treatment, and biological remediation.

II. Environmental Impacts

Many of the wastes associated with oil and gas well drilling activities have the potential to impact the environment. The physical and chemical properties of the drilling wastes influence its hazardous characteristics and environmental impact ability. The most common measure of the potential environmental impact of a material is its toxicity. Table I gives guidance for possible environmentally significant constituents of drilling wastes. The potential impact depends primarily on the material, its concentration after release and the biotic community that is exposed. This also depends on the length of exposure to a substance. The length of exposure to a substance can be divided into descriptive types as indicated in Table II. Exposure that causes an immediate effect is called acute, while repeated long-term exposure is called chronic. Most concentrations encountered during drilling activities are relatively low, therefore the environmental impact is generally observed only after chronic exposure.

Also, the heavy metals associated with the constituents of drilling fluid additives are of concern, although their potential to leach away from the pit and contaminate the groundwater is limited by their low concentration and low solubility [4]. A typical elemental composition of common constituents of drilling mud is given in Table III. A number of studies have been conducted on the impact of these elements [5].

TABLE I: Wastes Components and Environmentally Significant Constituents from drilling Activities

Type of Waste	Main components	Possible environmentally significant constituents
Waste lubricants	Lube oil, grease	Heavy metals, organics
Spacers	Mineral oil, detergents, surfactants	Hydrocarbon, alcohol, aromatics
Spent/contaminated water based muds (include brine)	Whole mud, mineral oil, biodegradable matters	Heavy metals, inorganic salts, biocides, hydrocarbons, solids/cutting, BOD, organics
Water based muds cutting	Formation solids, water based muds mineral oil	Heavy metals, inorganic salts, biocides, hydrocarbons, solid/cutting
Spent/contaminated oil based muds	Whole mud mineral oil	Hydrocarbons, heavy metals, inorganic salts, solids, BOD, organics, surfactants
Oil based muds cuttings	Formation solids, oil based muds	Heavy metals, inorganic salts, hydrocarbons, solid/cutting
Spent bulk chemical	Cement, bentonite, barites, viscosities, thinners, fluid loss reducers, speciality product	Heavy metals, hydrocarbon, organics, solids
Spent special products	H2S scavengers, defoamers, tracers	Zinc carbonates, iron oxides, hydrocarbons, silicon oils, potassium salts, radioactive material

Source: [6].

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TABLE II: EXPOSURE TYPE

Exposure type	Duration of Exposure
Acute	Less than 24 hours
Sub-acute	Less than 1 month
Sub-chronic	1-3 months
Chronic	More than 3 months

Source: [7].

TABLE III: ELEMENTAL COMPOSITION OF DRILLING FLUID CONSTITUENTS (MG/KG).

Element	Water	Cutting	Barite	Clay	Lignite	Caustic
Aluminum	0.3	40,400	40,400	88,600	6,700	0.013
Arsenic	0.0005	3.9	34	3.9	10.1	0.039
Barium	0.1	158	590.000	640	640	0.26
Calcium	15	240,000	7,900	4,700	16,100	5,400
Cadium	0.0001	0.08	6	0.5	0.2	0.0013
Chromium	0.001	183	183	8.02	65.3	0.00066
Cobalt	0.0002	2.9	3.8	2.9	5	0.00053
Copper	0.003	22	49	8.18	22.9	0.039
Iron	0.5	21,900	21,950	37,500	7,220	0.04
Lead	0.003	37	685	27.1	5.4	0.004
Magnesium	4	23,300	3,900	69,800	5,040	17,800
Mercury	0.0001	0.12	4.1	0.12	0.2	4
Nickel	0.0005	15	3	15	11.6	0.09
Potassium	2.2	13,500	660	2,400	460	51,400
Silicon	7	206,000	70,200	271,000	2,390	339
Sodium	6	3,040	3,040	11,000	2,400	500,000
Strontium	0.07	312	540	60.5	1030	105

Source: [8].

III. REGULATION REQUIREMENTS

Any waste materials which have the ability to cause cancer, and/or its toxicity to humans and other ecosystems are specifically regulated by a governmental authority. In the absence of governmental regulations, guidelines issued by relevant international or regional organisations are usually used.

Because of this, the discharge of spent drilling mud and their associated cuttings is prohibited in many areas around the world.

In many instance, the oil companies operating in the Niger Delta region of Nigeria are required to adopt good oil-field disposal practices as prescribed and approved by the Directorate of Petroleum Resources (DPR), the regulator of the Nigerian petroleum industry. In line with this therefore, the DPR have emphasised the implementation of the following guidelines and standards by the oil operators, as outlined in Table IV.

IV. HIERARCHY OF WASTE MANAGEMENT

The Waste Management Hierarchy sets out a preferred sequence of waste management options. The first and most preferred option is source reduction. Source reduction is any activity that reduces or eliminates either the generation of waste at the source or the release of a contaminant from a process. The next preferred option is recycling. Recycling is the reclamation of the useful constituents of a waste for reuse, or the use or reuse of a waste as a substitute for a commercial feedstock or as a feedstock in an industrial process. Together, source reduction and recycling comprise waste minimization. The last two options, and least preferred, of the hierarchy are treatment and disposal.

Effective waste management is an ongoing process within which the waste management plan can be revised as new waste management practices, or technological options of responsible disposal are identified.

Over the past decades, oil and gas operators have used waste management approaches that minimize the volume and/or the toxic fraction of wastes generated, and disposal techniques that offer greater environmental protection and public safety. The three-tiered waste management hierarchy, namely waste minimization, treatment and disposal, are normally followed by the operator in their bid to control and manage drilling wastes in the most environmentally friendly manner possible.

TABLE IV: REQUIREMENTS FOR DISCHARGE OF DRILLING MUD AND CUTTINGS IN NIGERIA

Water Based Drilling Fluids and Cuttings	Oil Based Drilling Fluid Cuttings	Synthetic Based Drilling Fluid Cuttings	Environmental Monitoring Requirements
• To discharge, must submit proof that mud has low toxicity to Director of Petroleum Resources (DPR) with permit application. Discharges will be treated to DPR's satisfaction. • DPR will examine WBM to determine how hazardous and toxic it is. • Cuttings contaminated with WBM may be discharged offshore/deep water without treatment.	• To discharge, must submit proof that OBM has low toxicity to DPR with permit application. Discharges will be treated to DPR's satisfaction. • OBM must be recovered, reconditioned, and recycled. • Oil on cuttings, 1% with 0% goal. • On-site disposal if oil content does not cause sheen on the receiving water. • Cuttings samples shall be analyzed by Operator as specified by DPR once a day. • Point of discharge as designated on the installation by shunting to the bottom. • DPR to analyse samples at its own discretion for toxic/hazardous substances. • Operator to carry out first post drilling seabed survey 9 months after 5 wells have been drilled. Subsequent seabed surveys shall then be carried out after afurther 18 months or further 10 wells • Operator must submit to DPR details of sampling and analysis records within 2 weeks of completion of any well. • Inspection of operations shall be allowed at all reasonable times.	• SBM must be recovered, reconditioned, and recycled. • SBM cuttings must contain 5% drilling fluid or less for discharge. (10% for esters) • Special provision for higher retention limits have been granted for some deepwater wells	• Operator to carry out first postdrilling seabed survey after 9 months or after 5 wells have been drilled, whichever is shorter. Subsequent seabed surveys shall then be carried out after a further 18 months or 10 wells.

Source: [9].

A. Waste Minimization

One important method for minimizing the amount of potentially toxic wastes generated is to use less toxic materials for the various operation processes. In the 1990s, drilling fluid companies devised new types of fluid that used non-aqueous fluids as their base. The base fluids included internal olefins, esters, linear alpha-olefins and linear parafins. These Synthetic-based muds (SBMs) share the desirable drilling fluid properties of Oil-based muds (OBMs) but are free of poly-nuclear aromatic hydrocarbons and have lower toxicity, faster biodegradability and lower bioaccumulation potential. Use of SBMs results in a cleaner hole with less sloughing and they generate a smaller cutting volume and can be recycled where possible. A variety of new water-based muds (WBMs) are being developed as possible substitutes for OBMs. The additives for these muds have included various low-toxicity polymers and glycols [10].

Many of the additives used in the past for drilling fluids have contained potential contaminants of concern such as chromium in lignosulfonates. Also, barite weighting agents may contain concentrations of heavy metals such as cadmium or mercury. The use of such additives has diminished. However, an operator should take care to select additives that are less toxic and that will, therefore, result in a less toxic drilling waste. Other mud additives and suggested substitute materials are given in Table V.

TABLE V: SUBSTITUTE MATERIALS FOR DRILLING FLUID ADDITIVES.

Additive	Toxic Component	Use	Substitute Material
Chrome Lignosulfonate/lignite	Chromium	Deflocculant	Polyacrylate and/or polyacryamide polymer
Sodium chromate	Chromium	Corrosion control	Sulfites, phosphonates, and amines
Zinc chromate	Chromium	H2S control	Non-chromium H2S scavengers
Lead-based pipe dope	Lead	Pipe thread sealant/lubricant	Unleaded pipe dope
Barite	Cadium, mercury, barium, lead	Mud densifier	Choose barite from sources low in cadium, mercury and lead.
Arsenic	Arsenic	Biocide	Isothiazolins, carbamates, and gluteraldehydes.

Source: [11]

B. Waste Minimization via Process Modifications

1) Slim Holes

The drilling industry has improved the technology of "slim hole" drilling over the past few years [12]. Slim hole drilling should be considered when planning a drilling project. If feasible and used, slim hole drilling reduces the volume of waste drilling fluid and the volume of drill cuttings. The total cost of a slim hole drilling operation may be considerably less than for conventional whole sizes due to the reduced fluid system and waste management costs. Also, smaller casing is required, which may help reduce the total cost of the operation.

2) Solids Control

An effective way to reduce the volume of drilling fluid waste is the use of solids control [13]. The efficient use of solids control equipment (e.g., hydrocyclones and centrifuges) in combination with chemical flocculants minimizes the need for makeup water to dilute the fluid system. An enhanced solids control system designed to compliment a specific drilling operation is a very effective waste minimization technique.

3) Mud System Monitoring

Diligent and comprehensive monitoring of drilling fluid properties is effective in reducing the frequency of water and additive additions to the system. Monitoring the system allow the operator to immediately identify unwanted changes in the drilling fluid system and make the necessary corrections. This technique, in addition to the solids control for the drilling fluid system can significantly reduce the costs of the drilling fluid system and the volume of drilling waste remaining at the end of the drilling operation [14].

C. Material Re-use or Recycle

Many of the materials in the drilling waste stream can be used more than once or be converted into a usable material. For example, reconditioned drilling mud could be reused for other wells, either by the operating company or by the vendor. Waste mud from one well can be used for plugging or spudding other wells. Used drilling mud can also be used to make cement [15]. Used OBMs and SBMs can be recycled where possible. Recycling avoid release of large quantities of wastes into the environment.

D. Treatment and Disposal

Treatment is used to reduce the volume and/or toxicity of wastes and put them in a suitable position for final disposal. Treatment and disposal options depend largely on the waste characteristics and regulatory requirements. There are various practices to get rid of drilling wastes in the oil and gas industry today. They are: onsite burial, land farming, thermal treatment, slurry injection and bioremediation.

1) Onsite Burial

Burial is the placement of waste in man-made or natural excavations, such as landfills. Burial is the most common onshore disposal technique used for disposing of drilling wastes (mud and cuttings). Generally, the solids are buried in the same pit (the reserve pit) used for collection and temporary storage of waste mud and cuttings after the liquid is allowed to evaporate. Pit burial is a low-tech method that does not require wastes to be transported away from the well site, and, therefore, is very attractive to many operators.

Burial may be the most misunderstood or misapplied disposal technique. Onsite pit burial may not be a good choice for waste that contain high concentrations of oil, salt, biologically available metals, industrial chemicals, and other materials with harmful components that could migrate from the pit and contaminate usable water resources.

In some oil field areas, large landfills are operated to dispose of oil field waste from multiple wells. Secure landfills are specially designed land structures which employ protective measures against off-site migration of contained chemical waste via leaching or vaporisation (Fig. 1). Burial usually results in anaerobic conditions, which limits any further degradation when compared with waste that are land-farmed or land-spread; where aerobic conditions predominate.

Fig. 1. Secure landfill with synthetic liner

2) Land farming

Land farming involves spreading the waste on a designated area of land and working it into the soil. The objective of applying drilling wastes to the land is to allow the soil's naturally occurring microbial population to metabolize, transform, and assimilation waste constituents in place. It may be safely utilised as a means of immobilising and biodegrading many oilfield wastes. Soil loading capacity must be known and should not be exceeded in order to maintain aerobic condition at site.

3) Incineration

Incineration is one of the best thermal treatment disposal options because thermally treated wastes are decomposed to none or less hazardous by-products. Controlled incinerators operate at sufficient temperatures for complete thermal decomposition of hazardous wastes. In addition, solid and gas emissions are controlled by afterburners, scrubbers, and/or electrostatic precipitators.

Non-hazardous and hazardous solids, liquids, and gases can be incinerated. However, incineration of heavy metals such as lead, mercury or cadmium is not recommended because these metals remain in the fly ash and present a leaching hazard when placed in a landfill. The advantages of incineration are numerous, including volume reduction, complete destruction rather than isolation, and possible resource recovery.

4) Thermal desorption

Thermal desorption process applies heat directly or indirectly to the wastes, to vaporize volatile and semi volatile components without incinerating the soil. In some thermal desorption technologies, the off-gases are combusted, and in others, such as in thermal phase separation, the gases are condensed and separated to recover heavier hydrocarbons. Thermal desorption technologies include indirect rotary kilns, hot oil processors, thermal phase separation, thermal distillation, thermal plasma volatilization, and modular thermal processors. Various thermal processes have been patented [16]- [18].

5) Deep-well Injection

This is a waste disposal technique where drill cuttings and other oilfield wastes are mixed into slurry. The resulting slurry is then injected into a dedicated disposal well where it is contained in the pores of permeable subsurface rocks far below freshwater aquifers. See Fig. 2. The primary disadvantage of this option is the possibility of freshwater contamination due to casing failure. Availability of the disposal option is also limited to certain geological setting. It is environmentally preferred when rock formations allow.

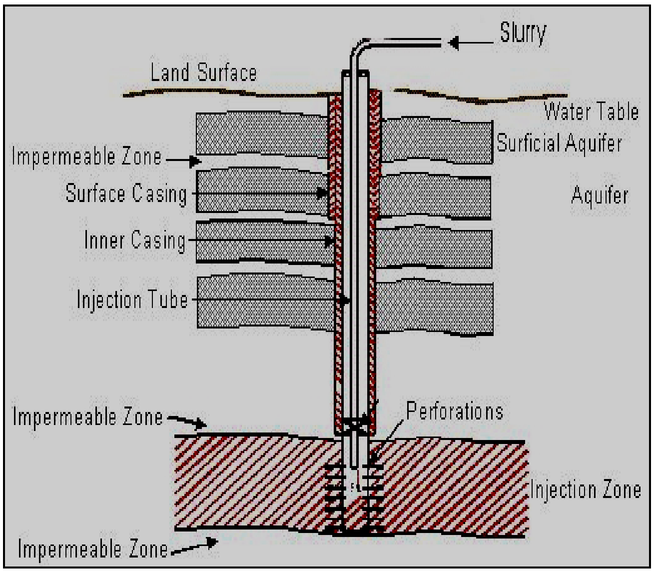

Fig. 2. Deep-well Injection of drilling waste

6) Vermiculture

Vermiculture is the process of using worms to decompose organic waste into a material capable of supplying necessary nutrients to help sustain plant growth. For several years, worms have been used to convert organic waste into organic fertilizer. Recently, the process has been tested and found successful in treating certain synthetic-based drilling wastes [19]. Researchers in New Zealand have conducted experiments to demonstrate that worms can facilitate the rapid degradation of hydrocarbon-based drilling fluids and subsequently process the minerals in the drill cuttings [20]. Because worm cast (manure) has important fertilizer properties, the process may provide an alternative drill cutting disposal method.

V. Waste Management Strategies

Successful implementation of waste management plan requires that the operations personnel generating and handling the wastes should be communicated adequately as to the available options there is to effectively manage waste. Table VI present a typical drilling waste management strategy. The application of each hierarchy theoretically diminishes the quantity of residual waste that ultimately requires disposal. The first and most important action in the waste management hierarchy is to reduce the volume of waste generated. The next is to recycle or reuse the wastes or materials in the wastes. Only after these should the remaining wastes be treated and disposed. By following this hierarchy, both the volume of waste to be disposed and the ultimate disposal cost will be minimized.

TABLE VI: DRILLING WASTE MANAGEMENT APPROACHES

I - Waste Minimization Approaches	**II - Recycle or Reuse Approaches**	**III - Disposal Approaches**
synthetic-based and oil-based muds generate less cuttings than water-based muds	road spreading when roads benefit from application of waste	land spreading or land farming
coiled tubing drilling	reuse synthetic-based and oil-based muds	road spreading
directional/horizontal drilling	use cleaned cuttings for fill or cover material	burial in onsite pit or offsite landfill
use of less toxic components and additives for muds	restoration of wetlands with clean cuttings	discharge to ocean
air drilling	use cuttings as aggregate for concrete or bricks	salt cavern disposal
	thermal treatment with fluid recovery	underground injection
		thermal treatment
		biotreatment (e.g., composting, vermiculture)

Source: [21].

VI. CONCLUSION

The following conclusions can be drawn:

1. That oil and gas well drilling activities generate large volume of drilling cutting s and spent mud.
2. That environmental impact of oil and gas well drilling can be classified into descriptive types such as acute, sub-acute, sub-chronic and chronic.
3. That most concentrations of oil and gas well drilling wastes encountered during drilling activities are relatively low and impacts are generally noticed after chronic exposure.
4. That the preferred sequence of drilling waste management option should be source reduction, waste recycling or reuse, waste treatment and waste disposal.
5. That waste minimization techniques via process modification include slim hole drilling, solids control and mud system monitoring.
6. That treatment and disposal of oil and gas drilling waste depend largely on waste characteristics and regulatory requirements and various practices to get rid of drilling wastes. These practices include onsite burial, land farming, thermal treatment, slurry injection and bioremediation.

VII. RECOMMENDATIONS

For effective control and management of oil and gas drilling waste that following recommendations are put forward:

1. Drilling mud and associated cuttings which have the ability to cause cancer and its toxicity to humans and other ecosystem should be prohibited or regulated.
2. All the DPR prescribed good oil-field disposal practices for oil companies operating in Niger Delta region should be adhered to and strictly enforced.
3. The three-tiered waste management hierarchy namely wastes minimization, waste treatment and waste disposal should be followed by all the operatives to control and manage drilling waste in the most economically friendly manner possible.
4. Operators should select additives that result in less toxic drilling wastes.
5. In adopting land farming technique, the soil loading capacity must be known and should not be exceeded in order to maintain aerobic conditions at the site.

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