ESTIMATION OF DRILLING WASTES – AN ENVIRONMENTAL CONCERN WHILE DRILLING OIL AND GAS WELLS

A

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ESTIMATION OF DRILLING WASTES – AN ENVIRONMENTAL CONCERN WHILE DRILLING OIL AND GAS WELLS

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ABSTRACT

Despite its numerous benefits the search and production of crude oil poses a lot of dangers to the environment. Among these include land, water and air pollution. Prominent among the major sources of E&P waste is drilling operations which form the second largest source of waste after production activities. The major drilling wastes are drill cuttings, drilling mud and obnoxious gas emissions. These wastes are introduced into the environment through intentional as well as accidental discharges and this expulsion into the environment has direct and indirect effects on aquatic life, personnel working on the rig, plants, flying birds, as well as the soil. This research work purposes to identify the various forms of drilling waste, their effect on the environment and to develop strategies in managing these waste effectively. The ability to effectively identify, quantify, classify and adopt strategies to eliminate or reduce the impact of drilling waste on the environment defines an effective waste management practice. In all situations source reduction of waste is the most favorable and economically feasible drilling waste management option and should in all cases be a priority over the other methods of waste management. However, this task of adopting an effective waste management tactics is not as simple as it looks. In its quest to developing effective strategies for managing drilling waste, it is identified that the quantity of waste generated plays an important role in drilling waste management. It dictates the type of waste management method to adopt, the design of waste boxes, waste disposal cost among others. A simple user-friendly spreadsheet is therefore developed for waste volume estimation. Again, a ten steps effective waste management procedure is developed to serve as guidelines for drawing waste management plans. Waste management plans should be updated regularly to capture changes in regulations, new technologies and new operations. In conclusion it is shown that the choice of the ideal drilling waste management is usually dependent on the local regulations in place, technical efficiencies, cost and the quantity of waste. The selection should always be therefore subjected to effective environmental, economic and technical analysis. As a result, a waste selection criterion has been developed which will help eliminate some of the options that are not favorable.

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Words are inadequate in offering my thanks to my family: my parents and siblings and most especially my fiancée, Mercy Nyamah Marfo. I could not have made it this far without your blessings, encouragement and support throughout my educational life. Lastly, I offer my regards and blessings to all of those who supported me in any respect during the completion of the project, to all my friends and classmates, I say God richly bless you.

DEDICATION

I dedicate this thesis work to my newly born nephew, Kelvin Afram, born on Thursday, 8th September, 2011. His birth brought me joy, inspiration and strength for the completion of this work.

May the success of this work bring success and prosperity to his life.

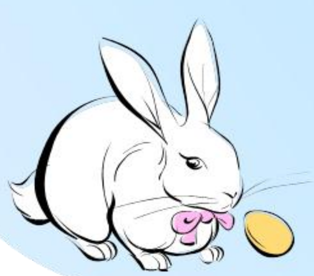

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TABLE OF CONTENTS

LISTS OF FIGURES

LISTS OF TABLES

CHAPTER ONE

FORMULATION OF PROBLEM

1.1 Problem Definition

Petroleum is among the world's most important natural resources. It is the most significant and highly traded primary commodity in the international market (Illedare, et al., 1999) and has remained the world's primary source of energy for both industrial and domestic applications since replacing coal early in this century. However, the finding and production of petroleum involves the generation of drilling waste which forms a major source of pollution in oil producing environment. Almost every process in the finding and production of petroleum generates wastes which impacts the environment negatively. Until 1980's, little or no thought was given to the generation and disposal of cuttings and excess drilling fluids. Typically, these materials were discharged overboard in offshore operations or buried when drilling in land-based locations. The global environmental awareness in the late 1980s to early 1990s made the oil and gas industry and its regulators to understand and appreciate the potential environmental impact of drilling waste (Geehan, et al, 2000).

In an effort to manage and reduce the impact of drilling waste on the environment, a number of technologies and publications have been written. Technologies such as directional drilling, slim-hole drilling, coil-tubing drilling and pneumatic drilling are few of the drilling practices that generates less amount of drilling waste. A number of drilling waste management plans and programs have also been designed by different companies and researchers. Drilling waste management refers to ways by which drilling and associated wastes could be handled effectively in order to minimize their effect on the environment. Wastes that are usually associated with drilling operations are: - drill cuttings, contaminated drilling fluids and additives, gaseous contaminants from internal combustion engines, produced water as well as heavy metals. The principal aim of waste management is to ensure that waste does not contaminate the environment at such a rate or in such a form or quantity as to overload natural assimilative processes. Eliminating or minimizing waste generation is crucial, not only to reduce environmental liabilities but also operational cost (Richards, 2007). The waste hierarchy is a common waste management technique that has been reported in a number of literatures. This refers to the "3 Rs" Reduce, Reuse and Recycle, which classify waste management strategies according to their desirability in terms of waste minimization (Anon [a], 2011). However, this technique is not extensive enough. Before the waste hierarchy is effectively applied, it is desirable to identify, classify and estimate the quantity or the volume of waste to be generated. An effective waste management technique must incorporate all these factors.

The volume of drilling waste generated when drilling a well is also an important and costly factor, especially when the waste must be transported, treated, or disposed off-site(Fleming, et al., 2010). It is an important planning tool which is usually not mentioned in the drilling waste management process. Drilling waste could be better managed if the anticipated amount or volume is appropriately quantified. Unfortunately, very few publications have reported on drilling waste volume quantification and estimation methods. This study seeks to identify the various types of drilling wastes that pollutes the environment and how to minimize it. It presents an effective method to quantify the volume of drilling waste generated for an efficient waste management plan.

1.2 Literature Review

Environmental pollution and waste management is a broad and extensive study area with lots of publications. There is a tremendous amount of valuable information available on the environmental impact of petroleum operations and on ways to minimize that impact: however, this information are scattered among thousands of books, reports and papers making it difficult for industrial personnel to obtain specific information on controlling the environmental effects of particular operations (Reis, 1996). Again, very little of these materials focuses on waste volume quantification.

The paper outlines the processes for identifying appropriate waste management strategies in specific area of operation. These strategies consider environmental regulations, company policies, operational and economic factors. The management practices discussed includes waste minimization, storage, handling and disposal. The writer reiterated that waste management in the industry is really a problem and this is basically due to inadequate understanding of the waste management options available. The writer gave six basic steps for effective waste management. However, one very important basic step was not included which happens to be one of the objectives of this study: the estimation of the quantity of waste generated. In conclusion the writer specified that categorizing an area waste and determining appropriate management option improves understanding of wastes, waste management requirement and options. He further pointed that, writing and implementing the plan as suggested improves communication and implementation of the established waste management goals and standards.

Several of the processes used to reduce the environmental impact of drilling waste are counter-productive. They can increase drilling cost and often worsen the waste disposal problem rather than solving or relieving it. Bouse, et al. (2000), conducted a research on the importance of solid control and its relevance to waste management. It was realized that the most effective means of reducing the volume of waste generated by the drilling operation is through efficient removal of drilled solids. For example, in deep well drilling, a 10 % improvement in drilled solids removal can reduce the waste by as much as 8000 to 10000 barrels. The use of closed mud systems reduce the environmental impact of oil well drilling to an absolute minimal however; this requires the removal of all drilled solids and the reuse of the liquid discharged by the solids removal equipment. The cost of maintaining this practice makes it very difficult to justify except under very special circumstances, such as drilling in an urban environment or in areas in which government regulations prohibit the discharge of drilling fluid wastes. Moreover, the option of transporting waste to an off-location disposal site is very costly especially when the volume of liquids is large.

The most economical means of handling the waste control problem without jeopardizing the drilling operation is to: optimize solid removal thereby limiting the volume of waste generated, eliminate or reduce the use of contaminating muds and additives, avoid the commingling of contaminating and non-contaminating waste and finally, treat and dispose of waste on location. The treatment and disposal of non-contaminating waste is relatively simple and inexpensive. However, the disposal of contaminating waste such as liquids and cuttings from water-based mud containing diesel oil, heavy metals etc. pose serious problems. The authors presented a number of instances for the disposal of such waste materials: one of such being the injection into salt water sand behind the casing. Other possible methods are the use of microbes (Bouse, et al, 2000) to consume containing oil, incineration, solidification, burial and transportation to an approved disposal site. In conclusion, the authors stated that, the operation of solids removal equipment should be closely monitored and should be structured to determine the quantity of solids separated and the breakdown between high-gravity and low-gravity solids.

Flemming et al, (2010) carried out a study on various methods for estimating the volume of drilling waste generated, both onshore and offshore. Four ways of estimating waste were considered: Estimating volume in an earthen pit, estimating volume from fluid deliveries, estimating volume by mud usage mass balance and estimating volume with waste hauling data. These methods were compared to a mathematical computer model that has been developed. In this research, the writer revealed an approach to model the contents of the waste estimation by the earthen pit method: that is, to develop a spreadsheet that calculates the average content from one segment in depth to another. From the results, waste estimation by the fluid delivery and hauling data yielded similar estimates with about 5% difference. Secondly, the ratio of waste to hole volume using the fluid usage method showed a declining trend however, there is no such trend using the waste hauling method. The writers attributed this to the possibility of some waste-filled boxes of one hole being attributed to a another hole. In conclusion, the model was used to validate other methods and the results showed that the ratio of waste to hole volume is 20:1. This has been a close fit to the other offset records methods but the writers stressed that these programs must be used by experienced users because if wrong assumptions are made, waste volume estimates could be in gross error.

Richards et al. (2007), defines drilling waste as any solid or liquid generated by the drilling process. It can range from dry solid to pure liquids. Technologies exist that easily transport solids in dry and liquid forms (screw auger conveyors, pneumatic transport systems or vacuum transport systems, centrifugal pumps, piston pumps and progressive cavity pumps). However, drilling wastes are usually a combination of solids and liquids and this makes their transportation a challenge. Ideally but impracticable, drilling waste must be separated into solid and liquid phase to enable existing technologies to move them efficiently. A second preference which adds extra waste volume and has cost implications is to build slurries of controlled density, thereby enabling traditional pumps and tank systems to move the waste in slurry form. This paper, introduces the Brandt Transfer System (BTS^{TM}), a patented pump and collection system designed to pump drilling wastes and heavy sludge's. The writers introduce some criteria for evaluating the pump.

When evaluated for both fast and slow drilling conditions, the amount of waste generated was 0.667 bbl/ft and 0.084 bbl/ft respectively. It takes one (1) hour to fill the collection tank under fast drilling conditions where asunder slow drilling conditions, it takes 95 hours. The longer time will pose extra problems in that, the solids will settle through natural decantation process. However, the variable-speed cutter head feature of the system breaks up the sediments. The evaluation shows that, the system is suitable for both conditions. When evaluated against economic ability, the system proves highly economical, since it requires fewer personnel to operate and less energy requirement. Each barrel of waste moved during the slow drilling costs only 0.09 kilowatts (kWh) of electricity (about 8 cents). Finally, the system was evaluated against balanced environmental goal. The system reduces the impact on marine life and also results in less impact on surface environment since less energy will be used which will cause fewer emissions into the atmosphere. The writers in their conclusion stated that, new and more environmental laws are forcing the industry to change ingrained practices, thus creating the need for new technologies and thus, for a successful waste management project, proper storage and transportation of drilling waste must be given a priority.

Rana, (2008), reviews environmental aspects of Oil & Gas drilling in view of economics of the projects benefiting industry professionals. Exploration and Production (E&P) wastes are introduced into the environment through accidental spills, leaks, blowouts and drilling operations. These wastes toxic chemicals pose significant risks to the environment, human health as well as wildlife. The potential for accidental or routine release of drilling wastes into the environment is alarming and thus threaten to sustain the industry operations. Many of the toxic chemicals associated with oil and gas drilling are known to accumulate and magnify in the food chain posing a risk to aquatic organisms higher in the food chain, such as fish and birds. From past safety records and statistics, the researcher identified that harmful environmental incidences will continue to take place, but the effects of these pollutants on human health and the environment can be minimized through proper environmental monitoring and mitigation measures; including the use of modern technological advances. Such technologies include; smaller drilling pads, directional drilling, smart wells, slimhole, coiled tubing, and measurement while drilling. Again these technologies for the petroleum industry are developed primarily to increase oil recovery and reduce the cost of recovery. Reducing costs often goes with reducing the environmental impact of exploration, drilling and completion procedures.

Rana, (2008), made mention of the “Smarter, Farther, Deeper, Cleaner and Smaller” operations. He pointed out that these make good business sense and help to protect the environment. Most companies have realized that going one step farther to protect sensitive environments and avoiding pollution, pays them back in increased benefits and improved public relations. The impact of better management and advanced technologies for exploration, drilling, production and oilfield operation can be seen in reduced footprint and air pollution, better monitoring, recycling, and management of generated wastes. These further prevent loss or pollution, preservation of resources, and on-site recycling of energy byproducts, thus improving environment and reducing costs.

Kinigoma, (2001), studied the effect of drilling fluid additives on the Soku oil fields environment in the Niger Delta State of Nigeria. Soil and reserve pits in various locations were assessed for physico-chemical characteristics and heavy metal content using standard methods for water and wastewater analysis. Plant growth and other biomass were also assessed. The result showed that the levels of most physiochemical characteristics are generally within the limits of guidelines by regulatory authorities. However, trace metal levels are generally below toxic levels, except Fe, Ca and Mg, which were higher than recommended values. These high values of Fe, Ca and Mg (17.70-220.2; 11.03-296.80; and 12.62-75.71 ppm) respectively are characteristic of the Niger Delta Swamp soils. The writer in conclusion attributed the poor plant growth observed in the immediate vicinity of location of drilling operations, to the indication of the toxic effect of drilling fluids on the environment

Seyle, et al. in 2002, also conducted an extensive offshore survey and environmental assessment of drilling additives offshore Brunei. A primary focus was to evaluate the environmental effects of disposal of Oil-Based Mud (OBM), Ester-Based Synthetic Mud (EBSM) and Water-Based Mud (WBM) in the tropical marine environment of the South China Sea. A number of well sites were surveyed for each of the mud types encompassing varying water depths (20 - 500 m) and time elapsed since drilling. Side-scan sonar, detailed hydrographic imaging, sea bed video, current information and benthic sampling results were also interpreted. Modified radial sampling patterns were used. The study concluded that the magnitude and persistence of environmental effects from discharge of drilling muds and cuttings range in order of severity from OBM to EBSM to WBM. The study found that the OBM and cuttings are toxic to marine life and can persist on the Brunei sea bed for over 13 years. WBM effects were however noted to be more widely dispersed (> 1200 m) and exhibited indications of faster benthos recovery (within 3 years than) than EBSM (typically dispersed within 200 m).

1.3 Scope of Study

All activities related to Oil & Gas Exploration, Production, Storage and Transportation involve waste generation associated to potential risk to environment. Waste types are related to primary Exploration and Producing (E&P) activities. These activities are: Drilling operations, Completion operations, Production operations, Work-over operations, Gas plant operations. Wastes associated with drilling operations deserve special attention due to the quantity and complexity of the pollutants they carry. Drilling wastes (mud and cuttings) represents the second largest sources of waste in the industry. The volume of drilling wastes usually ranges from 1,000 to 5,000 m^3 for each well. As a result, this study focuses on wastes generated through drilling operations. It does not however consider wastes generated during the preparation of drilling site, transportation and assembling of drilling rig, and the decommissioning of drilling operations. Completion and work-over wastes are also not considered.

It involves the identification and the minimization of the various forms of drilling waste, the estimation of the volume of drilling waste generated and the coding into Microsoft Excel to generate a user friendly program for drilling waste volume computation. Finally, this study outlines practical steps for effective waste management.

1.4 Objectives of Study

The Objectives of this study are:

- To identify various types of drilling waste that impacts the environment negatively.
- To develop equations for waste volume computation and build a Microsoft Excel User-friendly model for Waste Volume Estimation.
- To establish the best possible ways for minimizing drilling wastes.
- To develop a comprehensive waste management plan and to establish the best possible way of incorporating waste volume estimation into it.

1.5 Methodology and Materials Used

The following materials were used in the execution of this study:

- Internet and Library facilities from the African University of Science and Technology, AUST
- Microsoft Office Suite (Excel and Word)

The methodology used includes:

- Reviewing of relevant literature about the subject matter (drilling waste management).
- Developing of equations for drilling waste volume estimation.
- Programming of developed equations using Microsoft Excel Spreadsheet.
- Evaluation of parameters affecting waste volume and the validation of the excel program using data from literature.
- Integration of waste volume estimation into waste management and the development of a comprehensive waste management.

1.6 Organization of Thesis

The thesis is structured into five chapters. Chapter one gives a brief introduction and definition of the study problem. It also states the objectives and defines the scope and methodology used. Chapter two presents literature on drilling waste types and their repercussions on the environment. Environmental concerns based on location (offshore, onshore and deep offshore) is captured in chapter three whiles chapter four focuses on drilling waste minimization and management. It also covers the building of the spreadsheet model and its validation. Finally, chapter five summarizes the entire work and provides conclusions and recommendations for future work.

CHAPTER 2

TYPES OF DRILLING WASTES AND THEIR EFFECTS ON THE ENVIRONMENT

2.1 Introduction

Drilling activity is a major operation in the upstream petroleum industry which impacts negatively on the environment as it generates significant amount of wastes. Environmentally responsible actions require an understanding of these wastes and how they are generated. From this understanding, improved operations that minimize or eliminate any adverse environmental impact can be developed, (Reis, 1996). The wastes generated during any drilling operation includes: drilling cuttings, drilling fluids, chemical additives, heavy metals, as well as air pollutants.

2.2 Types of Drilling Waste

During drilling operations, drilling fluid or mud is pumped down the drill string to lift drill cuttings to the surface. The drilling fluid together with the suspended drill cuttings and some heavy metals are carried through the annulus to the surface where the cuttings are separated from the fluid and the fluid is re-injected to lift more cuttings. The solid cuttings are then either treated and disposed off, grinded into slurries and injected or kept in a waste pit for further treatment and disposal. From the ongoing, five major types of wastes could be associated with drilling operations: drill cuttings, contaminated drilling fluid, contaminated additives, air pollutants and heavy metals.

2.2.1 Drilling Fluids

Drilling fluids, simply referred to as mud are fluids used in drilling operations to remove drill cuttings from the wellbore. They also perform other functions such as cooling and lubrication of the bit, maintaining well stability and balancing underground hydrostatic pressure. These fluids are pumped down the drill pipe, through the bit, to carry the drill-cuttings through the annulus back to the surface. Depending on the continuous phase fluid, drilling fluid systems are either water-based (aqueous) or non-aqueous emulsion systems.

2.2.1.1 Aqueous Based Fluids

Aqueous Based Fluids or Water-Based Mud (WBM) are the types of drilling fluids that use water or brine as the continuous phase fluid. Water-based drilling mud most commonly consists of bentonite clay (gel) with additives such as barium sulfate (barite), calcium carbonate (chalk) or hematite. Various thickeners are used to influence the viscosity of the fluid, e.g. xanthan gum, guar gum, glycol, carboxymethyl cellulose, polyanionic cellulose, or starch. Deflocculants are also used to reduce viscosity of clay-based muds; anionic polyelectrolytes (e.g. acrylates, polyphosphates, lignosulfonates (Lig) or tannic acid derivates such as Quebracho) are frequently used (Anon. (a), 2011).WBM's are considered as environmentally better alternative for Non-Aqueous Based Fluids (NAF), and where possible their use is favored over NAF. The physical/chemical characteristics, and thus the applicability in drilling operations, of WBM are different compared to NAF. Even though WBM are environmentally favorable, for technical and safety reasons NAF may be required in situations where drilling operations are more complex. It is, therefore, common practice for WBM to be used for drilling the upper section of the well and NAF for the more complex sections (TMD, 1998). Some advantages of using WBM include: lower environmental impact and enhanced worker safety through lower toxicity, elimination of Polycyclic Aromatic Hydrocarbons, faster biodegradability, and lower bioaccumulation potential (CAPP, 2001).Table 2.1, gives a summary of typical elemental composition of common constituents of WBM.

Table 2.1: Elemental Composition of Water-Base Drilling Mud (Deeley, 1990).

Element	Water	Cuttings	Barite	Clay	Chrome-lignosulfonate	Lignite	Caustic
Aluminum	0.3	40400	40400	88600	6700	6700	0.013
Arsenic	0.0005	3.9	34	3.9	10.1	10.1	0.039
Barium	0.01	158	590000	640	230	230	0.26
Calcium	15	240000	7900	4700	16100	16100	5400
Cadmium	0.0001	0.08	6	0.5	0.2	0.2	0.0013
Chromium	0.001	183	183	8.02	40030	65.3	0.00066
Cobalt	0.0002	2.9	3.8	2.9	5	5	0.00053
Copper	0.003	22	49	8.18	22.9	22.9	0.039
Iron	0.5	21900	12950	37500	7220	7220	0.04
Lead	0.003	37	685	27.1	5.4	5.4	0.004
Magnesium	4	23300	3900	69800	5040	5040	17800
Mercury	0.0001	0.12	4.1	0.12	0.2	0.2	5
Nickel	0.0005	15	3	15	11.6	11.6	0.09
Potassium	2.2	13500	660	2400	3000	460	51400
Silicon	7	206000	70200	271000	2390	2390	339
Sodium	6	3040	3040	11000	71000	2400	500000
Strontium	0.07	312	540	60.5	1030	1030	105

2.2.1.2 Non-Aqueous Based Fluids

Non-aqueous systems use non-water soluble base fluid as the continuous phase with water (or brine) emulsified and dispersed in the base fluid. Non-aqueous drilling fluids (NAFs) may be categorized into two: Oil-Based Mud (OBM) and Synthetic-Based Muds (SBM).

- ***Oil-Based Mud (OBM):*** OBM are similar to WBM, except that the continuous phase is a refined petroleum product rather than water.
- ***Synthetic-Based Muds (SBM):*** In an effort to develop drilling muds that are more environmentally acceptable than OBM, with the technical advantages of OBM, the oil industry developed a group of SBM. The base fluids of synthetic-based muds, as the name suggests, are composed of well-characterized chemical compounds synthesized specifically for formulation of the mud product. In SBM, the continuous phase is a synthetic organic ester, ether, acetyl, or olefin. Most SBM used today in the Gulf of Mexico are linear-α-olefins, internal olefins, or esters. Some SBM formulations contain a mixture of 2 or 3 synthetic organic chemicals, usually olefins and esters.

NAF’s are often preferred for high temperature wells, wells containing water sensitive materials like salts, clays and shales, wells containing reactive gases like CO_2 and H_2S and horizontal wells requiring unusually high lubrications. They are usually more expensive than WBM’s and have greater potential for adverse environmental impact. During drilling, formation materials get incorporated into drilling fluid, further altering its composition and properties. Figures 2a and 2b (IPIECA, 2009), shows the chemical compositions (by weight, %) of WBM and NAF.

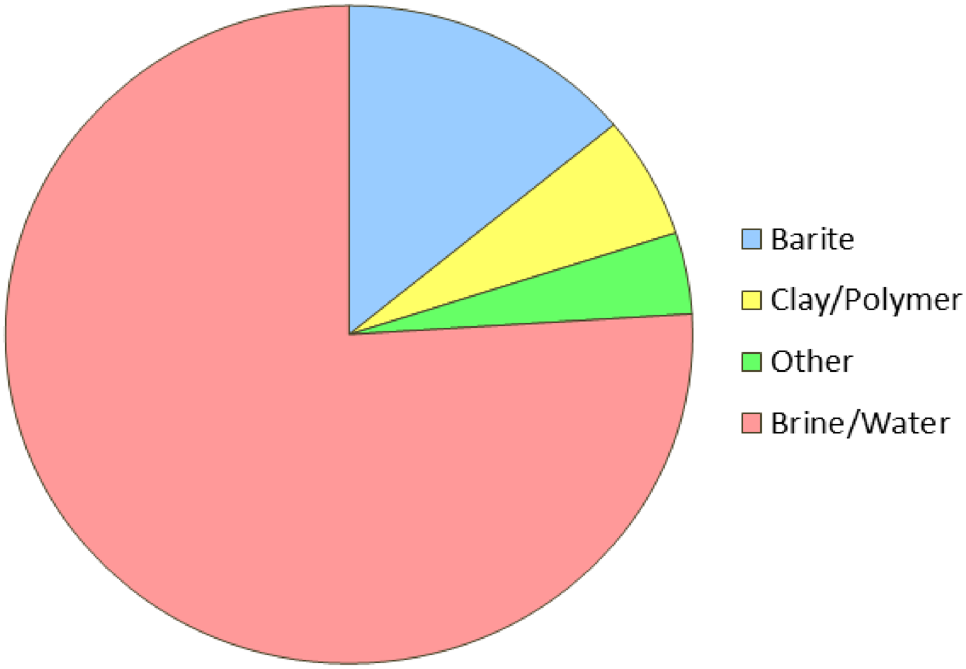


Figure 2a: Chemical Composition of WBM (Weight, %).

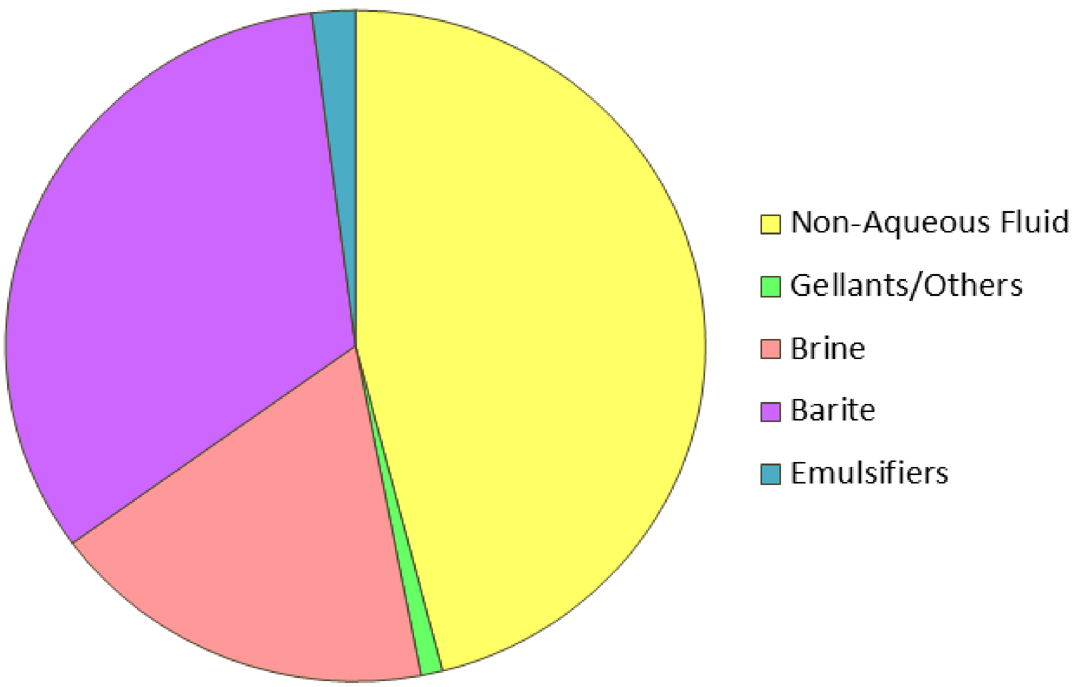


Figure 2b: Chemical Composition of NAF (Weight, %)

2.2.2 Drill Cuttings

Drill cuttings are particles of crushed rock produced by the grinding action of the drill bit as it penetrates into the earth. Drill cuttings range in size from clay-sized particles to coarse gravel having an angular configuration. The chemistry and mineralogy reflect that of the sedimentary strata being penetrated by the bit. Drill cuttings separated from drilling muds have a complex and extremely changeable composition. This composition depends on the type of rock, drilling regime, formulation of the drilling fluid, technology to separate and clean the cuttings, and other factors. However, in all cases, drilling fluids play the leading role in forming the composition of drill cuttings. Cuttings volume depend on the type of fluid used, the depth of the well, and the size of the borehole. Estimated volumes range from 130 m^3 to 560 m^3 per well (Melton et al, 2000). Problems occurring from drill cuttings are due to unplanned management. For example, long time drilling operations can result in huge piles of drilling cuttings settling on the surface of the ocean floor. According to CEF (1998), the volume of rock can range from 300 m^3 to 1200 m^3, and the volume of mud and cuttings combined can reach 3200 m^3 from each exploratory well.

Besides the temporary effects of the physical burial of benthic fauna under low-energy seabed conditions, there have been no observed adverse environmental effects due to the deposition of cuttings themselves (TMD, 1998). However, cuttings are often contaminated with drilling muds and some heavy metals from formation fluids which may have harmful effects. Drill cuttings associated with water-based mud are usually discharged at sea. However, due to the high concentrations of oil, cuttings associated with oil-based muds are not approved for such disposal (Khan et al, 2007). Cuttings associated with synthetic or enhanced mineral oil-based muds may be disposed by re-injection or direct disposal after cuttings have been treated to an acceptable level (concentration of oil must be below 6.9g/100g wet solid). The environmental impact of these cuttings is determined by the extent and nature of their contamination with drilling muds and heavy metals.

2.2.3 Chemical Additives

Drilling fluids serve a number of purposes in drilling a well. In most cases, however, the base fluid does not have the proper physical or chemical properties to fulfill those purposes, hence, other components called additives are added to provide various specific functional characteristics. Some common additives include lubricants, shale inhibitors and fluid loss additives (to control loss of drilling fluids into permeable formations). A weighting agent such as barite is added to increase the overall density of the drilling fluid so that sufficient bottom hole pressure can be maintained thereby preventing an unwanted (and often dangerous) influx of formation fluids (Anon. (c), 2011). Traces of these additives can contaminate drilling fluids as well as drill cuttings which make the composition of drill cuttings very complex and harmful. Table 2.2 summarizes some of the common additives to both WBM and NAF's and their functions.

Table 2.2: Functional Categories of Materials Used in Drilling Fluids (Modified After Neff, 2005)

Functional Category	Function	Typical Chemicals
Weighting Material	Increase density (weight) of mud, balancing formation pressure, preventing a blowout	Barite, Hematite, Calcite, Ilmenite
Viscosifiers	Increase viscosity of mud to suspend cuttings and weighting agent in mud	Bentonite or Attapulgite Clay, Carboxymethyl Cellulose, and Other Polymers
Thinners, Dispersants and Temperature Stability Agents	Deflocculate clays to optimize viscosity and gel strength of the mud	Tannins, Polyphosphates, Lignite, Lignosulfonate
Flocculants	Increase viscosity and gel strength of clays or clarify or de-water low-solids mud	Inorganic Salts, Hydrated Lime, Gypsum, Sodium Carbonate and Bicarbonates, Sodium Tetraphosphate, Acrylamide Based Polymers
Filtrate Reducers	Decrease fluid loss to the formation through the filter cake on wellbore wall	Bentonite Clay, Lignite, Na-Carbooxymethyl Cellulose, Polyacrylate, Pregelatinized Starch
Alkalinity, pH Control Additives	Optimize pH and alkalinity of the mud, controlling mud properties	Lime (CaO), Caustic Soda (NaOH), Soda Ash (Na_2CO_3), Sodium Bicarbonate ($NaHCO_3$), and Other Acids and Bases
Loss Circulation Materials	Plug leaks in the wellbore wall, preventing loss of whole drilling mud to the formation	Nut Shells, Natural Fibrous Materials, Inorganic Solids and other Inert Insoluble Solids
Lubricants	Reduce torque and drag on the drill string	Oils, Synthetic Liquids, Graphite, Surfactants, Glycols, Glycerine
Shale Control Materials	Control hydration of shales that causes swelling and dispersion of shale, collapsing the wellbore wall	Soluble Calcium and Potassium Salts, Other Inorganic Salts and Organics such as Glycols
Emulsifiers and Surfactants	Facilitate formation of stable dispersion of insoluble liquids in water phase of the mud	Anionic, Cationic or Nonionic Detergents, Soaps, Organic Acids and Water-Based Detergents
Bactericides	Prevent biodegradation of organic additives	Glutaraldehyde and Other Aldehydes
Defoamers	Reduce mud foaming	Alcohols, Silicones, Aluminum Stearate, Alkyl Phosphates
Pipe-Freeing Agents	Prevent pipe from sticking to wellbore wall or free stuck pipe	Detergents, Soaps, Oils, Surfactants

2.2.4 Air Emissions

Another waste stream associated with drilling operation is air emissions. These emissions arise primarily from the operation of internal combustion engines which are used to power the drill rigs. Basically, these air pollutants include oxides of nitrogen (NO_X), volatile organic compounds (VOCs) and oxides of sulfur (SO_X). There are also potential emissions of hydrogen sulfide present in natural gas deposits. The short and long-term direct effect on human health could be severe, from unconsciousness to death within a few breaths (Reis, 1993). Statistically, 0.5-1% of exploratory wells results in blowout, causing harmful emissions (Clark, 2002).

2.2.5 Heavy Metals

Heavy metals can enter drilling fluids in two ways: Many metals are naturally occurring in most formations and will be incorporated into the fluid during drilling. Other metals are added to the drilling as part of additives used to alter the fluid properties. The most commonly found metals have been barium from barite weighting agents and chromium from chrome-lignosulfonate defloculants. Naturally occurring metals of particular concern include arsenic, barium, cadmium, chromium, lead and mercury. The toxicity of heavy metals found in the upstream petroleum industry varies widely. The toxicity of many heavy metals lies in their interference with the action of enzymes, which limits or stops normal biochemical processes in cells. General effects include damage to the liver, kidney, or reproductive, blood forming, or nervous systems. With some metals, these effects may also include tumors or mutations (Reis, 1993).

2.3 Classification of Drilling Waste

Drilling waste classification varies from country to country but the most commonly used classifications are:

- Exempt Wastes and
- Non-Exempt Wastes

Exempt wastes are considered non-hazardous and are therefore exempted from the Environmental Protection Agencies (EPA's) regulations as hazardous to the environment. These wastes generally come from an activity directly associated with the drilling of an oil or gas well or the production and processing of hydrocarbon products. About 98 % of all drilling wastes fall under this category (Stilwell 1991).Non-Exempt Wastes on the other hand are drilling wastes that come from the maintenance of drilling equipment or otherwise are not unique to the oil and gas E&P industry. Though non-exempt, these wastes are not necessarily hazardous (Stilwell 1991). Wastes like cleaning wastes, painting wastes, and waste lubricating oil are not unique to the E&P industry and are therefore, not covered by the E&P exemption. Clearly, wastes such as drilling mud and cuttings are unique and as such are exempted.

Non-Exempt Wastes are further classified into:

- Non-Exempt Hazardous Waste
- Non-Exempt Non-Hazardous Wastes and
- Non-Exempt Special Wastes

An E&P waste is classified as hazardous if it exhibits any one of following four hazardous waste characteristics: ignitability, corrosivity, reactivity, and toxicity (RCC, 1993). In particular, for a waste to be exempt from regulation as a hazardous waste it must be associated with operations to locate or remove oil and gas from the ground or to remove impurities from such substances and it must be intrinsic to and uniquely associated with oil and gas exploration, development or production; the waste must not be generated by transportation or manufacturing operations. One common belief is that any wastes generated by, in support of, or intended for use by the oil and gas E&P industry are exempt. This is not the case; in fact, only wastes generated by activities uniquely associated with the exploration, development or production of crude oil or natural gas (i.e., wastes from down-hole or wastes that have otherwise been generated by contact with the production stream during the removal of produced water or other contaminants from the product) are exempt from regulation (RRC, 1993).

2.4 Toxicity of Drilling Waste

The toxicity of a substance is a measure of how it impairs the life and health of living organisms following exposure to the substance. In most cases, the effect of the substance on human life and health is of primary importance. Toxicity is determined through bioassays by exposing laboratory animals to different amounts of the substance in question (Res, 1993). The resulting effects on the health of the animals are observed. For petroleum industry wastes, common test species used for marine waters are the mysid shrimp and sheepshead minnow, while fathead minnow and daphnid shrimp are used for fresh waters (Reis, 1996).

Two types of toxicity measurements are commonly used: dose and concentration. The dose is the concentration of a substance that has been absorbed into the tissue of the test species, while the concentration is a measure of the concentration of a substance in the environment that the species lives in. Toxicity measurements using concentration also include a time interval of exposure. A dose that is lethal to 50% of the animals is called LD_{50}, whiles the lowest dose that is lethal, i.e., the dose resulting in the first death, is called LDLO. The dose levels required for any particular effect also depend on how the animal is exposed - by injection, ingestion, or inhalation. Similarly, a lethal concentration that kills 50% of the animals within a given period of time is called LC_{50} whiles the lowest lethal concentration for the same period of time is called LCLO (Reis, 1996).

Concentration is the toxicity measure most commonly used for materials associated with the petroleum industry. If a material is highly toxic, then only a small concentration will be lethal and the numerical values of the lethal doses and concentrations - LD_{50} and LDLO, would be low. Conversely, a high value of these parameters indicates low toxicity. LC_{50} values on the order of 10 are normally considered highly toxic, while values on the order of 100,000 are considered nontoxic (Reis, 1996).

2.5 Impacts of Drilling Waste on the Environment

Many of the materials and wastes associated with drilling activities have the potential to impact on the environment negatively. The potential impact depends primarily on the material, its concentration after release and the biotic community that is exposed. Some environmental risks may be significant whiles others are very low (Reis, 1993). The major impacts of great concerns are pollution of water bodies, pollution of land, as well as air pollution. Improper disposal of contaminated drill cuttings into water bodies (ocean) exposes marine life to danger. Excessive release of air pollutants from internal combustion engines makes the air unsafe for both humans and animals and some of their effects includes respiratory difficulties in humans and animals, damage to vegetation and soil acidification. Release of hydrogen sulfide, of course, can be fatal to those exposed. Table 2.3 summarizes the various impacts of drilling operations on the environment.

Table 2.3: Summary of Potential Environmental Impacts of Drilling Operations (Modified after EPF/UNEP, 1997)

Activity	Source	Potential Impact	Component Affected	Comments
Onshore (Exploratory and Appraisal Drilling)	Operations	Discharges, Emissions, Waste	H/At/B/Aq/T	Water supply requirements, noise, vibration and emissions from plant equipment and transport, extraneous light, liquid discharges: muds and cuttings, wash water, drainage, soil contamination: mud pits, spillage, leakages: Solid Waste Disposal: Sanitary Waste Disposal, sewage, camp grey water: emissions and discharges from well test operations: additional noise and light from burning/flare, Disturbance to wildlife
Offshore (Exploratory and Appraisal Drilling)	Operations	Discharges Emissions Wastes	H/At/B/Aq/T	Discharge to ocean: mud, cuttings, wash water, drainage, sewage, sanitary and kitchen wastes, spillage and leakages, Emissions from plant equipment: noise and light: solid waste disposal onshore and impact on local infrastructure. Disturbance to benthic and pelagic organisms, marine birds. Changes in sediment, water and air quality. Loss of access and disturbance to other marine resource users. Emissions and discharges from well test operations produced water discharges, burning and flare. Effect of vessel and helicopter movement on human and wildlife
H = Human, socio-economic and Cultural, T = Terrestrial, Aq = Aquatic, At = Atmospheric, B = Biosphere				

2.5.1 Effects of Drilling Waste on Human Health

Because the discharge of drilling muds impart a primarily local, rather than ecosystem-wide, it can be anticipated that the bulk of adverse human health effects would take place in those areas nearest to the site of discharge. Localized impacts of drilling mud could lead to the contamination of drinking water for human consumption or sport fish sources by a host of toxic chemicals. Furthermore, accumulation of the chemicals within local food chains would occur with continuous discharge or occasional accidental release of toxic drilling muds. The chemicals of concern could accumulate in the food chain organisms and increase in concentration as they move up the food chain, essentially growing in toxicity. Exposure via drinking water or fish consumption would adversely impact populations, even with low pollution levels in the exposure medium (Rana, 2008).

Drilling waste could impact human health via several routes of exposure. While inhalation is an occupational concern for drilling workers, ingestion of contaminated food or water remain the primary threats to the general population. This could happen through accidental release; intentional release, either permitted or not permitted, into the water body; or seepage from onshore storage areas into groundwater. The effects on human health include changes in the levels of certain blood enzymes, effects on children's neurobehavioral development, negative impacts on central nervous system, brain and eyes, and skin irritation. These include both non-carcinogenic and carcinogenic effects based on exposure to a particular chemical and duration and intensity of exposure (Rana, 2008). Health experts have concluded that pollutants emitted by diesel engines adversely affect human health and contribute to acid rain, ground-level ozone and reduced visibility. Studies have shown that exposure to diesel exhaust causes lung damage and respiratory problems and there is evidence that diesel emissions may cause cancer in humans (Haut et al, 2007).

2.5.2 Impact on Plants and Animals

Hydrocarbon concentrations of less than 1 mg/l in water have been shown to have a sublethal impact on some marine organisms (Reis, 1993). Other effects of hydrocarbons include stunted plant growth if the hydrocarbon concentration is above about 1 % by weight. Lower concentrations however can enhance plant growth. Marine animals that use hair or feathers for insulation can die of hypothermia if coated with oil. Coated animals can ingest fatal quantities of hydrocarbon during washing and grooming activities (Reis, 1993).

CHAPTER 3

ENVIRONMENTAL ISSUES BASED ON LOCATION

3.1 Introduction

The process of drilling oil and gas wells generates large volumes of drill cuttings and used muds. Onshore and offshore operators have employed a variety of methods for managing these drilling wastes. In offshore, options are limited to cuttings reinjection, offshore discharge and transportation to onshore disposal facility (Veil, 2002). This is as a result of the limited space and stringent environmental regulations governing an offshore drilling operation. As a result some offshore wastes have to be transported to an onshore facility for treatment and disposal. Onshore operations however, have a wider waste management options. The selection of a disposal method for a particular location depends on other factors which must be evaluated extensively before implementation. The main aim should be towards ensuring an environmentally safe waste disposal approach at the lowest possible cost. This chapter explores the various waste management options based on location (offshore and onshore).

3.2 Managing Waste Offshore

In drilling operations, drilling mud is pumped down the drill string and ejected through the nozzles in the drill bit at high velocity and pressure to lift cuttings to the surface. At the surface, solids control equipment is used to remove the unwanted solids from the drilling fluid to provide the maximum practical recovery of drilling fluid for re-use (OGP, 2003). The recovered drilling fluid is re-circulated down the drill string to lift more cuttings and the cycle continues. The remaining solid component which forms the waste stream is then subjected to one of these disposal methods: Offshore Discharge, hauling to Onshore Facility or reinjection into the formation. Managing waste in an offshore operation is usually more challenging and costly than on onshore operation. This is due to the stringent environmental regulations governing offshore drilling operations as well as limited space available for operation. The flow chart below (Figure 3.1) shows how drilling waste is managed in an offshore operation.

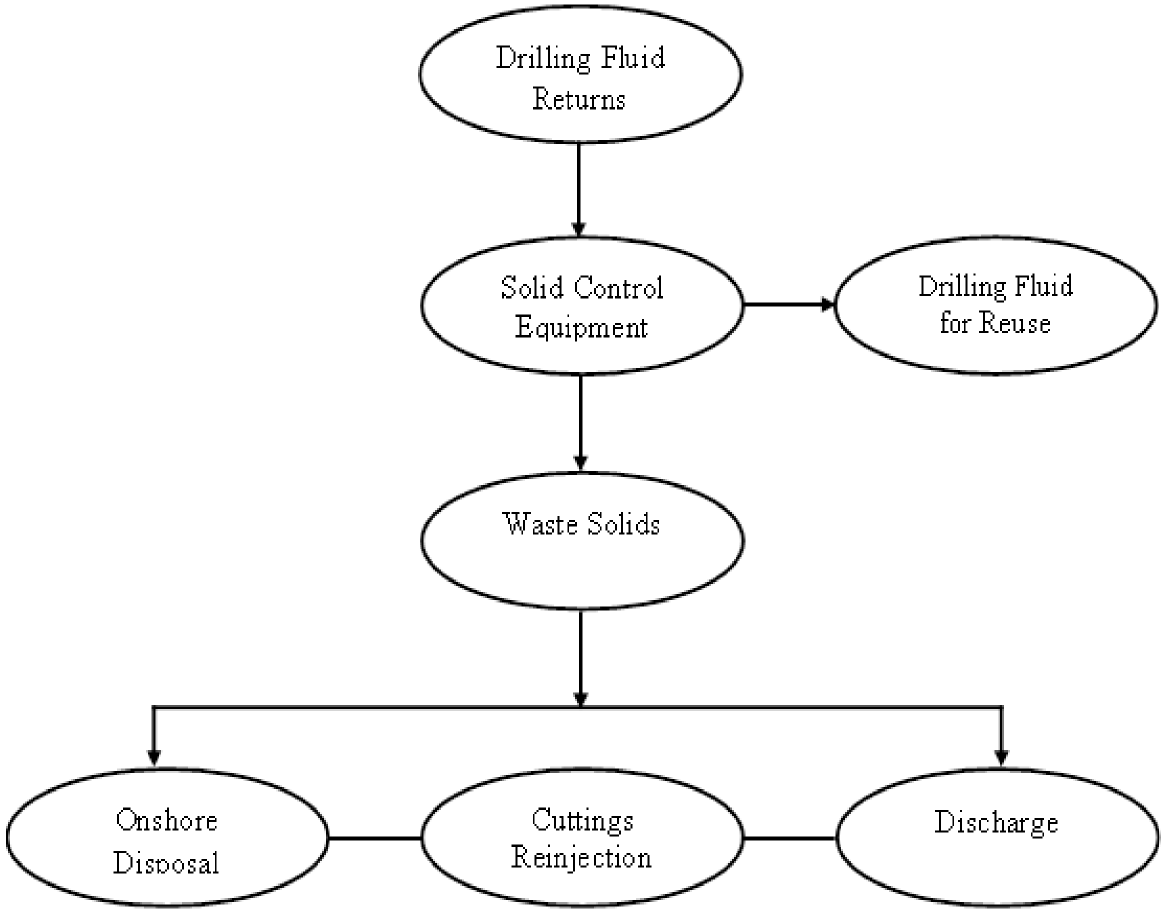


Figure 3.1: Offshore Waste Management (Modified After, OGP, 2003)

3.2.1 Solids Control Equipment

The solids control system forms the first waste management practice in any drilling operation. It removes drill cuttings from the drilling mud at the surface just before the mud re-enters the mud-pit for recirculation. Apart from drill cuttings, the solids control equipment also removes some gases and other contaminants in the mud before they are re-circulated. The early removal of these solids avoids accumulation and clogging of the system. The various mechanical separation devices separate solid particles by size (see figure 3.2). Table 3.1 shows classification and size of solids (Newpark, 3333). The components of the solids control system will depend upon the type of drilling fluid used, the formations being drilled, the available equipment on the rig, and the specific requirements of the disposal option (OGP, 2003). But basically, standard solid control equipment will comprise of shale shakers, degasers, desanders and desilters as shown in figure 3.2.

Table 3.1: Classification and Size of Solids (Newpark, 3333)

Classification of Solids	Example	Particle Size Range
Coarse	Small cuttings, gravel	>2000 microns
Intermediate	Coarse sand	250-2000 microns
Medium	Fine sand	74-250 microns
Fine	Coarse silt	44-74 microns
Ultra fine	Barite, fine silt	2-44 microns
colloidal	Bentonite, clay	< 2 microns

The mud passes over a shale shaker, which is basically a vibrating screen. This removes the larger particles, while allowing the residue to pass into settling tanks. The finer particles are further removed in the desanders and desilters. If the mud contains gas from the formation it will be passed through a degasser which separates the gas from the liquid mud. Having passed through all the mud processing equipment the mud is returned to the mud tanks for recycling (Anon, 2011), while the residue (drill cuttings with adhered drilling fluid) is either kept in a temporary storage facility for treatment and final disposal or direct discharged into the sea. In general, the solids control equipment reduces the volume of drilling waste requiring disposal.

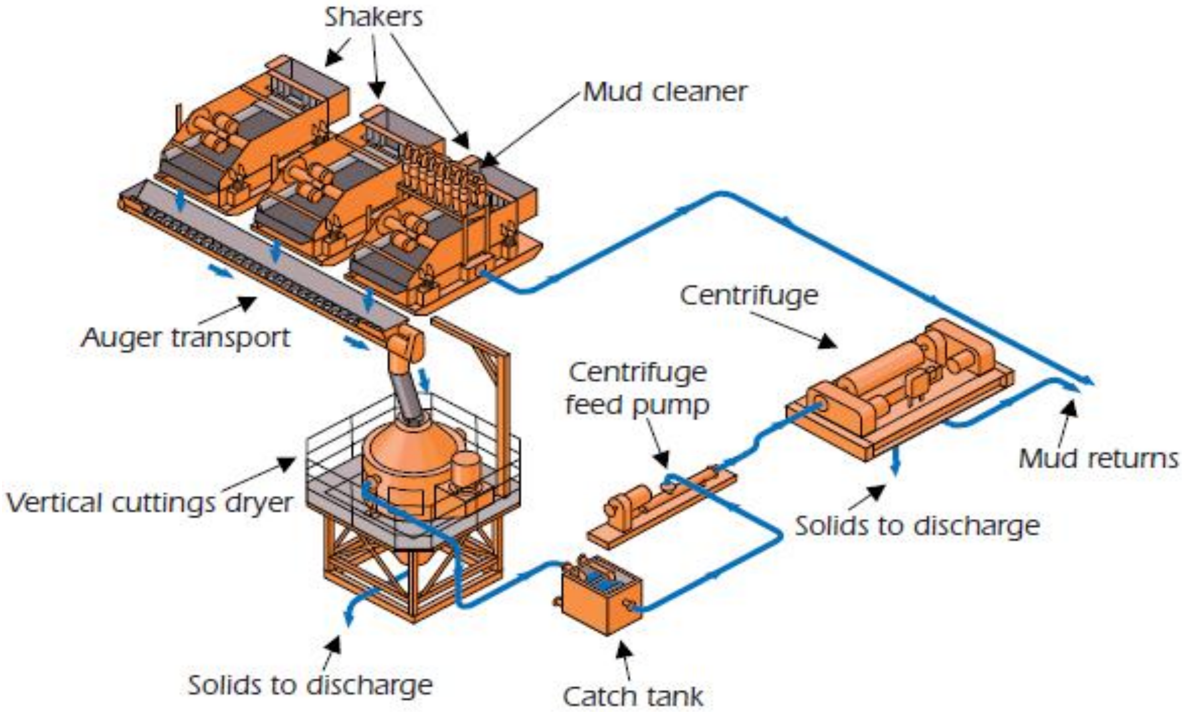


Figure 3.2: Standard Solids Control Equipment (OGP, 2003)

3.2.2 Disposal Methods for Offshore Operations

There are three basic drilling waste disposal options for offshore operations. These are, as shown in figure 3.1, offshore discharge, cuttings reinjection, and hauling to an onshore facility. The choice of disposal method to adopt is usually a very challenging task as this depends on other factors like the ecological conditions, environmental regulation and cost. For instance, it is cheaper to discharge waste into the ocean than to haul the waste to an onshore waste disposal facility, however, the environmental requirements for waste discharge is very stringent: waste must be treated to an acceptable level before being discharged and this implies extra cost. It is therefore highly recommended that, before any waste disposal method is selected, an extensive economic and environmental analysis be performed to evaluate the options. If offshore discharge is the selected disposal method, there will be no need for storage facilities.

3.2.2.1 Offshore Discharge

Discharging drilling waste into the ocean is perhaps the most economical and operationally safe disposal method. This is because; it does not require additional equipment (storage facility) than that conventionally found on the rig (OGP, 2003). This method of disposal is suitable for aqueous-based cuttings as they require little or no treatment before disposal. Non-aqueous based fluids, must however be treated to an environmentally accepted level before being discharged into the sea. Factors to consider when selecting this option include the sensitivity and capacity of the potential receiving environment, the concentration of potentially harmful components in the waste and the volume of the discharge stream.

The residue (cuttings with adhering drilling fluids) is mixed with sea water and discharged to the sea through a pipe known as "downcomer". The end of the downcomer is typically located a few meters below the water surface (OGP, 2003).The discharged residue will fall to the seafloor and accumulate to different degrees. For non-aqueous drilling fluids, concentration in the sediments will typically be elevated and benthic biota may be affected. With time the concentration will reduce and biota will recover but the time scales vary depending upon the thickness of the accumulation, and the characteristics of the receiving environment (e.g. water depth, temperature, waves and currents). Recovery for thicker accumulations (or piles) is thought to be much slower than for thin accumulations. Impacts to water column are considered negligible, because the cuttings settle quickly and the water solubility of the base fluids is low (OGP, 2003). A large cuttings pile and its residual drilling fluid load, poses a problem for facility decommissioning. Leaving the pile in-situ may provide a source of environmental contamination by uptake and bioaccumulation during the natural recovery of the site. Disturbance of a pile during the decommissioning and removal of the platform may significantly increase the potential for adverse impacts in the wider marine environment (Daan et. al. 1994). The advantages and disadvantages of this method of disposal is shown in table 3.2

Table 3.2: Advantages and Disadvantages of Offshore Discharge (Modified after OGP, 2003)

Economics	Operational	Environmental
+ Very low cost per unit volume treatment + No potential liabilities at the onshore facilities - Potential future liabilities - Cost of analysis of discharges and potential impacts (e.g. compliance testing, discharge modeling, field monitoring program	+ Simple process with little equipment needed + No transportation cost involved + Low power requirements + Low personnel requirements + Low safety risk + No shore-based infrastructure required +No additional space or storage required + No weather restrictions - Management requirements of fluid constituents	+ No incremental air emissions + Low energy usage + No environmental issues at onshore sites - Potential for short-term localized impacts on seafloor biology

3.2.2.2 Cuttings Reinjection

Recent strict regulations do not allow dumping of contaminated waste directly into the sea. As a result, reinjection of exploratory and drilling wastes, especially the drill cuttings is becoming more common practice when possible. Slurry injection technology involves the grinding of solids into small particles, mixing them with water or some other liquid to make slurry and injecting the slurry into an underground at pressures high enough to fracture the rock. The two common ways by which slurries are injected into the formations are through the annulus of the well or into a dedicated disposal well as shown in figure 3.3. Disposal wells are designed to provide a means of transporting fluid waste into an underground geologic formation in a manner that will not adversely affect the environment.

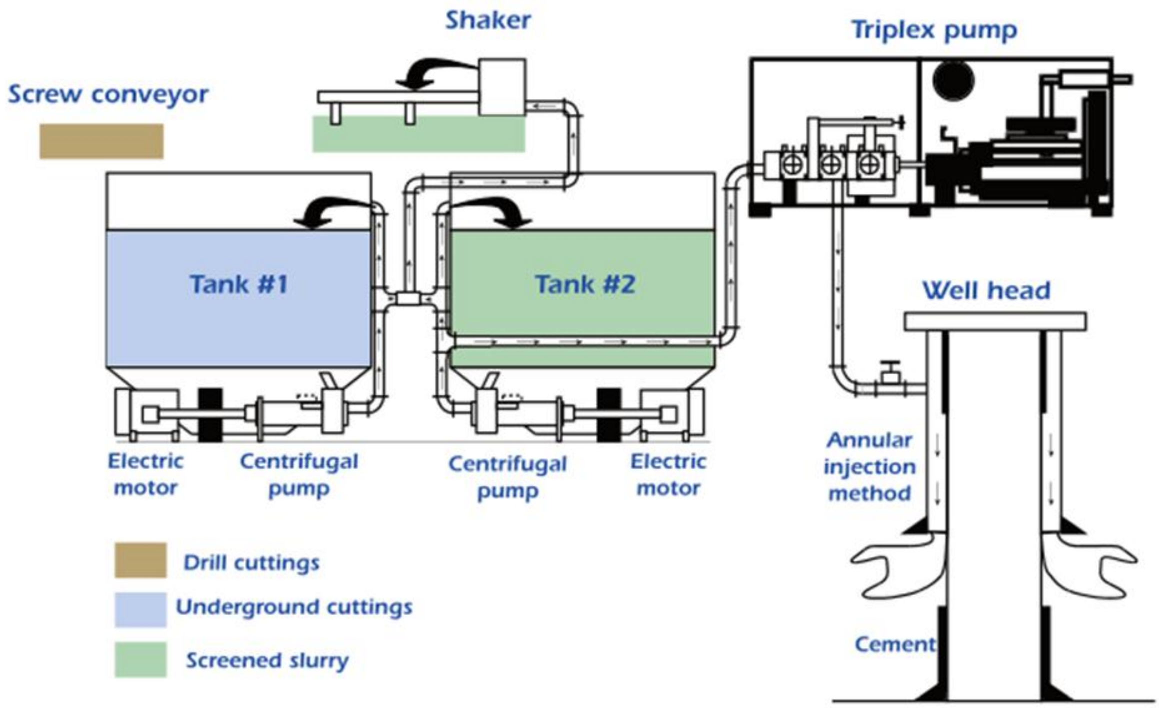


Figure 3.3: Offshore Cuttings Re-injection (OGP, 2003)

The choice of the optimum injection method must be made with reference to both operational and economic considerations. Drilling a dedicated injection well is sometimes ruled out in favor of an annular injection plan on a cost basis but more frequently, operators are deciding not to risk damaging their well and would rather drill a separate shallow injection well (Haut et al, 2007). The candidate formation for disposal must be geologically and mechanically isolated from usable sources of water to avoid seepage of the waste into the water body. This formation must not hold oil or gas in commercial quantities. Again the formation must have a good porosity and permeability. The process is recognized as highly environmentally friendly and has proven to be more economical than the disposal of drill cuttings onshore (Khan et al, 2007). The advantages and disadvantages of this method of disposal are listed in table 3.3

Table 3.3: The advantages and Disadvantages Cuttings Reinjection Disposal Method (Modified after OGP, 2003)

Economics	Operational	Environmental
+ Enables use of a less expensive drilling fluid + No offshore transportation needed + Ability to dispose of other wastes that would have to be taken to shore for disposal - Expensive and labor-intensive - Shutdown of equipment can halt drilling activities	+ Cuttings can be injected if pre-treated + Proven technology - Extensive equipment and labor-requirement - Application requires receiving formation with appropriate properties - Difficult for exploratory wells due to lack of knowledge of the formation	+ Elimination of seafloor impact + Limits possibility of surface and ground water contamination - Increase in air pollution due to large power requirements

3.2.2.2 Transporting to Onshore

This involves the hauling of cuttings and associated drilling fluid to an onshore treatment facility if necessary and finally disposed off by techniques such as land-farming/land-spreading, injection or reuse. These techniques are applicable to non-aqueous drilling waste which cannot be discharged or re-injected due to its toxic nature or volume. Factors to consider when evaluating these methods include the availability and cost of chattering a vessel and distance from platform to shore. It is important to evaluate the cost of chattering or transporting waste to shore before considering this option. The advantages and Disadvantages of Onshore Disposal Method (Modified after OGP, 2003) are summarized in table 3.4.

Table 3.4: The advantages and Disadvantages of Onshore Disposal Method (Modified after OGP, 2003)

Economics	Operational	Environmental
+ Waste can be removed from drilling location eliminating future liability at the rig site + Transportation cost can be high for vessel rental and vary with distance of shore base from the drilling location - Transportation may require chartering of additional supply vessel - Additional costs associated with offshore transport equipment (vacuum augers, cuttings boxes or bulk containers) and personnel	- Safety hazards associated with loading and unloading of waste containers on and at the shorebase - Increased handling of waste is necessary at the drilling location and at shorebase - Additional personnel required - Risk of exposure of personnel to aromatic hydrocarbons is greater - Efficient collection and transportation of waste are necessary at the drilling location	+ No impacts on benthic community + Avoids impacts to environmentally sensitive areas offshore + Fuel use and consequent air emissions associated with transfer of wastes to shorebase - Increased risk of spills in transfer (transport to shore and offloading) - Disposal onshore creates new problems (e.g. Ground water contamination)

3.3 Disposal Methods for Onshore Operations

Cutting reinjection is common to both offshore and onshore operations. However, due to the availability of space for an onshore operation, there are a lot more management options available. The most common onshore disposal method is perhaps onsite burial. Other methods include the construction of a waste reserve pit, thermal methods like incineration, kilns, open burning etc. There are also biological methods like composting, landspreading, landfarming etc. In an onshore environment, waste can be treated and used for other beneficial applications like road spreading, construction materials etc. This section explores the various options available for onshore waste treatment and disposal

3.3.1 Onsite Burial

Burial is the placement of waste in a man-made or natural excavation such as pits or landfills. Due to its simplicity, it has remained the most common onshore disposal technique for disposing drilling wastes. Other advantages of this method include low cost, low technology and also do not require transportation of waste from the well site. With the current awareness of pollutant migration pathways, the risks associated with burial of wastes should be carefully considered (Owens et al, 1993). For waste that contains high concentrations of oil, salt, biologically available metals, industrial chemicals and other materials with harmful components that can contaminate usable water resources, onsite burial may not be a good option. Burial is a logical choice for wastes that have been stabilized, since migration of the constituents of the waste will be retarded by the stabilization process (Owens et al, 1993).

The disadvantage of this method is that, burial usually results in anaerobic conditions. This limits any further degradation when compared with wastes that are land-farmed or land-spread, where aerobic conditions predominate (Aird, 2008).For proper protection of soils and water resources, consideration of factors such as the depth to groundwater, and the type of soil surrounding the pit should be made before wastes are buried. Finally, when burial and/or pit closure is complete, the area should be graded to prevent water accumulation, and revegetated with native species to reduce potential for erosion and promote full recovery of the area's ecosystem (Owens et al, 1993)

3.3.2 Waste Pits

The use of waste pits (earthen or lined) is an essential part of any onshore drilling waste management operation. While serving many purposes, one of the primary purposes is to collect and hold all of the drilling associated wastes generated from the drilling operation (Flemming et al, 2010). Other uses include evaporation and storage of produced water and management of work-over/completion fluids and for emergency containment of produced fluids. Waste pits must be strategically located to prevent spillage of waste materials onto the drilling or production site or into nearby water body or residential area. To prevent seepage into ground water bodies and contamination of the soil, the pits are usually lined with natural and or synthetic liners (see figure 3.4).

Figure 3.4: Reserve Pit Lined with Synthetic Liner (Ramirez, 2009).

Although pits are an accepted component of any drilling waste management program, they may represent an environmental liability if managed improperly. Reserve pits can contaminate soil, groundwater, and surface water with metals and hydrocarbons if not managed and closed properly (Owens et al, 1993). As reserve pit fluids evaporate, water-soluble metals, salts, and other chemicals become concentrated. Precipitation, changes in shallow groundwater levels, and flooding can mobilize these contaminants into adjacent soils and groundwater, Liners most often do not adequately seal the drilling wastes, especially if they are torn (Ramirez, 2009). Following well completion, reserve pits are left in place after the drilling rig and other equipment are removed from the site. Reserve pit fluids are allowed to dry and the remaining solids are encapsulated with the reserve pit synthetic liner and buried in place (Ramirez, 2009).

3.3.3 Landfills

Under this option, cuttings, either treated or untreated, are placed in a containment unit with a liner and cover that have been designed to contain the waste. The ability of the landfill to contain waste will depend upon the quality of the design and materials, and underlying geological units (OGP, 2003). A key consideration in the operation of a landfill site is the need to ensure long-term containment because landfilled wastes are not destroyed, but are actually in long-term storage. Landfills are usually operated by offsite commercial operators in which case waste can be received from different drilling sites. However, some oil companies with large amount of drilling activities may construct and operate private landfills. Figure 3.5, shows a picture of a commercial oilfield waste landfill facility.

Figure 3.5: Commercial Oilfield Waste Landfill (Aird, 2008)

3.3.4 Bioremediation

This is a treatment process that uses naturally occurring micro-organisms (yeast, fungi or bacteria) to break down and degrade organic substances. The micro-organisms break down the organic substances into harmless carbon dioxide and water. Once the wastes are degraded, the micro-organism population will reduce naturally as they will have nothing to feed on. Bioremediation process is fairly flexible and can be used for all manner of drill cuttings and other wastes. Some advantages of bioremediation are: it is relatively environmental benign; it generates few emissions; wastes are converted into useful products and it requires minimal, if any, transportation (Aird, 2008).There are various forms of bioremediation but the common types are land-farming/land-spreading, composting, and vemiculture.

3.3.4.1 Land-farming /Land Spreading

This waste management technique can be considered both as a treatment method and a disposal methods. The aim behind this method is to allow the soils naturally occurring microbial organisms to metabolize, transform and assimilate waste constituents in place (Aird, 2008). In general, land farming refers to the repeated application of untreated waste to the soil surface whereas land spreading refers to the one time application of the waste to the soil surface. This is usually followed by mechanical tilling with addition of nutrients, water, air and or oxygen to stimulate biodegradation and aeration of the soil by naturally occurring oil-degrading bacteria. This method of drilling waste management is relatively low cost and may even improve the water retaining capacity of sandy soils. Depending upon the location of the land-farm, a liner, overliner, and/or sprinkler system may be required. Both land-spreading and land-farming are more efficient in warm tropical climates, and may be inapplicable in areas where the ground is frozen in most part of the year (OGP, 2003).

3.3.4.2 Composting

Composting involves the mixing of drilling waste with bulking agents such as wood chips, straw, rice hulls or husks to provide increased porosity and aeration potential for biological degradation. Manure and other agricultural wastes are usually added to increase the water holding capacity of the waste/media mixture and to provide trace nutrients. Adding nitrogen and phosphorus-based fertilizers and trace metals also enhance microbial activity and reduce the time required to achieve the desired level of biodegradation (Aird, 2008).

Mixtures of the waste, soil (to provide indigenous bacteria) and other additives, may be placed in piles small enough (less than 3 feet deep) to be tilled for aeration, or placed in containers or on platforms designed to allow forcing of air through the composting mixture (Aird, 2008). The combination of placing the material in a pile, and addition of bulking agent result in high temperatures in the pile, which further increase rates of biodegradation and volatilization gives composting an advantage over land-spreading or land-farming in cold climates (OGP, 2003). Composited wastes that meet health-based criteria can be used to condition soil, cover landfills and supply clean fills (Aird, 2008). Figure 3.6, shows a picture of compost in windrows.

Figure 3.6: Compost in Windrows (Aird, 2008).

3.3.4.3 Vermiculture

This method of treating waste was developed by a research group in New Zealand. It involves using earthworms to enhance the bioremediation process and convert the drill cuttings into organic fertilizer. The process has been tested and proven successful in treating certain synthetic-based wastes (Norman et al, 2002). The contaminated drill cuttings are mixed with sawdust, undigested grass, and water and applied to worm beds. The feeding consists of applying the mixture as feedstock to windrows which are covered to exclude light from the worm bed and protect it from becoming waterlogged (Aird, 2008). This technique of treating waste not only cleanses the cuttings but also converts them into a valuable resource. Figure 3.7 is a picture of a vermiculture showing the worms

Figure 3.7: Vermiculture Showing Worms (Aird, 2008).

3.3.4.4 Thermal Methods

Thermal technologies that have been used to treat wastes include thermal desorption and incineration. With thermal desorption, the cuttings are placed in a treatment unit and then heated. The liquids are volatilized and re-condensed back to two phases: water and oil. The resulting waste streams are water, oil and solids. The wastewater will require treatment prior to disposal. The resulting solid residue has essentially no residual hydrocarbons, but does retain salt and heavy metals, and can be disposed of in a landfill or by land-spreading, or may be used in road construction. Incineration involves heating cuttings in direct contact with combustion gases and oxidizing the hydrocarbons. Solid/ash and vapor phases are generated (OGP, 2003). Incineration can be performed by open burning of wastes in pits or by the use of commercial incinerators. In order to ensure the removal of incomplete combustion products, incinerators emitting particulates, SO_x and NO_x are often equipped with air pollution control devices. Stabilization of residual materials may be required prior to disposal to prevent constituents from leaching into the environment (OGP, 2003).

3.4 Other Beneficial Uses of Drilling Wastes

Treated or untreated drilling waste can be converted to other useful materials. However, before cuttings can be used for other beneficial purposes, it is necessary to ensure that the hydrocarbon content, moisture content, salinity and clay content are suitable for the intended use of the material (Aird, 2008). Among the many beneficial uses of drilling wastes, two are very pronounced; road spreading and construction of building materials. Other proposed applications include incorporation into roofing tiles, use for trench cover, soil re-conditioning, restoration of wetlands and use of cuttings as fuels. Most of these applications are however just proposals and have not yet been implemented or demonstrated on the field.

3.4.1 Road Spreading

Drilling wastes are mixed with other construction materials and spread over gravel roads. The oily waste acts as an effective binding material which helps hold the road materials together and making such wastes an effective dust suppressant. Research has shown that the environmental impact of road spreading is low for properly prepared wastes. The metal contents of most oily wastes can be lower than that of asphalt; a common road paving material. Most of the wastes used for road spreading are of high volume, low toxicity solids; hence, disposal by road spreading reduces the volume of wastes that must be disposed of in overused landfills. Nevertheless, the lack of control over the spread of wastes is expected to limit and may even prohibit its future use (Reis, 1996).

3.4.2 Re-Use of Cuttings as Construction Materials

After treating drilling wastes to remove all the liquid contents, the clean solid residue can be employed in the manufacturing of construction materials. Some of the possible applications include the use of drill cuttings as a fill material, aggregate or filler in concrete, brick or block manufacturing (Aird, 2008). The economics of this technique must not be based on the value of the finished product but on the cost of other disposal methods. Usually, the cost of treating waste to remove all possible liquid contaminants makes this method less preferable to other methods like land-farming and composting.

CHAPTER 4

MINIMIZATION AND MANAGEMENT OF DRILLING WASTE

4.1 Introduction

Waste management refers to ways by which the generation and pollution of waste could be controlled to minimize or eliminate its negative impact on the environment. Over the past decade, there has been an increasing international concern for proper waste management in order to minimize their potential to cause harm to human health and the environment. The overall aim of managing drilling waste is to cut down on cost. As a result, effective and responsible waste management has been a key element of any organization's environmental management system. Besides, effective waste management practices will not only be a valuable tool for waste minimization programs, but also, source of data in the event of any question of liability for contamination, and site remediation. Waste management includes the incorporation of a hierarchy of waste management practices in the development of waste management plans. Being able to identify and quantify waste stream and assessing its potential impacts on the environment can help provide a baseline for identification of opportunities to improve practices. The potential benefits to a company that implements an effective waste management practices include (RCC, 1993):

- increased revenue;
- reduced costs of operating, materials, waste management and disposal, energy, and facility cleanup;
- improved operating efficiency;
- reduced regulatory compliance concerns;
- reduced potential for both civil and criminal liability; and
- enhanced public perception of the company and the industry as a whole.

4.2 Waste Management Hierarchy

Generally, the waste hierarchy refers to the "3 Rs" Reduce, Reuse and Recycle, which classify waste management strategies according to their desirability in terms of waste minimization (Anon. (b), 2011). It is usually represented by an inverted triangle with reduction occupying the upper portion, followed by reuse and finally recycling as shown in figure 4.1. In some instances waste treatment and disposal is incorporated as the least preferred option in the hierarchy. Proper management of wastes begins with pollution prevention. Pollution prevention refers to the elimination, change or reduction of operating practices which result in discharges to land, air or water. If elimination of a waste is not possible, then minimizing the amount of waste generated should be investigated.

4.2.1 Source Reduction

Source reduction involves the process of controlling waste generation at source. This might include generating less discharges through more efficient practices (e.g. using inhibitive mud systems, better solids control equipment, mud loss engineers, equipment to recover waste materials etc.), or looking into the possibilities for horizontal drilling, slim hole drilling, downsized casing designs etc. (Page et al, 1998). Source reduction is given the highest priority in the waste management hierarchy for the reason that avoiding waste generation altogether, or generating the least toxic waste possible, minimizes the problems associated with waste management. Waste that is not generated need not be managed and waste that is generated, but is of the lowest possible volume and/or toxicity, can be managed most cost-effectively (RCC, 1993). The generation of less waste involves practices such as: material elimination, inventory control and management, material substitution, process modification etc.

4.2.2 Waste Recycling

In instances where source reduction is not technically and economically feasible, recycling methods must be considered. Recycling involves the conversion of wastes into usable materials and/or extraction of energy or materials from wastes. Recycling may also involve the use or reuse of a waste as a substitute for a commercial product, or as feedstock in an industrial process. Recycling helps to preserve raw materials and reduces the amount of material that requires disposal (RCC, 1993).

4.2.3 Waste Reuse or Recovery

The use of materials or products that is reusable in their original form such as oily wastes for road construction and stabilization and burning waste oil for energy lessens the quantity of the waste released into the environment. If feasible, drilling fluid may be reused in another drilling project. The result of this is a significant cost savings and highly reduced waste management concerns. If reuse within a company is not feasible, there are several companies that take waste drilling fluids for reconditioning and reuse. This also has an economic benefit in that; materials that are to be disposed at a cost may be reused for extra income.

4.2.4 Waste Disposal

From an environmental perspective, disposal is the least preferred waste management option. Disposal generally involves the discharge, deposition, injection, dumping, spilling, leaking, or placing of any waste into or on land, water, or air (RCC, 1993). Disposal also involves the greatest potential liability and as such is the least preferred waste management option. The various disposal options have been elaborated in chapter three.

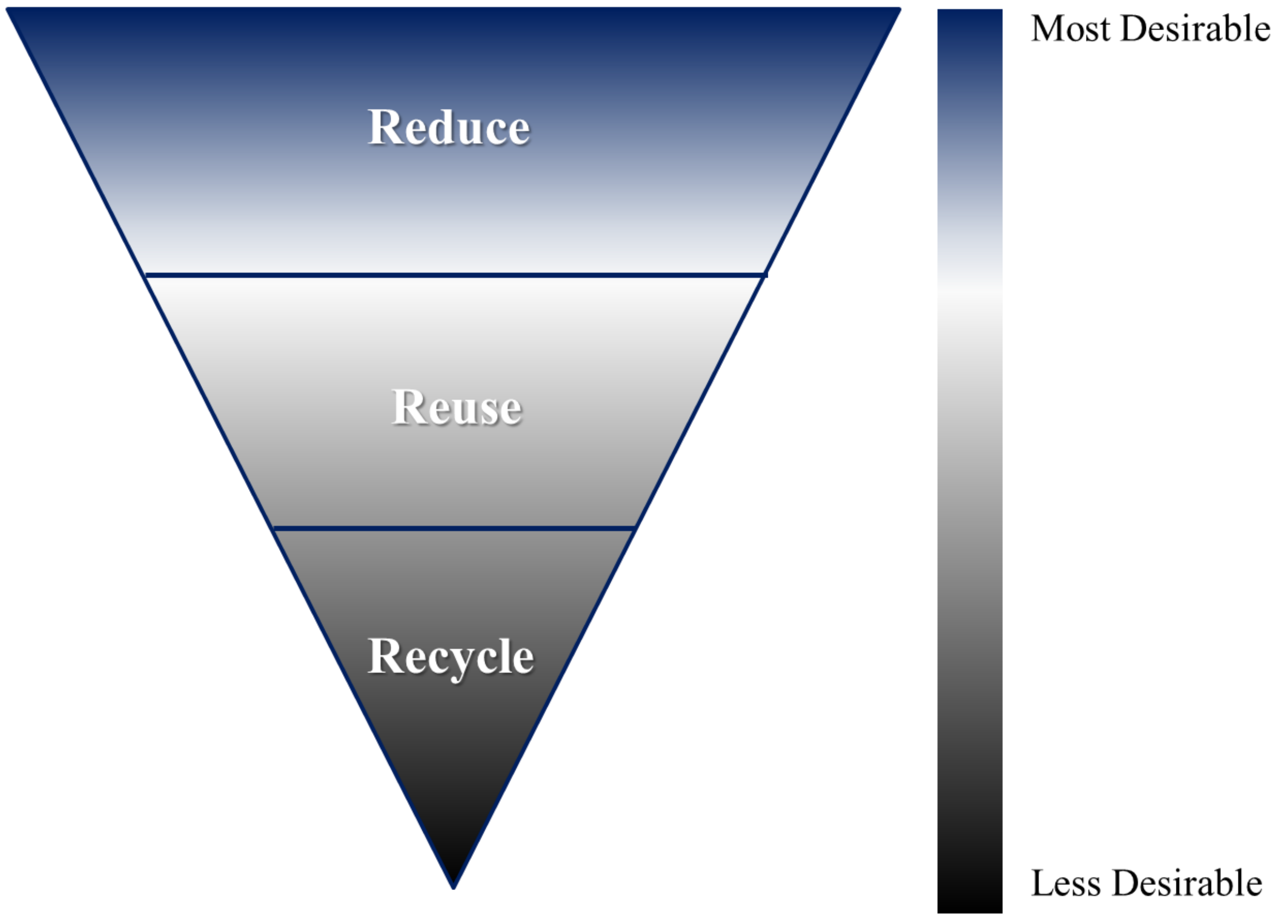


Figure 4.1: Waste Management Hierarchy

4.3 Practices that Minimize Drilling Waste Generation

Waste minimization program is an important element of any comprehensive waste management plan. As shown in the waste hierarchy, waste minimization or source reduction is the most preferred waste management practice. Where possible, the volume of waste released into the environment must be reduced. By reducing the volume, the potential toxicity and effects to the environment is minimized. It is also more economical to manage less volume of waste. Source reduction or minimization of waste also has operational advantages as less waste implies less personnel and equipment on board. The various waste disposal options for both offshore and onshore operations have been discussed in chapter three. This section identifies practical drilling practices that minimize the volume of waste generated.

4.3.1 Directional Drilling

Directional drilling allows drilling to be made at angles off the vertical. It involves the use of steerable/directional downhole tools allowing the driller to direct the wellbore in any angle to reach the target. Directional drilling allows drilling to be made in environmentally sensitive areas. Thus, a drilling rig could be sighted about several miles away and yet drill a target located underneath a market center. This reduces the environmental impacts of drilling especially air pollution on the public. Usually, directional drilling is more expensive and more difficult than conventional vertical techniques; however, it improves the efficiency and economy of oil recovery operations. Above all, directional drilling also generates a smaller volume of cuttings compared to the conventional vertical drilling technique. This is because; a reservoir which could be depleted with three conventional vertical wells with its associated wastes could be depleted with a single horizontal well with lesser volume of cuttings. Three variations of directional drilling include extended-reach drilling, horizontal drilling and multiple laterals of a single main well bore (Aird, 2008). Figure 4.2, is a picture of the various kinds of directional drilling.

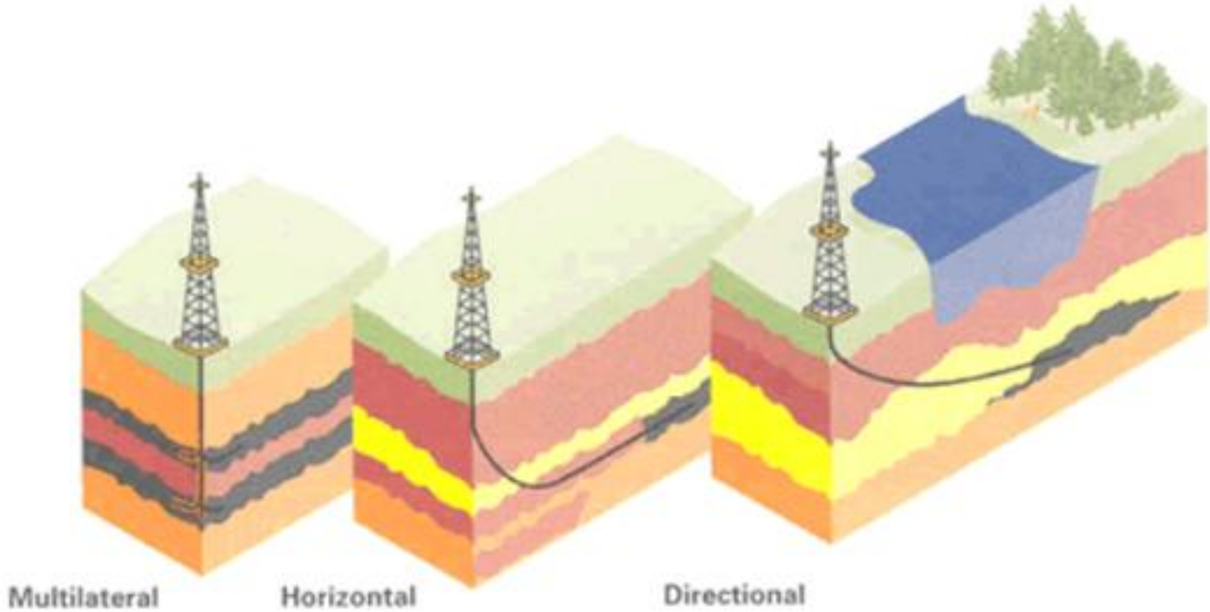


Figure 4.2: Directional Drilling Technology (Aird, 2008)

4.3.2 Drilling Small Diameter Hole

The volume of drilling cuttings generated is directly related to the hole size or bit size. Reducing the diameter of the hole will generate less volume of waste and hence reducing the quantity of toxic waste discharged into the environment. Two main drilling practices make use of small diameter holes. These are slimhole drilling and coiled tubing drilling. DOE (1999), defines slimhole wells as wells in which not less than 90 % of the hole has been drilled with a six inches (6′) bit or less. Slimhole drilling has not been used in previous times because it hampers stimulation, production and other downhole tooling operations, however, advancements in drilling technology has overcome these limitations. In addition to generating smaller volume of drill cuttings, this slimhole rigs have a smaller footprint on the drilling pad (Aird, 2008). Slimhole drilling also poses fewer problems when drilling through very hard geological formations. Unlike the conventional drilling where the drill string is assembled by fastening together the drillpipe joints, coiled tubing drilling uses a long and continuous pipe of smaller diameter rolled onto a spool without connections.The coiled tubing has a smaller diameter than the traditional drill pipe, thence, it generates a smaller volume of cuttings. Other advantages include smaller surface footprint, lower noise level and lower air emissions. Its applications comprise: underbalanced drilling, re-entry, rigless platform operations (Igbokoyi, 2011). Figure 4.3 is a picture of a coiled tubing assembly (Aird, 2008).

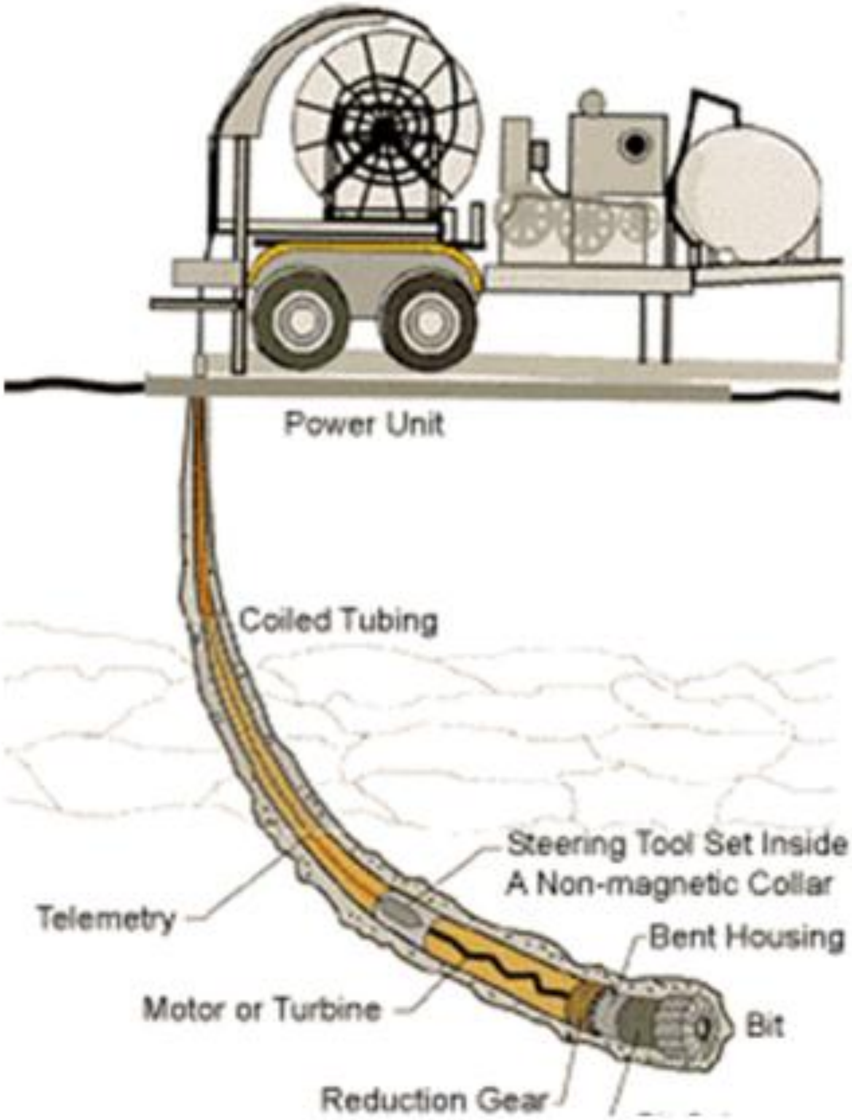


Figure 4.3: Coiled Tubing Assembly (Aird, 2008)

4.3.3 Techniques that Uses Less Drilling Fluid

From all indications, oil based mud performs better than water-based muds. This is in line with its ability to perform well in difficult drilling situations like deep wells, highly deviated wells and reactive shales. However, the environmental concerns associated with oil-based muds are very enormous and hence the environmental regulations governing its use are usually very rigid. In order to maintain the desirable properties of oil-based mud with a lower environmental impact, the synthetic-based mud was developed. Synthetic-based muds share the desirable drilling properties of oil-based muds but are free of polynuclear aromatic hydrocarbons, have lower toxicity, faster biodegradability and lower bioaccumulation potential. It drills a cleaner hole than water-based muds with less sloughing, and generates a lower volume of drill cuttings (Veil, 2002). Where practicable, synthetic based muds must be used instead of oil based muds due to their environmentally friendly nature.

The use of pneumatic drilling is another way of reducing the environmental effects of drilling fluids. Pneumatic drilling is the use of air or other forms of gases to circulate cuttings out from the well. There are four basic types of pneumatic drilling: air dust drilling, air mist drilling, foam drilling and aerated mud drilling. Pneumatic drilling does not require the large surface reserve pits common to traditional drilling thereby making it possible to be used in environmentally sensitive areas (Aird, 2008). Elsewhere palm oil has been used to design a more environmentally benign drilling fluid. Air drilling may be favoured over drilling using water-base or oil-base fluids when the underlying formation are hard and dry or in shallow locations where the use of fluids to maintain subsurface pressure is not required. In these circumstances, air drilling is considerably faster and less expensive than drilling using water-base or oil-base fluids (EPA, 1987).

4.3.4 Use of a Cleaner Energy Source

The most frequently used source of energy for running drilling activities on the rig is the internal combustion engines. These engines are usually powered either by natural gas or diesel fuel. Their operation introduces oxides of nitrogen and partially burned hydrocarbons which are harmful to both human health and the environment. The use of other alternative clean energy sources such as solar, hydro and wind to power the drilling rig will eliminate or reduce some of these harmful effects to the environment.

4.4 Waste Volume Estimation

The volume of waste generated when drilling a well is an important and costly element of any comprehensive waste management plan. It serves as an appropriate planning tool as most of the components of waste management plan depend on it. The amount of waste can be calculated in advance so that waste disposal can be planned (Osisanya, 2011). For instance, suitable waste minimization plans could only be drawn if the volume of waste to be generated is approximately known. Again, requirements for containers and support vessels will depend upon the volume of cuttings. For offshore operations, once the wastes are brought ashore, treatment and disposal costs will be dependent upon this volume as well (RCC, 1993). However, not enough research have been conducted on waste volume estimation. Proper waste management must account for the quantity of waste generated. The total volume of cutting waste generated per well can be estimated as the sum of the nominal volume of hole drilled, the amount of hole washout, and the volume of drilling fluid retained on the cuttings (OGP, 2003). Figure 4.4, summarizes some applications of waste volume estimation.

Figure 4.4: Applications of Waste Volume Estimation

4.4.1 Governing Equations for Waste Volume Estimation

Several researchers have developed different equations for estimating waste volume. Khan et al (2003) developed equations 4.1 to 4.9 for waste volume estimation. The dry drill cuttings volume is estimated based on equation 4.1. In this estimation, the dry drill cuttings are equivalent to gauge hole volume plus washout (Khan et al, 2003):

$$Drill\ Hole\ Volume\ [ft^3] = \left[\frac{\pi d^2}{4} L\right] \times (1 + Washout\ factor\ of\ 0.075) \qquad [4.1]$$

Where:

D = Hole Diameter, ft

L = Hole Length ft

$$Drill\ Cuttings\ [bbls] = Hole\ Volume\ \times 0.1781\ bbls/ft^3 \qquad [4.2]$$

$$Drill\ Cuttings\ [lbs] = Drill\ Cuttings\ [bbls] \times 910\ lbs/bbls \qquad [4.3]$$

Waste Components are estimated following Equations 1.4 and 1.5. The units are in lbs.

$$Total\ Waste\ [TW] = Base\ Fluid + Water + Barite + Drill\ Cuttings \qquad [4.4]$$

$$TW = (RF \times TW) + \left(\left[RF \times \left(\frac{WF}{SF}\right)\right] \times TW\right) + \left(\left[RF \times \left(\frac{BF}{SF}\right)\right] \times TW\right) + (DF \times TW) \qquad [4.5]$$

Where:

TW = Total Waste [Whole Drilling Fluid + Dry Cuttings], lbs

RF = Retort Weight Fraction of Synthetic Base Fluid

WF = Water Weight Fraction from Drilling Fluid Formulation

SF = Synthetic Base Fluid Weight Fraction from Drilling Fluid Formulation

BF = Barite Weight Fraction from Drilling Fluid Formulation

DF = Drill Cutting Weight Fraction

DF is calculated as follows:

$$DF = 1 - \left(RF \times \left[1 + \left(\frac{WF}{SF}\right) + \left(\frac{BF}{SF}\right)\right]\right) \qquad [4.6]$$

Total Waste Volume is then calculated as:

$$TW = \frac{Drilling\ Cuttings, lbs}{DF} \quad [4.7]$$

The whole drilling fluid volume is estimated following Equation 4.8

$$Whole\ SBF\ Volume\ [bbls] = Synthetic\ Base\ Fluid\ [bbls] + Water\ [bbls] + Barite[bbls] \quad [4.8]$$

The formation oil in whole mud discharged is 0.2 % [volume] calculated based on Equation 4.9

$$Formation\ Oil\ [bbls] = 0.002 \times Whole\ SBF\ Volume\ [bbls] \quad [4.9]$$

Richards (2002), developed equation 5.0 for estimating the solids generated per foot drilled. In his estimation, the total solids generated per foot drilled depends on the hole size/bit size, wash out factor, solids removal efficiency, and percent solid in waste.

$$V_w = \left[\frac{[(D^2 \times 0.000971) \times WO] \times SRE}{\%S}\right] \quad [5.0]$$

Where:

V_w = Amount of Drilling Waste (bbls/ft)
L = Length of Hole (ft)
D = Bit Size (inches)
WO = Wash Out Factor of (%)
SRE = Solids Removal Efficiency (%)
% S = Percent Solid in Waste

Equations 5.1 – 5.3 is another set of equations for calculating the amount of cuttings drilled per foot. These sets of equations were developed by Lapeyrouse (2002). In these equations, the volume of cuttings generated is a function of the hole diameter, hole length, porosity and specific gravity of the cuttings.

$$Barrels = \frac{D^2}{1029.4}(1 - P) \quad [5.1]$$

$$Cubic\ Feet = \frac{D^2}{144} \times 0.7854(1 - P) \quad [5.2]$$

$$W_{cg} = 350 \times V_h \times L(1 - P)SG \quad [5.3]$$

Where:

W_{cg} = Solids generated (pounds)

V_h = Capacity of Hole (bbl/ft)

L = Footage Drilled (ft)

SG = Specific Gravity of Cuttings

P = Porosity (%)

Osisanya (2011) presented a simple set of equations for estimating waste volumes based on experience. This technique is a rule of thumb which is frequently used in the industry for estimating waste volume. It is based on equation 4.1 presented above. This approach takes into accounts hole size/bit size, hole capacity and hole length. The rule of thumb approach is summarized in table 4.1 below. All the various equations for estimating waste volume produced similar results. Example 1, explains how to use the rule of thumb approach to estimate waste volume.

Example 1: (Osisanya, 2011):

After drilling 3000′ of $12^1/_4{}''$ hole followed by 7000′ of $9^5/_8{}''$, how much waste in total is likely to require disposal? How much of this will be solid waste?

Solution 1: (Osisanya, 2011):

(i) $Total\ Waste = (3000 \times 1) + (7000 \times 0.6) = 7200ft^3 = 1282\ bbl$

(ii) $Solid\ Waste = \frac{3000 \times 12.25^2}{1029.5} + \frac{7000 \times 12.25^2}{1029.4} = 1067bbl$

Table 4.1: Drilling Waste Amounts: Rule of Thumb (Osisanya, 2011)

Hole Size	ft^3/ft
$14^1/_2''$	1.3
$12^1/_4''$	1.0
$9^5/_8''$	0.6
$8^3/_4''$	0.4
$6^1/_4''$	0.2

4.4.2 Waste Estimation by the Pit Size Method

The primary purpose of the waste pit is to collect and hold the drilled cuttings and associated waste from the drilling operation. Knowing the amount of cuttings contained in the pit will give an approximate estimate of the waste generated during drilling. This approach assumes that the pit only contains drilling waste. From the shape and dimensions of the pit, the volume of the empty pit can be calculated. At the final condition (after drilling) the volume of empty pit is determined. The difference is the estimated volume of waste (Flemming et al, 2010). At a glance, this method seems easy; however, the complexity comes in when the pit has no regular shape. The assumption that the pit contains only drilling waste makes this estimation method less accurate. However, it can be used as check for other drilling waste estimation methods.

4.4.3 Deductions from Waste Volume Equations

According to Richards (2002), the solids removal efficiency is the percentage of the solids that is removed from the waste generated from the hole. This parameter is very difficult to calculate and is usually purely based on assumptions. The SRE is usually 60 – 80 % for WBM but may be 95 % for NAF (CAPP, 2001). From experience (CAPP, 2001), the use of WBM results in larger holes, consequently, a washout factor of 15 % – 20 % is usually added to estimate the total volume of cuttings generated when drilling with WBM. Also, the fraction of drill solids may range from 8 – 10 % by volume for NAF and 3 -5 % for WBM.

4.5 Factors Influencing the Volume of Drilling Waste

Virtually, every aspect of drilling operations affects the quantity of waste generated. Table 4.2 presents a list of factors which can influence waste volumes. These factors are strongly interrelated that the effect of a single factor can be difficult, if not impossible, to evaluate (EPA, 1987). Knowing and identifying these parameters will help the planner to factor them into the waste management plan. It also helps in the waste minimization process.

Table 4.2: Factors Influencing the Volume of Drilling Waste (Modified after, EPA, 1987)

Factor	Example
Geology	• Hard rock formation • Shale • Sandstone
Well Depth/Hole Size	• Footage drilled • Different bit sizes
Drilling fluid	• Water based mud • Oil based mud • Synthetic based mud • Air/Foam Drilling
Extent of solids control equipment used	• Solids removal efficiency • Cuttings washing efficiency • Amount of water added to the circulating mud system
Problems encountered during the operation	• Stuck pipe • Lost circulation • High pressures and temperature • Side tracking
Service products used	• Type of product used • Number of products used • Solids versus liquids

4.5.1 Hole Size and Hole Length

The volume or quantity of drilling waste generated is directly proportional to the product of the hole diameter and hole length. Hole size or diameter in this case is equal to the size of the bit used in drilling the particular hole section. The bigger the bit size the larger the volume of waste generated. It is based on this argument that the use of slim holes and coiled tubing results in the generation of less waste. Longer hole lengths will likewise result in higher waste volume estimates.

4.5.2 Geology (Porosity)

The type of formation (geology) being drilled through dictates the type of drilling media to be used. The use of water-based mud generates larger volumes of waste whereas that of oil based muds introduces several other wastes into the environment. If water formations are encountered for instance, the volume of waste increases. The presence of formation water causes changes in the drilling media which must be compensated (EPA, 1987).

4.5.3 Fluid Type (Washout Factor)

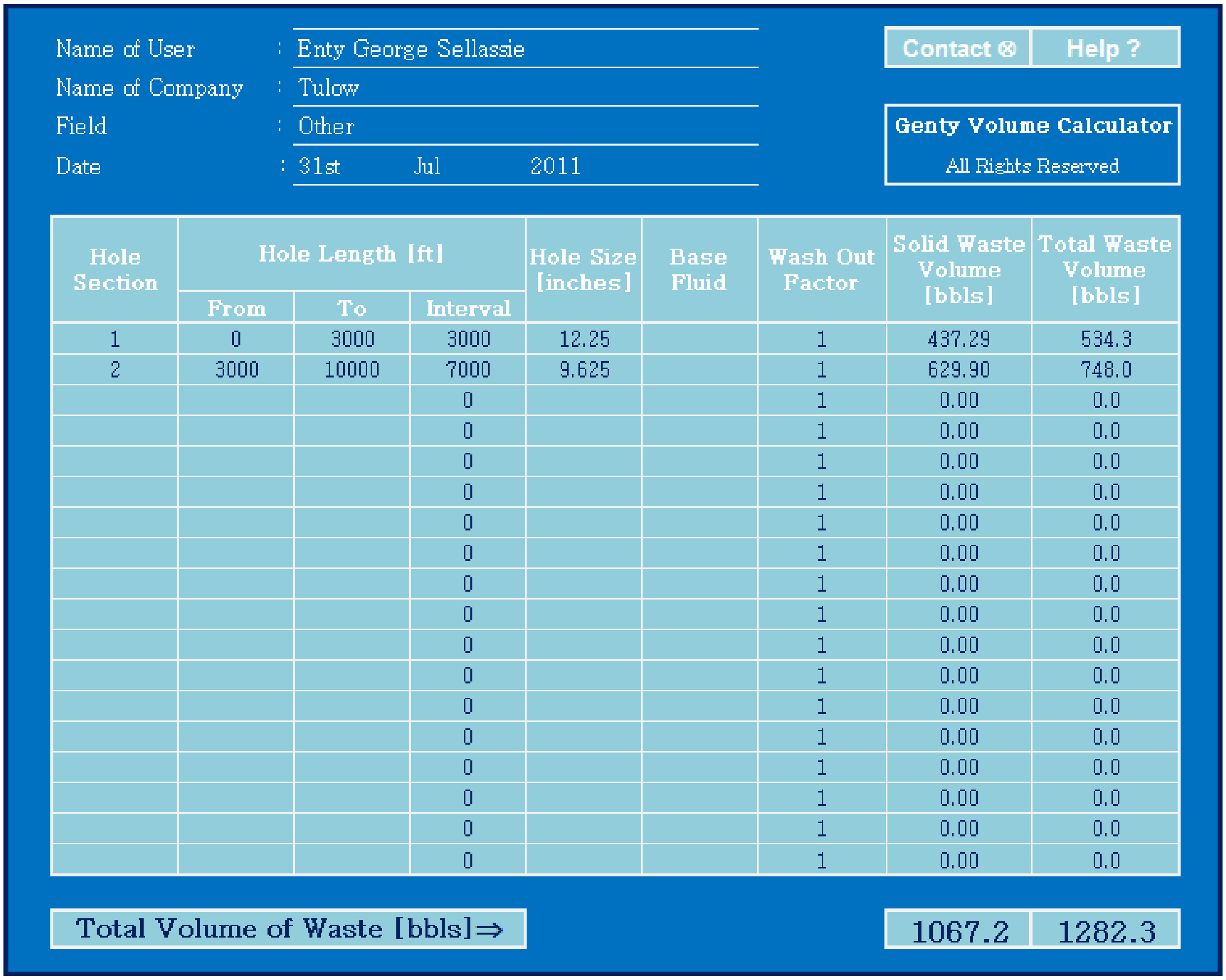
The volume cuttings drilled represents the minimum volume of waste in drilling a well. However, the volume of waste generated is usually greater than this because of hole enlargement or wash-out. This factor is added to the volume of cuttings drilled to estimate the total volume of waste. Hole enlargement is basically caused by hydration and dispersion of shales and clays. Other causes include fluid erosion and mechanical abrasion. Oil-based muds and synthetic-based muds inhibit hydration and dispersion. However, hydration and dispersion of shales for water-based muds is really a challenge. The inhibition and dispersion of shales and clays in water based muds are accomplished through the addition of chemicals. In as much as the addition of chemicals inhibits shale and clay hydration, it also lowers the LC_{50} of the mud and this sometimes leads to a trade-off between reduced toxicity and reduced waste volume. The use of water-based muds therefore results in larger holes, consequently, a wash-out factor of 15 – 20 % is usually added to estimate the total volume of cuttings generated when drilling with water-based muds (CAPP, 2001).

4.5.4 Solids Removal Equipment (SRE and % S)

Once the drilling fluid and cuttings are brought to the surface, the type and extent of solids control equipment used influences how well the cuttings can be separated from the drilling fluid and hence influences the volume of waste discarded in the reserve pit. This implies that as the effectiveness of the solids control equipment declines, the volume of drilling waste inceases (EPA, 1987), as it cannot efficiently separate the cuttings from the fluid for recirculation. The cuttings volume required for disposal therefore will increase.

4.6 Generation of Spreadsheet for Waste Volume Estimation

The quantity of waste generated is an important parameter in drilling waste management process. Knowing the amount of waste in advance can help in the planning process. The cost and type of disposal methods depend on the quantity of waste generated. There is no doubt that accurate waste volume estimation is an important factor in the waste management process. Considering the relevance of waste volume estimation, there is the need for the development of spreadsheet to help estimate waste volume. The spreadsheet is developed with Microsoft Excel 2010. It is validated using data presented by Osisanya (2010). The equations presented in section 4.4.1 were used to compute the waste volume which yielded similar results. A help file has been attached to ensure user friendliness. The use of Excel in building this model will make it easier for every worker that has basic computer knowledge to use. The user interface is shown in figure 4.5.



Name of User : Enty George Sellassie
Name of Company : Tulow
Field : Other
Date : 31st Jul 2011

Contact ⊗ Help ?

Genty Volume Calculator
All Rights Reserved

Hole Section	Hole Length [ft]			Hole Size [inches]	Base Fluid	Wash Out Factor	Solid Waste Volume [bbls]	Total Waste Volume [bbls]
	From	To	Interval					
1	0	3000	3000	12.25		1	437.29	534.3
2	3000	10000	7000	9.625		1	629.90	748.0
			0			1	0.00	0.0
			0			1	0.00	0.0
			0			1	0.00	0.0
			0			1	0.00	0.0
			0			1	0.00	0.0
			0			1	0.00	0.0
			0			1	0.00	0.0
			0			1	0.00	0.0
			0			1	0.00	0.0
			0			1	0.00	0.0
			0			1	0.00	0.0
			0			1	0.00	0.0
			0			1	0.00	0.0
			0			1	0.00	0.0
			0			1	0.00	0.0
			0			1	0.00	0.0

Total Volume of Waste [bbls]⇒ 1067.2 1282.3

Figure 4.5: User Interface of the Waste Volume Estimator

4.6.1 Assumptions Made

The following assumptions were made in the building of the model:

1. The model was built using the rule of thumb approach.
2. Wash-out factor of 7.5 % was assumed for Synthetic Based Mud (SBM) and Oil Based Mud (OBM) whereas 20 % was assumed for Water Based Mud (WBM).
3. The model can only be used to estimate waste volumes for vertical wells only.

4.6.2 Current Practices of Waste Estimation

Current practices for waste estimation involve the Rule of Thumb approach and the Khan et al (2003) approach. These methods are quite tedious as the user has to repeat the same calculations involving different conversion factors for each hole section. Waste estimation becomes very hectic when the hole sections are drilled with different drilling fluids as the different wash-out factors has to be taken into accounts for the different hole sections. Besides, the estimator is prone to making mistakes due to the simultaneous use of calculator and recording by writing. These reasons are motivations behind the building of this model for waste estimation. The aim of this is speed and reduction in human error. Other reasons include low cost, simplicity and user friendliness.

4.6.3 Validation of the Model

The Khan et al (2003), Lapeyrouse (2002) and the Rule of thumb were used to validate the model and the results are presented in table. The differences in the results are as a result of the different wash-out factors that were used in the different equations. Table 4.3 summarizes the results of the model validation performed.

Table 4.3: Model Validation Results

Method	Results
Excel Model	1147.2
Khan et al (2003)	1147.3
Lapeyrouse (2002)	960.5
Rule of Thumb	1067

4.7 Waste Management Plan

Waste management plan is a written document that outlines all the waste streams and treatment options applicable. An effective waste management plan directly relates the choice of waste handling and disposal options to the ecological sensitivities, regulatory requirements and available facilities of the geographical area involved. The plan should be written from the field perspective and provide specific guidance for handling each waste stream. The main purpose of the waste management plan is in two folds: to provide processes to identify the appropriate waste management strategy by considering all regulatory, environmental, operational and economic criteria, and to ensure effective implementation of the appropriate waste management strategy by the development and use of understandable, effective guidelines for field operations personnel. Modern waste management plan also provides an extensive economic analysis of the different drilling waste management techniques. Waste management plans are necessary to ensure compliance with existing regulation and possible future regulations. It must therefore be able to access how company operations impact the environment and provide practical steps for adjusting to minimize or eliminate the impacts.

A good plan is one that is simple and can be understood by all personnel in the industry. Once developed, waste management plan will serve as a document for all the people to use in making decisions regarding wastes. Thus, it will be a reference guide for determining safe, reliable, long- term disposal options for waste materials. An important property of a good waste management plan is its ability to allow for regular update. The plan must be updated regularly to incorporate, new projects that may generate new wastes, changes in the regulations, and development of new technologies for treatment and disposal of wastes (Osisanya, 2011).The following ten steps in table 4.3 have been developed as a guide for ensuring effective waste management plan.

Table 4.4: Step-By-Step Waste Management Plan

Step	Activity
Step 1	**Seek for management approval and support for the following** • Key personnel required • Resources and scheduling issues • Timing and scope of the plan
Step 2	**Identify area of coverage on the basis of the following** • Regulations • Geology • Environment • Operations
Step 3	**Identify all waste in an operation area** • Solid (Drill Cuttings and Heavy Metals) • Liquid (Drilling Mud and Additives) • Gaseous (Fumes from Diesel engines, NORM)
Step 4	**Classify each waste according to the following category** • Exempt • Nonexempt nonhazardous • Nonexempt hazardous • Nonexempt special
Step 5	**Estimate the volume of each waste stream** • Drill cuttings • Drilling Mud
Step 6	**Identify Opportunities for waste minimization based on** • Volume of waste • Toxicity of waste
Step 7	**Identify all management options for each waste from these sources** • Current practice for waste in the area • Practice used in other areas • Practice used for other wastes • Practice used by other companies or industries
Step 8	**Select management practices that satisfy all regulations** • Regulatory policy • Company Policy
Step 9	**Prioritize selected options on the basis of the following** • Company Policy • Practicality • Cost
Step 10	**Plan review and update** The plan must be updated regularly to incorporate: • New projects with new wastes • Change in regulations • Development of new technologies

4.8 Economics of Drilling Waste Management

Drilling waste management is no longer only about ensuring environmental compliance for the operator, but can also be proactively applied to reduce well construction costs (Browning et al, 2005). As stated earlier, the choice of which management to adopt is usually a very complex task and must be subjected to serious economic analysis. Efficient economic analysis of drilling waste management must therefore be an integral part of every waste management plan. The cost of drill cuttings disposal depends on a number of factors including costs for drilling fluids, solids control equipment, transportation and handling of cuttings, cuttings injection equipment and onshore treatment and disposal. Other factors include the amount of waste per well, cost of increased drilling time due to inability to offload cuttings due to bad weather (OGP, 2003). Table 4.4 summarizes some of the key parameters to consider when conducting drilling waste management economic analysis.

Veil (1998), conducted a research for U.S EPA and U.S DOE to evaluate the cost of the different types of offshore waste management methods. The information was gathered basically through telephone conversations with offshore oil and gas operators. According to the study, the cost of offshore disposal ranges from $7.50/bbl to $150/bbl. Onshore disposal costs ranges from $10/bbl to $40/bbl. This estimate is rather conservative. A more extensive economic evaluation including the cost of transportation, boat and cuttings box rental fees, cuttings box cleanup charges, and cleanup water disposal costs raise these estimate to as much as $107/bbl and $350/bbl. Costs for injection range from $20/bbl to $450/bbl. One company charges $7.50/bbl for disposing of WBM cuttings and from $8.50/bbl to $11/bbl for disposal of OBMs and OBM cuttings. If wastes are delivered to the transfer stations, there is additional offloading fee of $3/bbl - $3.50/bbl.

Table 4.5: Drilling Waste Management Cost Drivers (Browning et al, 2005)

No	Factors
1	Waste management personnel at rigsite
2	Waste management equipment at rigsite
3	Specialty drilling fluids or additives to meet regulations
4	Waste containers (boxes, skips, bags)
5	Waste transport (trucks, boats)
6	Waste treatment (fixation, thermal units, dewatering)
7	Waste disposal (landfills, licenses, injection wells)
8	Accidental spills or discharge clean-up and remediation
9	Fines / lost time for non-compliance with regulations
10	Future liabilities and remediation costs
11	Potential damage to corporate image

4.9 Drilling Waste Management Screening Criteria

The different waste management methods are dependent on the local environmental regulations in place, cost of disposal, technical feasibility as well as quantity of waste generated. They are also location (offshore and onshore) specific. This means, the waste management process must be rigorously evaluated before it can be applied. The evaluation process should include extensive economics and environmental analysis. It is important to also consider the current practice for waste in the area, practice used in other areas, practice used for other wastes or practice used by other companies or industries in the area. Since there is no rule-of-thumb for selecting the most appropriate management method for a particular area, there is the need to develop a screening and selection criteria for such a purpose. The drilling waste management screening criteria should be used as the first-pass selection of potential processes that can be viable for the waste being evaluated for management. This helps to eliminate some of the options that are not relevant to the particular location. The screening criteria should however not replace further intensive evaluation procedures required for waste management processes. Table 4.5 shows screening process for waste management.

Table 4.6: Screening Criteria for Drilling Waste Management Methods

Disposal Method / Parameters	Offshore Discharge	Underground Injection	Onshore Transportation	Bioremediation	Burial	Thermal Treatment
Location	Offshore	Offshore Onshore	Offshore Onshore	Onshore	Onshore	Offshore Onshore
Technical Cost	Low	High	High	Medium	Low	Medium
Extra Cost	Low	Low	High	Medium	Low	Medium
Environmental Rigidity	High	Medium	Medium	Medium	Medium	Low
Air Emission	Low	Low	High	High	Low	Medium
Personnel Requirement	Low	High	High	Medium	Medium	Medium
Long Term Liability	Medium	Medium	High	Low	High	Low

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

The objectives of this study are (1) to identify various types of drilling waste that impacts the environment. (2) to develop equations for waste volume computation and to generate a Microsoft Excel User-friendly Program for Waste Volume Estimation. (3) to establish the best possible ways of minimizing drilling wastes. (4) to develop a comprehensive waste management plan and establish the best possible way of incorporating waste volume estimation into it.

From chapter 2 of this study, the main type of drilling wastes are drill cuttings, contaminated drilling mud and gas emissions. These wastes form the second largest sources of waste in the E&P industry after produced water which is considered as production waste. In order to effectively manage drilling waste, it is very important to know the quantity of waste that is expected. Different equations for waste volume computations were reviewed in chapter 4 and a spreadsheet program for waste estimation developed. It was presented that the hole length, bit size, geology and SRE are the main drivers that affects the volume of waste generated. These understanding help to plan ahead for the expected volume of waste.

Knowing the anticipated quantity of waste, various measures could be employed to minimize the waste volume. Chapter 4 further details methods like efficient solids removal equipment, slim hole drilling, coil tubing drilling and horizontal well drilling as measures of minimizing the volume of waste generated. There are a number of waste management methods available. An extensive explanation of the different methods has been captured in chapter 3. From these explanations, a simple drilling waste screening and selection criteria has been outlined. This screening process will help to eliminate some of the different waste management options that are not relevant. Owing to the third objective, a ten steps waste management procedure has been outlined and is captured in chapter 4.

5.2 Conclusions

Based on the theoretical and practical observations made from this research work, the following deductions and conclusions can be made:

- Waste volume estimations plays a critical role in managing drilling and associated waste and should at all-times be estimated and incorporated into the waste management plan. A Microsoft Excel Model has been developed to this effect.
- The disposal and waste management cost is directly related to the volume of waste generated and as such, minimization as a waste management method must be a priority to other methods.
- Selection of the optimum drilling waste management method must always be subjected to extensive environmental, technical and economic analysis as these are the main drivers. A screening criteria has been developed to help quicken the decision making process.
- For effective drilling waste management, the ten waste management steps must be followed critically.

5.3 Recommendations

Owing to the limited time for this research work, the following are recommended:

- More comprehensive study should be done on the waste management screening criteria using real field data.
- The multi-criteria selection application in Geographic Information Systems (GIS) and a more engineering technique like Operations Research (OR) could be used to select the optimum waste management method.
- It is understood from this research that, waste management in general is a problem in Africa. One way to tackle this problem is to sensitize the public about the environmental effects of drilling waste on the environment. It is therefore recommended that an institution like AUST should incorporate waste management as a course into its academic curricular.

NORMENCLATURE

AADE	American Association of Drilling Engineers
Anon	Anonymous
AUST	African University of Science and Technology
bbl	barrels
BF	Barite Weight Fraction from Drilling Fluid Formulation
BTS	Brandt Transfer System
D	Bit Size (inches)
DF	Drill Cutting Weight Fraction
DOE	Department of Energy
EBSM	Ester-Based Synthetic Mud
E&P	Exploration and Production
EPA	Environmental Protection Agency
kWh	Kilowatts
L	Length of Hole/Footage Drilled (ft)
NAF	Non-Aqueous Based Fluids
NO_X	Oxides of Nitrogen
OBM	Oil-Based Mud
P	Porosity (%)
RF	Retort Weight Fraction of Synthetic Base Fluid
% S	Percent Solid in Waste
SBM	Synthetic –Based Mud
SF	Synthetic Base Fluid Weight Fraction from Drilling Fluid Formulation
SG	Specific Gravity of Cuttings
SO_X	Oxides of Sulfur
SPE	Society of Petroleum Engineers
SRE	Solids Removal Efficiency (%)
TW	Total Waste
V_h	Capacity of Hole (bbl/ft)

VOC	Volatile organic compound
V_w	Amount of Drilling Waste (bbls/ft)
WBM	Water-Based Mud
WF	Water Weight Fraction from Drilling Fluid Formulation
WO	Wash Out Factor of (%)
W_{cg}	Solids generated (pounds)

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