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Evaluating Drivers of Liability, Risk, and Cost While Enhancing Sustainability for Drilling Waste

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Abstract

Drilling waste is a significant component of an operator's well cost and liability. According to the American Petroleum Institute, an average of 1.2 barrels of drilling waste are generated per foot drilled[1]. The chemical constituents present in drilling waste drive liability and waste management practices, which in turn drive treatment and disposal costs. It is essential to understand these compounds for the risks they pose, the liability they generate, and the costs their management creates while achieving regulatory compliance and corporate sustainability goals.

The constituents present in drilling waste are driven by formation properties, the geochemical properties of the cuttings, and the types of drilling fluids used. Significant quantities of organics, metals, salts, and other inorganics are generated for each well drilled. Regardless of the type of drilling fluid used, it is critical to minimize the risk and liability these materials pose to human health and the environment. By effectively accounting for and addressing the constituents in drilling waste, an operator can reduce liability and well costs at the same time.

This paper has been developed to support operators with the considerations of the impacts of drilling waste constituents on liability and cost.

Introduction

Drilling waste consists of the rock cuttings and fluids that are produced from drilling a new wellbore into the subsurface[1]. On average, drilling waste is approximately 50% solids and 50% fluids[2]. Liquid drilling waste primarily consists of waste drilling fluid[3]. Solid drilling waste primarily consists of drill cuttings and drilling fluid residue retained on cuttings[3]. According to the American Petroleum Institute, an average of 1.2 barrels of drilling waste are generated per foot drilled[1]. Over 392,000,000 barrels of drilling waste were generated onshore in the U.S. in 2014[2].

Drilling waste is subject to non-hazardous waste regulation under the Resource Conservation and Recovery Act (RCRA) Subtitle D and state waste regulations[4]. Drilling waste is also subject to regulation under the Clean Air Act (CAA), Clean Water Act (CWA), Safe Drinking Water Act (SDWA), Oil Pollution Act of 1990 (OPA), and other Federal requirements[2]. Drilling waste is exempt from hazardous waste regulations under RCRA Subtitle C[4]. However, seven environmental groups filed a lawsuit against the USEPA in May 2016 to increase regulation of oil and gas wastes, including drilling waste[5]. A settlement agreement was finalized in a consent decree in December 2016 which requires the EPA to review oil and gas waste regulations and determine whether a revision is necessary by March 2019. The EPA must update the regulations by July 2021 if a revision is determined to be necessary[6].

Drilling waste is classified according to the type of base drilling fluid or mud. Wastes generated from wells drilled with water-based fluids include freshwater mud and cuttings (FWMC), saltwater or brine mud and cuttings (SWMC), and high-performance water-based mud and cuttings (HPWBMC). Wastes generated from wells drilled with non-aqueous based muds include oil-based mud and cuttings (OBMC) and synthetic oil-based mud and cuttings (SBMC). Pneumatic, or air-drilled, cuttings are produced from pneumatically-drilled well sections.

Constituents and Parameters

Drilling waste is comprised of several classes of chemical constituents which include salts, metals, and organics (including hydrocarbons). Other drilling waste parameters that are evaluated include pH, Sodium Absorption Ratio (SAR), and radioactivity (NORM/TENORM).

Salts

Salts, almost always chlorides, in drilling waste usually include sodium chloride, calcium chloride, and/or potassium chloride. Chlorides are found in all mud types. Chlorides in FWMC are typically at low concentrations (<3,000 mg/kg). Chlorides in SWMC and HPWBMC may range from moderate to extremely high concentrations (10,000 to >300,000 mg/kg). Chlorides in OBMC vary from low concentrations to extremely high concentrations (<2,000 to >200,000 mg/kg). All of the chlorides mentioned here are water soluble and very mobile through the environment. There is no known natural process by which chlorides are broken down, metabolized[7], taken up, or removed from the environment. Excessive chloride concentrations can be toxic to vegetation and aquatic life. High salt levels increase osmotic potential in soil, which lowers available water in plants[8]. High chloride levels also cause loss of soil structure[8].

The USEPA has set a secondary standard limit for chloride in drinking water of 250 mg/L[9]. The weight of chlorides generated per horizontal well can range from 4,000 to 170,000 pounds (2.5 to 85 tons) (See **Figure 1**).

In conjunction with chloride concentration, the sodium absorption ratio (SAR) is a measure of sodium, magnesium, and calcium cations[8]. Sodic soils exhibit poor physical and chemical properties, which impede water infiltration, water availability, and ultimately plant growth[8]. Saline-sodic conditions break down soil structure and inhibit plant growth[8].

Metals

Metals are present in both cuttings and drilling fluids. Solvation, complexing, chemisorption, and cation exchange processes control the mobility and bioavailability of metals[8]. Primary risks in the environment are water soluble and exchangeable forms[8]. The RCRA 8 metals (arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver) are toxic at elevated concentrations. Toxic effects to humans vary by metal and can include problems with the circulatory, nervous, respiratory, or digestive systems as well as the liver, kidneys, skin, and hair[10-12]. Other toxic effects can include developmental disorders, mental problems, and increased risks of cancer and diabetes[10-12]. Characteristics of the RCRA metals in solid drilling waste are listed in **Table 1**.

Arsenic naturally occurs in soils, rocks, and groundwater[8, 11]. Arsenic can be reduced to a form toxic to plant growth under anaerobic conditions[8]. Barium naturally occurs in soils at concentrations of 100-3,000 ppm[8]. Barium is present in drilling waste in drill cuttings and also in the form of the weighting agent barite. Although barite is highly insoluble, barite solubility can be altered somewhat under certain conditions[13-16]. Cadmium, lead, and mercury are also present in barite[17]. Lead is present in native soils and rocks and also in drilling muds. Lead may be present in soluble forms in high-chloride muds[8].

Organics

A wide variety of organic compounds, including petroleum hydrocarbons, can be found in drilling waste. Crude, drilling fluids, and mud additives are sources of organic constituents. Petroleum hydrocarbons such as diesel and mineral oil may be found in OBM and SBM[8]. Mineral and vegetable oils are used as additives in WBMs, including HPWBM[18-19]. Organic additives can be present in oil-based, water-based, and pneumatic drilling waste. Additives are further discussed subsequently in this paper.

Petroleum hydrocarbons are a very large class of thousands of chemical compounds made up of hydrogen and carbon atoms. Because the class is so large, they are commonly measured and reported as Total Petroleum Hydrocarbons (TPH). The definition of TPH and the methods used to quantify concentrations vary between jurisdictions. The Interstate Technology and Regulatory Council (ITRC), a public-private coalition of federal and state regulators, industry experts, consultants, academia, and community stakeholders, is currently developing a guidance document on evaluating TPH risks in order for TPH to be measured and assessed more consistently and systematically[20].

Human health risks vary greatly by hydrocarbon compound and can affect the circulatory, immune, and nervous systems as well as the lungs, skin, eyes, liver, and kidneys[21]. Environmental effects also vary greatly depending on the compound[21].

Diesel is commonly used as a base fluid in OBM. Diesel is a hydrocarbon mixture that contains volatile and aromatic constituents[22]. In terms of toxicity, diesel is often characterized by the concentrations of BTEX (benzene, toluene, ethylbenzene, and xylene) in the mixture[22]. EPA drinking water standards for BTEX are 0.005, 1.0, 0.7, and 10 mg/L, respectively[10]. For horizontal wells in which OBM is used, approximately 5,000 to 24,000 gal/well of diesel is generated in drilling waste.

Additives

Drilling muds contain numerous additives, both organic and inorganic, for various mud functions. Analysis of the risks and impacts of the vast number of possible mud additives is beyond the scope of this paper. In addition, many drilling mud additives are proprietary, which can generate uncertainty about potential risks and toxicities[3]. Accounting for the uncertainties of mud constituents and their potential risks is critical in order to develop effective drilling waste management strategies.

pH

Drilling waste pH is typically between 7 and 13, though sometimes the waste can be slightly acidic. Drilling Fluids are typically alkaline to disperse clay and increase effectiveness of drill fluid[8]. Impacts from pH can lead to caustic or acidic conditions, which can affect nutrient availability to vegetation[8] and the hydraulic conductivity of clays[23]. Additionally, pH affects the mobility of other constituents[8].

NORM/TENORM

Most NORM (Naturally Occurring Radioactive Material) is from decay of Uranium 238 and Thorium 232 in the earth's crust, resulting in 40 daughter products[8]. The most common isotope in NORM is Radium 226[8]. NORM typically emits alpha particles[8]. Typically regulated isotopes are Radium 226 and Radium 228[8].

Because the extraction process concentrates the naturally occurring radionuclides and exposes them to the surface environment and human contact, these wastes are classified as Technologically Enhanced Naturally Occurring Radioactive Material (USEPA NORM/TENORM page). NORM/TENORM levels depend on the concentration and type of radionuclides, chemistry of the formation, and characteristics of the exploration and production process.

Risk Considerations

Drilling waste constituents can create adverse environmental impacts if not managed properly. Proper waste management is critical for successful drilling operations, environmental protection, and risk minimization[3]. Considerations of impacts to human health and the environment are critical to minimize risk and liability. **Table 2** highlights potential health and environmental impacts of drilling waste constituents.

In addition to evaluating the health and environmental impacts of the drilling waste constituents themselves, potential risks and liability from drilling waste management practices also need to be evaluated. By nature, drilling waste is highly variable with inherent uncertainties. The characteristics of drilling waste can vary drastically from well to well, and even throughout the same well[2]. Transporting drilling waste carries risks of accidents and spills, especially over long haul distances. Waste from different operators may be commingled. Certain drilling waste management practices such as land spreading require a large land area to be impacted. With many waste management practices, the end-state of the waste is unknown or uncertain.

The most fundamental element of any drilling waste management strategy is to know what is in the waste[17]. Proper waste characterization is critical to develop effective and sustainable waste management strategies[2]. Representative sampling and testing of the chemical and physical waste characteristics is necessary to effectively account for and manage the highly variable nature of drilling waste, and to properly evaluate waste management options.

Waste Management Hierarchy

The USEPA has developed a waste hierarchy which lists four categories of waste management in order from most preferred (or sustainable) to least preferred (**Figure 2**). Waste management strategies can be evaluated based on the characteristics of the drilling waste.

Source reduction and reuse is simply preventing or reducing waste at the source[24]. There are several aspects of source reduction for drilling waste which can be incorporated by simply increasing the efficiency of certain operations at the rig. For example, increasing the efficiency and effectiveness of solids control can reduce the amount of drilling fluid that is lost, thus reducing waste volumes and drilling fluid costs. Reuse of captured drilling fluids, which is widely established, also reduces waste and fluid costs. Diligent monitoring of the mud system helps reduce unnecessary additions of additives[17]. Another form of source reduction is simply faster and more efficient drilling. Fewer drilling days leads to less energy consumption and air emissions[3].

Recycling involves processing drilling waste into a new product[24]. Drill cuttings are currently being recycled as construction material for road base, lease roads, drill pads, and production pads[25-26]. Drill cuttings recycling processes vary greatly, from placing cuttings as a road aggregate to using solidification / stabilization to immobilize constituents and construct engineered roads and drill pads[25, 27]. Recycling can also be coupled with source reduction in scenarios such as reducing the need for virgin construction materials due to recycling of drilling waste or coupling recycling processes with increased solids control efficiency.

"Energy recovery from waste is the conversion of non-recyclable waste materials into useable heat, electricity, or fuel through a variety of processes."[24]. Energy recovery has involved thermal desorption or incineration in the oil and gas industry[3, 26].

Treatment and disposal is often utilized for drilling waste and includes the practices of onsite burial, land application (landfarming and landspreading), bioremediation, and disposal at facilities such as landfills or disposal pits. Liquid and slurry wastes are often disposed by injection wells[17, 26].

Risk, Liability, and Waste Management Strategies

Knowing the characteristics of drilling waste is essential in order to incorporate appropriate drilling waste management strategies that will not create adverse environmental impacts. Good, sound, sustainable waste management strategies that effectively address the characteristics of drilling waste can significantly reduce an operator's risk of environmental impacts. However, waste management strategies that are not properly matched to drilling waste chemical and physical characteristics can significantly increase an operator's risk of environmental impacts and exposure to liability. It is also important to note that in many cases, an operator may be in compliance with regulations, yet create a significant environmental footprint and be exposed to significant liability. Operators have statutory liability for their drilling waste related to environmental impacts from CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act), RCRA, CWA, OPA, and State Laws[28-30]. Additionally, operators have tort liability for migration of contaminants or other harmful conditions from nuisance and trespass[28, 30]. It is thus crucial for operators to minimize their liability exposure through sustainable waste management strategies that take into account drilling waste characteristics.

Onsite Burial

Use of onsite burial for drilling waste with high concentrations of hydrocarbons and/or chlorides can result in leaching and damage to soils, groundwater, and surface water[3, 17, 26]. Hydrocarbons, chlorides, shale inhibitors, high pH, and freeze/thaw cycles can degrade clay pit liners, increase the hydraulic conductivity of clay liners, and cause contaminants to leach out of the pit[23, 31-32]. Additionally, burial should not be relied on for bioremediation as burial usually results in anaerobic conditions[26].

Land Application (Landspreading / Landfarming)

Land application of drilling wastes with high concentrations of salts, hydrocarbons, metals, and/or high molecular weight organic compounds can result in damage to land and water from multiple mechanisms[26,33] (**Figure 3**). High salt concentrations can inhibit biodegradation of hydrocarbons and other organics[26]. Biologically available metals can accumulate in the soil and render the land unfit for use[26, 33]. High molecular weight organic compounds in drilling waste biodegrade slowly and can accumulate and degrade soil and vegetation from repeated applications[26]. Land spreading drilling waste can lead to constituents being carried by storm water runoff into nearby streams or leaching into groundwater[26]. Additionally, land application can also lead to dusting, with dust particles containing hydrocarbon or metallic constituents emitted into the air[26, 34-36].

Disposal Facilities

Since liability for drilling waste always remains with the generator, an operator can get stuck with the bill for cleanup costs of improperly managed disposal facilities[26, 28, and 30]. If disposal at a commercial facility is selected as part of a drilling waste management strategy, it is important for an operator to select reputable waste management providers with properly engineered facilities, good business practices, and strong compliance history[26].

Sham Recycling

"There are some cases in which individuals or companies may attempt to circumvent legitimate waste management regulations or laws by "sham recycling" in order to avoid costly waste management requirements (e.g., some wastes are recycled for end uses with little value solely to avoid complex and expensive hazardous waste management rules)"[26]. In drilling waste management, there are practices of sham recycling which provide little or no reuse benefit, or rely heavily on dilution disposal under the label of recycling. Some practices provide virtually no protection to human health and the environment from drilling waste constituents.

As an example, road spreading of oil-based mud and cuttings is often advertised as recycling, but provides little or no geotechnical benefit to the road structure and leads to negative environmental impacts. Contrary to conventional road construction and maintenance operations which are typically performed according to specifications[37-38], road spreading is performed with few, if any, specifications. As vehicles pass over road sections that have had oil-based mud and cuttings applied, the load from the vehicles increase the pore pressure of the cuttings, thus squeezing out diesel, which subsequently runs off into roadside ditches and waterways (**Figures 4 and 5**). Other undesirable results of this practice include dusting and off-gassing. Needless to say, this creates immense liability exposure for an operator when this is performed on county roads, especially when adjacent to residences and communities.

Other examples of sham recycling include practices that are actually landfarming or burial, but are touted as recycling. Sham recycling, though compliant with regulations in certain jurisdictions, creates significant environmental risks and liability exposure for operators.

Minimizing Risk, Liability, and Cost

Establishing effective, sustainable waste management goals is essential to minimize risk, liability, and costs. "Proper application of waste management principles is required for both efficient drilling operations and environmental protection.[3]" Waste management goals should be an integral component of corporate responsibility goals. A paramount waste management goal is protection of human health and the environment, which involves minimizing or eliminating impacts to soil, water, air, vegetation, animal life, and people. Knowing the end-state, physical and chemical specifications, and location of drilling waste is critical to manage future risks and liability. Waste management goals should also be established to prepare for future changes and trends, including changing regulatory policies, establishing and maintaining social license to operate, and increased attention to sustainable practices[3]. Changes to waste management policies and operations are more fluid and economical when proactively initiated by a company rather than being forced to change by regulations or public pressure[39].

Waste management strategies which properly address the characteristics of drilling waste constituents are economically beneficial for operators. Regulatory compliance costs can be minimized along with avoiding fines for violations. Costs related to risk and liability can also be minimized. Drilling waste management costs can be minimized and become more predictable, which in turn enhances budgeting. Sustainable and effective drilling waste management strategies are also attractive to investors[40].

Conclusions

Salts, organics, metals, proprietary additives, and other constituents are present in drilling waste. Large quantities of these constituents are generated during drilling. These constituents can have significant environmental and health impacts. Proper chemical and physical characterization of the waste based on representative sampling and testing is crucial in order to develop appropriate waste management strategies that will effectively minimize or mitigate these risks. Sound, sustainable waste management strategies that protect human health and the environment, including the soil, water, air, vegetation, and animal life, will reduce risks along with an operator's exposure to liability. Such strategies also enhance an operator's corporate responsibility goals, social license to operate, and bottom line.

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Nomenclature

CAA = *Clean Air Act*
CERCLA = *Comprehensive Environmental Response, Compensation, and Liability Act*
CWA = *Clean Water Act*
EPA = *United States Environmental Protection Agency*
ITRC = *Interstate Technology and Regulatory Council*
OPA = *Oil Pollution Act*
RCRA = *Resource Conservation and Recovery Act*
SDWA = *Safe Drinking Water Act*
TCEQ = *Texas Commission on Environmental Quality*
FWMC = *Freshwater mud and cuttings*

HPWBMC = *High-performance water-based mud and cuttings*
OBMC = *Oil-based mud and cuttings*
SBMC = *Synthetic oil-based mud and cuttings*
SWMC = *Saltwater mud and cuttings*
BTEX = *Benzene, Toluene, Ethylbenzene, and Xylene*
NORM = *Naturally Occurring Radioactive Material*
TENORM = *Technologically Enhanced Naturally Occurring Radioactive Material*
SAR = *Sodium Absorption Ratio*
TPH = *Total Petroleum Hydrocarbons*
VOC = *Volatile Organic Compound*

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Table 1: RCRA Metal Characteristics in Solid Drilling Waste

RCRA Metal	National Primary Drinking Water Standard[10] (mg/L)[a]	Concentrations Observed in Solid Drilling Waste (mg/kg)	Weight per well generated (lbs)
Arsenic	0.01	Trace to 211	Trace to 530
Barium	2.0	Trace to 400,000	5,000 to >500,000
Cadmium	0.005	Trace to 16	Trace to 35
Chromium	0.1	Trace to 160	15 to 350
Lead	0[b]	Trace to 270	Trace to 600
Mercury	0.002	Trace to 1.9	Trace to 4
Selenium	0.05	Trace to 27	Trace to 57
Silver	0.1	Trace to 7.2	Trace to 15

a: USEPA National Primary Drinking Water Standards https://www.epa.gov/ground-water-and-drinking-water/table-regulated-drinking-water-contaminants

b: Lead is regulated by a treatment technique that requires systems to control the corrosiveness of their water. If more than 10% of tap water samples exceed the action level, water systems must take additional steps. For lead, the action level is 0.015 mg/L[10].

Table 2: Potential Impacts of Drilling Waste

Media / Receptor	Potential Impacts
Soil	Breakdown of soil structure Changes in hydraulic conductivity Blockage of nutrients and water from plants
Groundwater	Leaching of constituents
Surface Water	Runoff of constituents into streams
Air	Dusting of constituents Off-gassing
Vegetation / Crops	Blockage of nutrients and water from plants Uptake and toxic effects of constituents
Wildlife / Cattle	Uptake and toxic effects of constituents
Humans	Uptake and toxic effects of constituents

Figure 1: High-Chloride Drilling Waste

The weight of chlorides generated per horizontal well can range from 4,000 to 170,000 pounds (2.5 to 85 tons)

Figure 2: USEPA Waste Management Hierarchy

Source: https://www.epa.gov/smm/sustainable-materials-management-non-hazardous-materials-and-waste-management-hierarchy

Figure 3: Effects of Landspreading

Damaged field from landspreading oil-based cuttings

Figure 4: Diesel Runoff from Roadspreading

Diesel runoff in roadside ditch on a county road. Oil-based cuttings had previously been roadspread on this road.

Figure 5: Diesel Runoff from Roadspreading

Close-up of diesel runoff in roadside
ditch on a county road