POLITECNICO DI TORINO

Petroleum and Mining Engineering
(Department of Environmental, Territorial, and Infrastructural Engineering)

Master's degree Thesis

Environmental Impact Assessment (EIA) of Drilling Fluid Rheology and Cutting Disposals.

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Abstract

The need, consumption, and extraction of oil, coal, and gas are contrary to each other's. The prime source of all power generation the world needs and relies on, comes from petroleum resources the extraction and production of the same doesn't fall on the same page. The pollution produced by the drilling and production operation is not negligible. This thesis addresses the evaluation of the environmental impact associated with drilling fluid rheology and its supportive additives and factors. And also assesses the efficacy and sustainability of different cuttings disposal methods. Drilling fluid, a vital component in the drilling process, influences wellbore stability, lubrication, and the overall efficiency of drilling operations. There are various pieces of evidence presented in this thesis that show the level of pollution upstream engineering is creating for the environment. It also well analyzed and reviewed the regulations concerned with them, the country's role, and also explained in detail how it's degrading the ecosystem balance. But importantly, this thesis has presented the effective techniques being adopted for its control and prevention and also has a discussion section where it has been predicted the possible future measures which will significantly reduce the pollution without harming the drilling efficiency.

Acknowledgement

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Up frontally I would like to extend my sincere admiration to my thesis supervisor **Professor RAFFAELE RAMAGNOLI**, for his unparalleled patience, guidance, and supervision till the end.

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CHAPTER 1

Introduction

The year 2023, and the next few decades will be meant to be revolutionary in the prospects of energy source outlook. Currently no matter but renewable energy sources are growing yearly actively and world energy consumption will rely mostly on renewable energy sources. But despite of all enforces that have been indulging renewables, for the next few decades, the non-renewable energy source, the oil & gas from the subsurface will be the prime source. Most of the world's energy is generated from non-renewable sources, specifically oil, coal, and gas. Just over 13 percent of global power is derived from renewable sources, 10.6 percent of which is from combustible renewables and renewable municipal waste. The remainder of renewable energy comes from hydro-, geothermal, solar, wind, and tidal and wave sources.

In 2022, the U.S. transportation sector used nearly 90% petroleum fuel. Biofuels contributed 6% of biofuels and were blended petroleum fuels. Whereas natural gas only covered 5% [2]. In 2021, the available energy sources range in the EU, primarily consisted of five different sources: crude oil and petroleum products (34%), natural gas (23%), renewable energy (17%), nuclear energy (13%), and solid fossil fuels (12%) [1].

Drilling operation is essential or can say the first and foremost action for the extraction and production of oil and natural gas. Drilling is also becoming equally important for environmental remediation and protection. It helps to investigate and remove chemical and radioactive wastes from the subsurface and also helps in placing barriers in the subsurface to discontinue the reach of contamination. Improvements in drilling technology will improve the efficiency of waste extraction and thereby lower the cost of clean-up efforts which is fruitful for the environment. Produced water and drill cuttings are the operational discharges from oil and gas platforms which are the continuous source of contaminants to continental shelf ecosystems. Oil and produced chemical spills can arise during operation. In 2012 almost 100 – 150 incidents have been recorded of oil discharge and chemical spills. In 2007, 2009, and 2010, chemical spills came from injection wells leakage. Further, to date, no such leakage has occurred after the required technical improvements.

Environmental risks associated with the three main mentioned reasons are generally possessed by offshore and directional drilling in oil and gas exploration:

(a) Drilling wastes emissions from drilling sites and potential run-offs,

(b) Leaks and spills of natural gas and

(c) Human health degradation

Oil/grease, arsenic, chromium, cadmium, lead, mercury, & naturally occurring radioactive materials are some of the toxic materials that are present in the drilling fluid circulating through the well hole. Drilling fluid or drilling mud is made up of a composition of different chemicals and metals. Drilling Fluids is an essential part of well drilling, completion, and workover. Usually drilling mud and its significance refers to solving various difficulties and complexities caused by formation, working string, tight spot, loss circulation, stuck pipe, wellbore instability, stick-slip, influxes, and blowout. So mud helps in good cleaning, wellbore stability and integrity, formation protection, lubricating and cooling working string and bit, transmitting hydraulic power, and well/formation information. Freshwater, saltwater, oil, synthetic-based, and pneumatic fluid systems are some indifferent drilling fluid systems being used in the oil and gas industry. In general, drilling fluids in the oil and gas industry are used to assist tools during well drilling.

The main functions of drilling fluids are:

1. Cutting transport to the surface
2. Drilling tools and hole-cleaning
3. Helps reduce friction
4. Helps in bore stability
5. Command over hydraulic pressure with pore pressure
6. Formation protection from possible damages

Drilling fluids are generally made up at the drilling site in the required quantity using various desired additives and stored in a tank or a sump. Additives and chemicals possessed by the drilling fluid have their purpose and characteristics. It varies with the nature of the formation and the desired role during the drilling process. On the other parallel hand, drill cuttings are the solid metals and formation cut left over which is brought to the surface with the support of drilling mud.

CHAPTER 2

Scope & Objectives

2.1. Application of petroleum products:

1. Because of insulating and heat-resistant properties, plastics and other relevant products are used in electronic components such as speakers, smartphones, computers, cameras, and televisions.

2. Petroleum-based fibers including acrylic, rayon, vegan leather, polyester, nylon, and spandex are commonly used for making clothes. Also, shoes and purses use petrochemicals.

3. Even sports materials such as basketballs, golf balls and bags, football helmets, surfboards, skis, tennis rackets, and fishing rods use petrochemicals.

4. Personal care products are derived from petroleum including perfume, hair dye, cosmetics (lipsticks, makeup, foundation, eye-shadow, mascara, and eyeliner), hand lotion, toothpaste, soap, shaving cream, deodorant, pantyhose, combs, shampoo, eyeglasses, and contact lenses.

5. Plastics are used in a wide range of medical devices and petrochemicals are relied on for pharmaceuticals such as hospital equipment, IV bags, aspirin, antihistamines, artificial limbs, dentures, hearing aids, heart valves, and many more.

6. From construction materials such as roofing and furniture, appliances, and home décor such as pillows, curtains, rugs, and house paint. Kitchen items including dishes, cups, non-stick pans, and dish detergent use oil in their creation.

2.2 Current Scenario

Worldwide, protests and slogans to stop oil production are spreading groundling, and it's all mainly because of the huge amount of environmental pollution emerging out of the drilling operations, drilling wastes improper disposal, gas pipeline leaking, contagious drill mud discharge, and quality, etc.

Fig. 1. Protest against oil companies

Drilling operations produced water spent drilling mud disposal & discharge, drill cutting disposal, etc are the main culprits of the above ongoing protest. Factors like economics, period, and deployment of unapproached technology are a few of the factors enriching the pollutants.

2.3 Major Objectives

1. In-depth investigation of the rheological properties of various drilling fluids including their viscosity, density, gel strength, and fluid loss characteristics.
2. Evaluation of different methods for disposing of drilling cuttings
3. Environmental impact assessment associated with both drilling mud and drilling cutting disposal methods.
4. Quantification of the severity and extent of these impacts to inform mitigation strategies
5. Engagement with industry experts, regulatory agencies, local communities, and environmental organizations to gather insights on drilling fluid rheology and cutting disposal practices.

CHAPTER 3

Rheological Properties of Drilling Fluids

In the upstream engineering sector, drilling fluid is essential at nearly every stage. Well conditions and processing heavily rely on the density and rheological properties of the drilling mud. The rheological properties of drilling fluid describe how it flows and deforms under external force. Additionally, these properties are crucial for determining hole cleaning efficiency, frictional pressure losses in pipes, equivalent circulating density (ECD) in down-hole conditions, flow regime in pipes, swab and surge pressures, and hydraulic optimization for better drilling efficiency. These properties vary among different drilling fluids.

3.1 The major rheological properties:

1. Apparent Viscosity
2. Plastic Viscosity
3. Yield Point
4. Gel Strength

A drilling fluid viscometer or rheometer is used for obtaining fluid rheology which is a measure of the resistance of a fluid to flow.

Fig 2. Rheometer

1. **Viscosity**

Viscosity is fluid molecules' friction between each other. When the liquid flows through the tube, the particles near the tube's axis move more rapidly and near walls more slowly. Some pressure difference between the tube's two ends is necessary to get over this friction and force the fluid to move. The penetration rate is affected by the viscosity at the bit, therefore when viscosity is lower the rate will be better. For example, mud must be characterized by appropriate viscosity in order to transport the cuttings up to the surface.

2. **Gel strength**

As the fluid stays in static conditions for some time, the time-dependent forces induce a viscosity increase. So, the gel strength comprises the electrochemical forces in the liquid at stationary conditions. This parameter relies on the solid contents, suspended solids, chemical composition, time, and temperature. Usually, a high concentration of clay has it.

3. **Yield point**

It is a parameter characterizing the initial/static fluid flow resistance or it is a pressure needed to make fluid move. The attractive force among the colloidal particles is called yield point (YP). Also, YP is the shear stress which is extrapolated to a zero-shear rate, as for the Bingham plastic model.

4. **Apparent viscosity**

It is a fluid shear stress upon the shear rate. For non-Newtonian fluids, the apparent viscosity is influenced by the shear rate, while for Newtonian fluid the apparent viscosity is constant and equal to the Newtonian fluid viscosity.

In this study, water-based drilling fluids underwent different pressure and temperature readings and hence analyzed the deformation range and behavior of WBM samples. Bentonite concentration was altered to compare its behavior with varying compositions.

The rheological properties were measured using a high-pressure high-temperature (HPHT) rheometer. It is a high-pressure and high-temperature, rotational, and coaxial cylinder rheometer that can withstand up to 1000 psi pressure and 262°C temperature.

Table1: Composition of WBM Sample

Material	**Quantity**	**Mixing Time (Minutes)**
Distilled Water	307 (g)	-
Defomer	0.34 (cm^3)	0.49
Xanthan gum	1.6 (g)	19
Starch	5 (g)	19
KCL	81 (g)	19
KOH	0.33 (g)	1
Sodium sulfide	0.26 (g)	1
CaCo3	31 (g)	11

Behaviour Analysis:

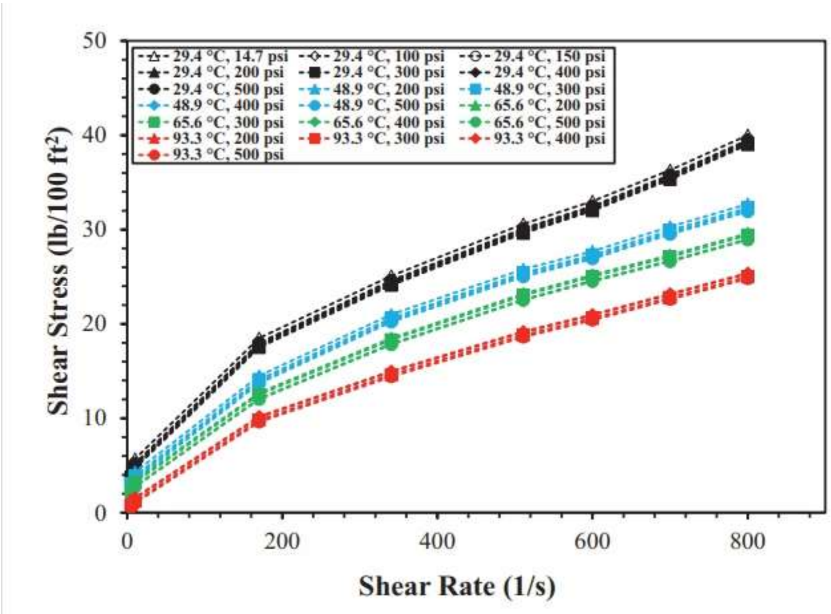


Figure 3: Base drilling fluid with variable temperatures and pressures

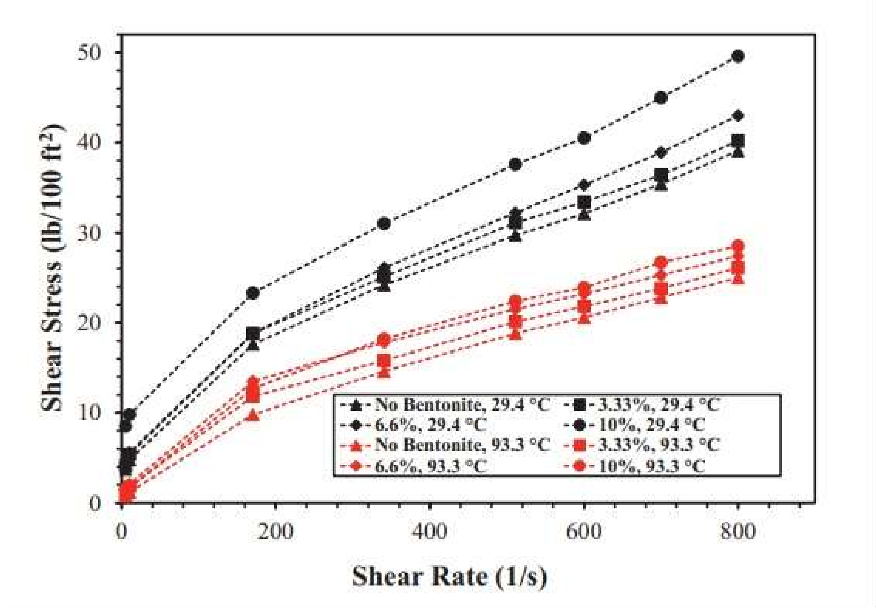


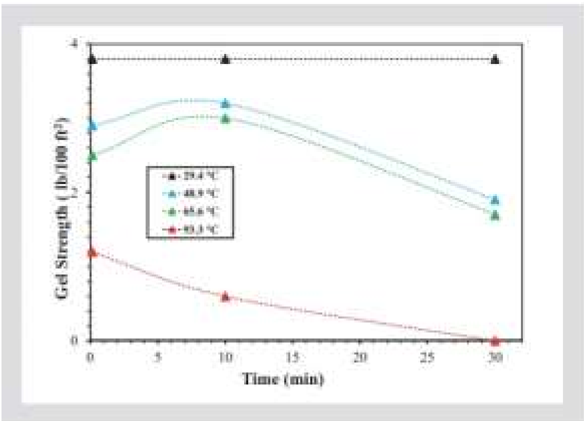
Figure 4: Effect of bentonite concentration on rheological properties of base drilling fluid.

The plastic viscosity is the slope and the yield point is an intercept obtained by plotting the shear rate versus shear stress. The rheological properties were measured at a different shear rate to estimate the yield point and plastic viscosity. Figure 3 shows the dial reading of the HPHT rheometer at different temperatures and pressures by varying shear rates. The dial reading records no pressure effect. The behavior of the drilling fluid was observed almost the same at different pressures at a given shear rate. At high temperatures, the pressure also does not affect the rheological properties. As pressure did not affect the rheological properties, the effect of bentonite, concentration on rheological properties was studied at a fixed pressure (300psi) and two different temperatures (29.44°C and 93.33°C). Adding different concentrations of bentonite to the drilling fluid increased the rheological properties at all investigated temperatures. Figure 4 shows the rheological properties of drilling fluids with various bentonite concentrations at 29.46°C and 93.35°C. At 29.46°C, the drilling fluids then showed positively improved rheological properties compared to the base drilling fluid which is without bentonite concentration.

A. Gel Strength

We measured the gel strength of basic drilling fluid at different times 10 seconds, 10 minutes, and 30 minutes and temperatures 29.46°C and 93.35°C at 300 psi, as shown in Figure 5. At 29.46°C, the gel strength remained constant. However at 93.35°C, the gel strength was zero after 30 minutes, which is a negative sign for gel strength which means there is a problem in cuttings carrying and holding and also can cause sticking issues.

To fix this, different amounts of bentonite were added to the drilling fluid. Figure 6 shows the gel strength with different bentonite concentrations. With 3.35% bentonite, the gel strength increased from 4.5 lb/100ft² at 10 seconds to 5.6 lb/100ft² at 10 minutes and stayed at 5.6 lb/100ft² at 30 minutes. With 6.7% bentonite, the gel strength increased from 4.5 lb/100ft² to 7.4 lb/100ft² after 30 minutes.



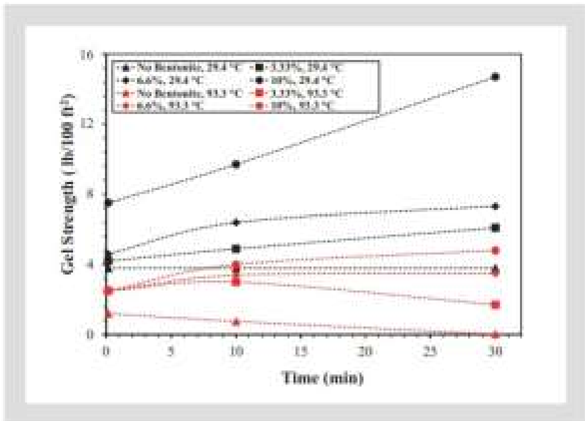
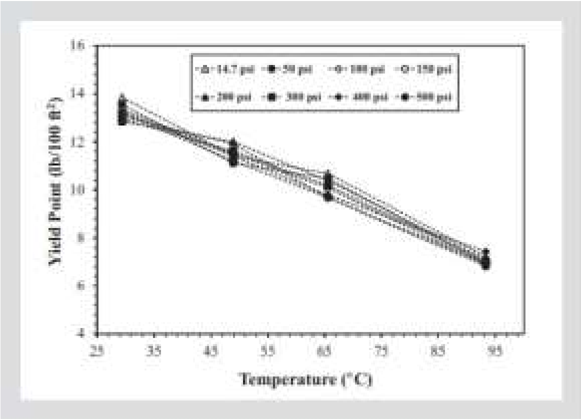


Figure 5: Drilling fluid gel strength with a varied temperatures
Left, Right- Figure 6: Effect of bentonite concentration on gel strength of base drilling fluid.

B. Yield Point

Fig. 7 below shows the yield point behavior of base drilling fluid at constant temperature which shows no pressure difference. However, in Fig 8, we can see that after increasing, pressure decreased. Bentonite was added in a later case. The drilling fluid has a yield point of 13.84 lb/100ft2 at 29.46°C and decreased to 7.21 lb/100ft2 at 93.35°C.



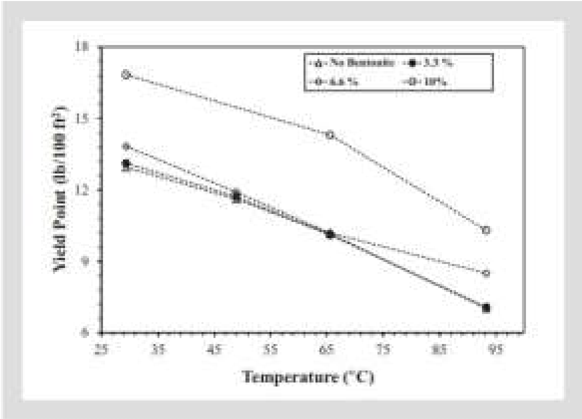
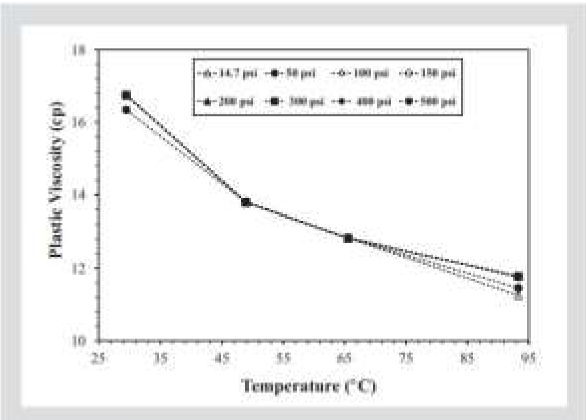


Figure 7: Drilling fluid yield point with a varied temperatures and pressure-Left,

Right- Figure 8: Effect of bentonite concentration on the Yield Point of the base drilling fluid

C. Plastic Viscosity

The plastic viscosities of base drilling fluid at different temperatures and pressure is shown in Figure 9. The drilling fluid has a plastic viscosity of 16.76 cP at 29.46°C and decreased to 11.75 cP at 93.35°C. The final base drilling fluid has higher plastic viscosity behavior noted at each temperature range due to the addition of bentonite fig 10.



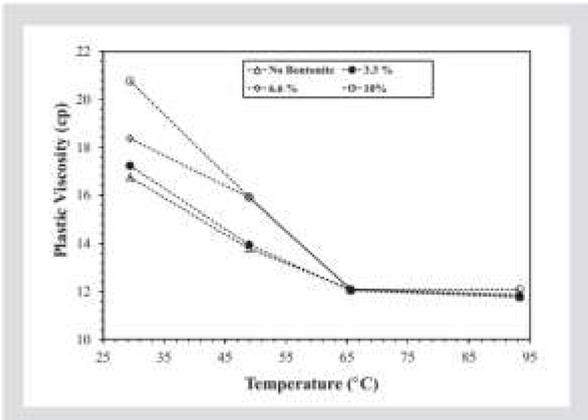


Figure 9: Drilling fluid plastic viscosity with a varied pressure range.-Left, Right- Figure 10: Effect of bentonite concentration on the plastic viscosity of the base drilling fluid

D. Filtration Properties

The optimum level of drilling fluid should make a filter cake on the wellbore of low permeability to prevent formation damage. Based on the rheological results, the good concentration of bentonite which is 6.5 wt by percentage was confirmed to perform the filtration experiments and was measured 93.35 °C at 300 psi. The filtration volume of the drilling fluid was lower compared to the base drilling fluid.

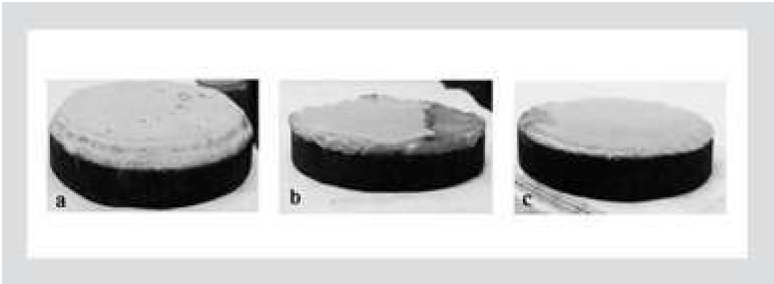


Figure 11: Filter cakes thickness: (a) base drilling fluid, (b) drilling fluid with 7.5 wt% nanosilica, (c) drilling fluid with 6.5 wt% bentonite.

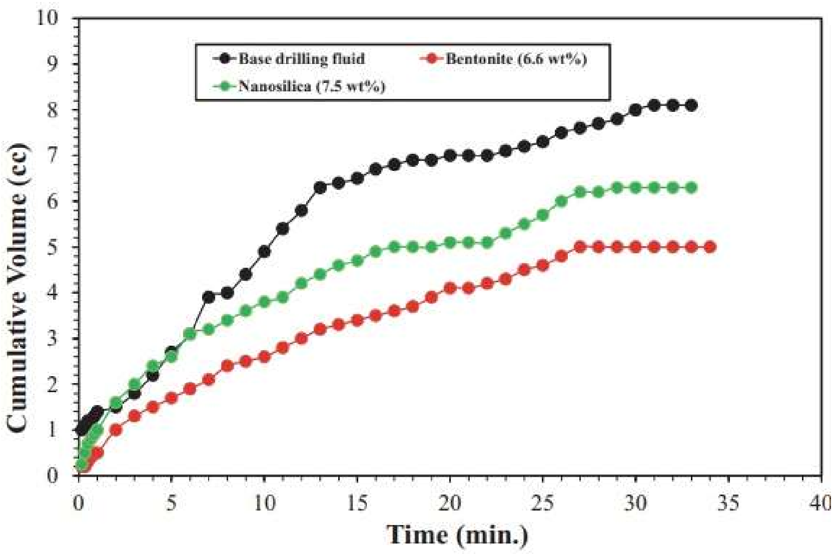


Figure 12: Filtration measurements of drilling fluid.

Conclusion

Based on rheology tests conducted under high pressure and high-temperature conditions on drilling mud used in Qatar for drilling operations, the following conclusions are drawn:

1. Viscosity, yield point, and gel strength decrease as temperature increases.
2. Increasing pressure enhances viscosity and yield point, particularly when the temperature is below the failure point.
3. The influence of pressure on mud rheology is less pronounced compared to temperature.
4. The regular oil-based mud sample failed at a temperature of 400°F.
5. The oil-based mud formulated for HPHT conditions did not fail.
6. The joint impression of temperature and pressure on OBMs rheology possess extraordinary and non-linear in nature.

3.2 Impact of rheological properties on cutting transports

The rheological properties of drilling fluids play a significant role in cuttings transport and overall drilling performance. Here are some examples of how specific rheological properties can impact these aspects:

1. **Viscosity** is one of the prime and vital properties of a drilling fluid. It is the one that signifies how fine the drill cuttings are carried out from the well bore to the surface. The selection of viscosity majorly depends on the density of the fluid being used in the drilling mud. Very dilute mud fails to carry the cuttings whereas highly viscous mud often requires high pumping performance. A special consideration should be put forward while confronting the viscosity of drilling mud.

2. **The yield point** is the minimum shear stress to initiate fluid flow. Also, too high a yield point fails to perform for the cuttings because of the flow issues. An optimum feature comes with the low yield point of the selected drilling fluid as it is easy and flexible to suspend the cuttings to the surface.

3. **Plastic viscosity** represents a fluid's ability to flow once it has started moving under shear stress. A lower plastic viscosity allows for easier flow of the drilling fluid, which is essential for efficient cuttings transport. When plastic viscosity is too high, it can lead to increased energy consumption and reduced cuttings transport efficiency.

4. **Gel strength** measures a fluid's resistance to flow when it is not subjected to continuous shear stress. High gel strength is desirable during drilling pauses or when the pumps are not active because it helps prevent cuttings from settling at the bottom of the wellbore. Without sufficient gel strength, cuttings can accumulate and cause problems when drilling resumes.

5. **Thixotropic fluids** become less viscous when subjected to continuous shear stress, which is beneficial during drilling operations. When the pumps are running, the fluid becomes more fluidic and can efficiently carry cuttings to the surface. However, when the pumps are stopped, the fluid quickly regains its original viscosity, which prevents cuttings from settling.

CHAPTER 4

Environmental Impact Assessment of drilling fluid rheology

Drilling fluid rheology is a key factor to present that while preparing and using a suitable drilling fluid, supportive additives which is favourable for an efficient drilling operation should also be environmental friendly and cannot harm to the environment while discharging. This chapter has explained how extent a drilling fluid rheological additives and hence the inorganic and heavy metals possessed by it can harm the environment.

Effect of Rheological properties on the environment.

1. Surface leakage or spill can be caused due to equipment blockage when the viscosity of the drilling mud is high. Whereas, the low viscosity of drilling mud may accidentally discharge into the environment due to less effectively controlled.

2. Also low viscosity spent drilling fluid can disperse widely covering a large sum of area compared to spent drilling mud which possesses high viscosity and can remain stagnant but for a longer period affecting that plot adversely.

3. There are some rheological additives present in drilling mud like thinners, surfactants, and lubricants which have been proven very toxic to aquatic life. Also, thick drilling mud harms the local ecosystem after it settles at the bed of the sea and lakes.

4. The outmost function of optimum rheological properties of a drilling mud is how well it transports the drill cuttings. Any improper or deficiency in the proportion or diversity in the proportion can cause resting the drill cuttings at the seabed or nearby environment which has severe effects to bear.

5. Drilling fluid with complex rheological properties can be hard to handle because its treatment requires high maintenance and highly skilled labor. Any accidental mistake or carelessness can cause high negative risk and prolonged unbearable damage to the environment.

6. (Onwuka et al., 2018; Ayotamuno et al., 2007; Jadoon and Malik, 2017). Adewole et al. (2010) documented that the lead content in disposed drill wastes from two offshore wells studied exceeded the recommended limit of 0.005 mg/l set by DPR and the

international threshold of 0.05 mg/l (Table 2). This level of lead can pose risks such as toxicity, corrosion, reactivity, and carcinogenicity, among others.

7. The variation in geographical formation and drilling fluid composition used according to the desired formation mixes up to form a hazardous waste that has extreme toxicity. For example, in OBFs base oil may be of various natures, and also the additives used in OBFs may be of very complex form such as surfactants, organophilic clays, and viscosities.

8. From 1981 to 1986, the average annual discharge of oil on cuttings to the Norwegian Continental Shelf (NCS) was 1940 tons. It was estimated that about 45,000 m3, a height of around 25m, and a footprint of more than 20,000 m2 cutting piles are still present in the northern and central parts of the North Sea. About 79 large (>5000 m3) and 66 small.

9. However, even WBM cuttings with less hydrocarbon content may seriously affect benthic fauna by elevating oxygen consumption in sediments.

10. These compounds, which are highly environmentally hazardous, are shattered oil, heavy metal, aromatic hydrocarbon and alkylphenols (AP), and naturally occurring radioactive material (NORM)- are still prevailing in the black sea which in return we can see the adverse effect on its marine ecosystem.

11. Direct discharge of drilling fluid can affect the local ecosystem in all three possible ways which includes the toxicity on direct discharge, favouring the degradable bacteria, and making conditions fit for anoxic reactions.

12. Unwanted secondary substances cause even prolonged damages such as infertility, and negative mutations, and narrow the living space of aquatic organisms.

13. The most eye-catching adverse effect of the chemicals used to protect the borehole is to induce eco-toxicological reactions in the marine environment. These reactions destroy the habitats of aquatic organisms slowly but all with permanent effect.

14. It also causes more predictable problems such as respiratory diseases, cancer, declining in the population against human welfare.

15. Roughly 200,000 migratory birds are killed each year near offshore drilling rigs in the Gulf of Mexico. They often fly circles around platforms for hours at a time, exhausting themselves or colliding with platforms or other birds. Birds' feathers can get coated with oil, preventing them from being able to keep warm and reducing their ability to float.

16. Oil and related chemicals may also damage the immune and reproductive systems of exposed birds, fish, and shellfish, lowering populations of affected species and denying food to the predators that depend on them.

CHAPTER 5

Cutting Disposal Techniques

Cuttings are the results of every drilling operation which are solid fragments that need to be transported back to the surface by drilling mud. Boreholes drilled in this way include oil or gas wells, water wells, and holes drilled for geotechnical investigations or mineral exploration. With the increasing drilling operation, parallel drill cuttings are also becoming a prime concern to be accounted for in the proper eye. Bulk of drill cuttings are disposed of worldwide in different ways. The main focus should be shifted towards the drill cuttings from the OBM because the one from WBM has very little or no such environmental effects. After all, water is the main domain used to prepare drilling fluid.

Waste disposal has always been an important part of the exploration, development, and operation of oil and gas fields, especially considering the enormous amount of waste generated. Approximately, one well produces 1000 to 5000 m3 of drilling waste. Drill cuttings carried by mud are usually transported at the surface of the platform where they go through shakers or vibrating machines to separate the cuttings from the drilling fluid which allows the circulating fluid to re-enter the drilling process.

5.1 Offshore

5.1.1 Direct Discharge

It is meant to be one of the most easy and maintenance free method. This is because it requires no additional equipment than conventional ones. This method of disposal is suitable for aqueous-based cuttings as they require little or no treatment before disposal. Non-aqueous fluids must 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 dangerous components in the waste, and the volume of the discharge stream. The spent drilling mud is mixed with the seawater and discharged to the sea through a pipe called a downcomer which is placed just a few meters above the sea when spilled into the sea directly.

Advantages:

1. Optimal maintenance with low cost and simpler process
2. Safer comparison to other methods
3. Very less space required
4. Environmental friendly

Disadvantages:

1. Management of fluids constituents
2. Higher cost for fluid analysis before discharge
3. High risk for marine ecosystem

5.1.2 Cutting re-injection

Following the recent environmental regulation not to discharge sewage into the sea, the most commonly cutting re-injection methodology came into existence and was used. Slurry injection technology is used to inject after crushing it into finely crushed and mixing it up with the mud to make slurry which then in the subsurface fractures the rocks without harming the wellbore. The desired number of disposal wells are designed to assist the discharge into the underground target without any harm to the environment at all. (Figure 13). The whole candidacy should be separately carried out to not reach out near any surface or underground water bodies. 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.

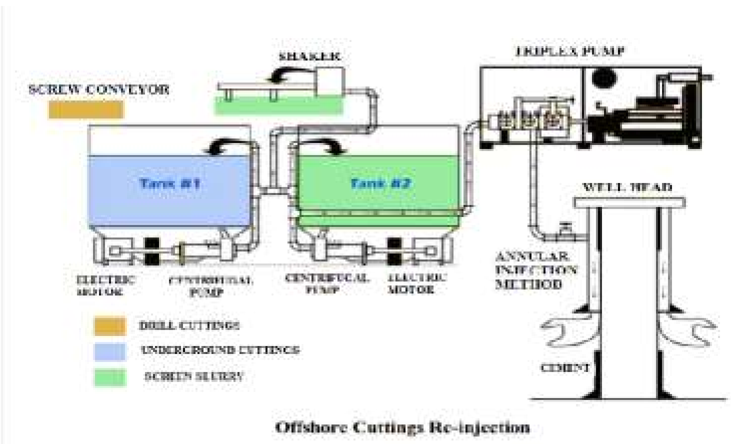


Fig 13: Offshore cutting re-injection

Advantages:

1. Simpler proven technology is required for cuttings pre-treatment
2. No offshore transportation required
3. Limits the surface and groundwater contamination

Disadvantages:

1. High and significant maintenance alertness required
2. High-skilled labor requirement
3. Air pollution due to large power required

5.1.3. Collection and Transport to shore

It is a very simple method of taking all the drill cuttings to the shore for further treatment. These techniques apply to non-aqueous drilling waste which cannot be discharged or re-injected due to its toxic nature and volume. Factors to consider when evaluating these methods include the availability and cost of chattering a vessel and the distance from the platform to shore. It is important to evaluate the cost of chattering or transporting waste to shore before considering this option.

Advantages:

1. Zero risk for marine ecosystem
2. Transportation of drilling waste eliminates future liability.
3. Fuel and labor benefits for future use

Disadvantages:

1. High equipment and transportation cost
2. Additional vessels and systems required
3. Double project time required
4. Double labour costs

5.2. Onshore Disposal

Cutting reinjection is common in both offshore and onshore operations. Due to the availability of space for an onshore operation, there are a lot more management options available. Some of the most common and widely used techniques are described below:

5.2.1 Onsite burial:

Onsite burial is one of the simplest methods of disposing of the drill cuttings into the naturally excavated pits or man-made sump. Because of its low-cost investment and low maintenance with almost zero risk factors, it is widely used at different levels as required. On the other hand, onsite burial may not be a good option for the waste containing high concentrations of harmful components that can contaminate usable water resources. Key factors like depth of pits, reach to underground water bodies, and residential areas should be considered strictly which in return also obeys the Environment Safety Act.

5.2.2. Waste pits:

The concept of the waste pit is almost similar to the onsite burial. The only difference is that the waste is limited or mainly focused on the produced fluid. And also for emergency containment of produced fluids. Other safety factors like being far from the residential area, or following any environmental acts apply the same as onsite burial. It has little maintenance issue as waste is stored for future use. To prevent seepage into groundwater bodies and contamination of the soil, the pits are usually lined with natural and or synthetic liners (Figure 14).

Fig 14. Drilling waste management program

5.2.3 Landfills:

Cuttings (treated and untreated) are placed in a specific area with designed containment and liners. The volume of the landfill to comprise waste will depend upon the quality of the design, materials, and underlying geological units. The main thing to be cautious about is that it needs to be stored for a prolonged period. Landfills are usually operated by offsite commercial where waste can be received from different drilling sites. However, few oil companies with large amounts of drilling activities construct and operate their private landfills. (Figure 15)

Fig. 15 : Commercial Oilfield Waste Landfill.

5.2.4 Bioremediation:

It is a different treatment method which uses microbes to decay the waste materials. The micro-organisms break down the organic substances into harmless CO2 and H2O. Microorganisms fuse off as they no longer have any content to feed on. The bioremediation process is mostly flexible and can be used for all types of drill cuttings and wastes which distinguishes it from all treatment methods. Some advantages of bioremediation are relatively environmental, generates few emissions, wastes are converted into useful products and requires minimal or no transportation. However, it takes a long time to carry out the whole process which limits for mass production of waste every year from the largest E&P companies. The most common types are land-farming/land spreading, composting, and vermin-culture.

5.2.5 Land-farming /land spreading

This waste management system consists of both treatment and disposal schemes. The soil itself naturally metabolizes, disintegrates, and analyses the material from waste with the help of microbes present in the soil. This is usually followed by mechanical tilling with the addition of nutrients, water, air, and or oxygen to stimulate biodegradation and aeration of the soil by naturally occurring oil-degrading bacteria. This method confirms the very low-cost investment, no maintenance costs, is much environment friendly, and most importantly it helps in water retaining capacity for sandy soils.

5.2.6 Composting

Manual mixing of the drilling wastes with organic contents like wood chips, straws, rice hulls, or husks increases porosity and aeration potential for biological degradation. Nitrogen and phosphorous fertilizers are also added to it for better and faster degradation. Maximum 3-meter depth of piles are prepared to sump the wastes with a thick aerobic liner and borders are designed with the passage of water supply. Additional bulking agents into it can increase the temperature and volatilization giving composting an advantage over land-spreading or land-farming in cold climates. (Figure 16).

Fig 16: Compost in Windrows

5.2.7 Vermi-culture:

This New Zealand-origin method deploys earthworms to help in the bioremediation process and convert the drill cuttings into organic fertilizer. Synthetic-based wastes are mainly treated with this method in which wastes are mixed with sawdust, undigested grass, and water and applied to a worm line. A unique bio-organism technique that shades off from the light for worms and later the final decomposed product is very fruitful for farming and other agricultural uses. Even it has international demand which has made it a good measure of domestic as well as international leveled business. (Figure 17).

Fig 17 .Vermi-culture Showing Worms

5.3 Thermal methods

Thermal technologies use **thermal desorption** and **incineration methods** to treat the wastes. The residues are treated with the required heat in contentment (**thermal desorption)** which filters out the water vapor and oil which is then condensed back for reuse. The solid residues that contain heavy metals also are disposed of accordingly or may be used for road construction. Whereas **incineration** heats cuttings in direct contact with combustion gases and oxidizes the HCs. Incineration can be performed by open burning of wastes in pits or by the use of commercial incinerators. SOx and NOx are used as incinerators to reduce pollution.

5.4 Other beneficial uses of drilling wastes:

Drill cuttings or any other drilling wastes can be used for multiple other uses. But before using it as other useful resources, it should be assured that it does not contain any harmful or toxic content which has hazardous effects after use.

Road spreading: It can be used as a very effective dust suppressant as it has tendency to bind the road gravel or other road construction materials together very well.

Re-use of cuttings as construction materials: After the treatment, the residue solid materials can be used as the filler material in concrete, brick, and block manufacturing which is also very effective and economical.

CHAPTER 6

Environmental impact assessment of cutting disposal

If oil and gas exploration rigs and production installations are allowed to dump drilling wastes unchecked and uncontrolled, the effects on marine life can be extensive and biologically extinct. The HCs found in the drill cuttings damage the seabed which is a kind of protection shield and thus destroy the marine life. According to the US Department of Energy, WBMs produce short-term, minor impacts on the seabed, whereas OBM cuttings introduce long-term, more severe impacts. WBM is relatively harmless because it contains water as its primary lubricant/coolant and no oil. In some situations, additives may have organic properties but these are only allowed in very small quantities. As a result, there is no residual oil on the cuttings. Any salts or minerals coming from the mud are not biologically available as they are in non-organic forms coming generally from the barite used as the cutting medium.

6.1 Marine Ecosystem

Some of the key environmental impacts associated with the disposal of drill cuttings into the marine ecosystem are mentioned below;

1. **Contamination of Seabed:** Capturing of seabed is the first shield damage and a step closer to marine life destruction. Heavy metals present in the drill cuttings tear the seabed permanently as it has prolonged and heavy impact.

2. **Chemical Pollution:** Lubricants, biocides, and heavy metals bringing various toxic and poisonous ecosystem chemically.

3. **Bioaccumulation:** Bioaccumulation is more dangerous than it sounds. It can limit itself to marine life but also get transferred over time to humans if consumed by any fish.

4. **Disruption of Ecosystem Balance:** The marine ecosystem plays a vital role in prevailing of the life existence on Earth. Disruption of the marine ecosystem has adverse effects on the aquatic flora as well as on the fauna.

6.2 Terrestrial Ecosystem

As discussed in the chapters above, there are many more options available for disposal methods of drill cuttings onshore which refers also to the terrestrial contamination risk. A few of them are shortly introduced below;

1. **Soil Contamination:** Despite any burial or dumping methods, drill cuttings containing heavy metals always pollute the soil and its efficiency.

2. **Groundwater Contamination:** From multiple pits, dumping yards, and injection wells, there is always some leakage of wastes into their nearby underground water bodies which pollutes human as well as animal health.

3. **Disruption of Native Vegetation:** Equally, the vegetation and soil biodiversity will come in danger with contamination roots of drill cuttings to the soil which will affect the natural vegetation for many upcoming years.

4. **Habitat Disturbance:** It also disturbs the ecological flora and fauna which affects the habitat of thousands of living beings including, animals, birds, micro-organisms, and insects which play a vital role in balancing the existing ecosystem.

5. **Air Quality Impacts:** First and major air pollution will be caused due to the foul smell and contaminants spreading from cutting wastes into the air directly.

6. **Potential for Erosion:** Various natural disasters may occur due to the disturbance in the soil ecosystem including landslides, erosion, and many other air pressure and wind issues.

7. **Long-Term Soil Changes:** The drill cuttings may cause even infertility and mortality of soil microbes which results in long-term damage to soil quality and may leave useful for nothing.

To conserve and prevent such issues an Environmental Impact Assessment (EIA) should be enacted so that it will foresee both the waste management solution and also the conservation of the environment in parallel. The regulatory board should be assured of the fact that the water-producing companies are following the guidelines legislated. The governing command should be executed at local, national as well as international levels.

It's an equally important responsibility of the companies and stakeholders to seek and implement the possible practices and solutions that enhance environmental sustainability for future use.

6.3 Groundwater

The different water bodies in the subsurface get polluted by the same issues. For which primarily geological locations, quality of waste management checks, and proper regulatory filers are most important.

Here are some ways in which drill-cutting disposal can affect groundwater:

1. **Leaching of Contaminants:** Rather than primary and direct leaks, most of the time because of improper command, rainwater and other sources of water can carry the pollutants from one place let's say a dumping site to the nearby water bodies.

2. **Migration through Soil Layers:** Factors like soil permeability, porosity, and the presence of fractures in the soil layers can also become a transport to carry the contaminants from pits to the nearby underground sources. Soil layers are a more dangerous and unpreventable means of migrating the wastes into the water sources.

3. **Hydraulic Fracturing and Conduits:** During hydraulic fracturing at drilling sites, rarely the fractures may occur through the conduits to the nearby aquifers which also get mixed up with the drilling wastes.

4. **Local Hydrogeological Conditions:** It depends upon the geological location where also because of the local hydro-geological conditions like direction and rate of groundwater flow, contaminants, and chemicals sweep away in groundwater. Understanding these conditions is essential for predicting the potential impacts of drill-cutting disposal on groundwater.

CHAPTER 7

Case Studies

Case summary 1

There was a case study done at Franklin, USA by Joshua Swigart et al. in 2021 to measure the soil pH, electrical conductivity (EC), total nitrogen and carbon, and extractable nutrient levels as in soil contamination assessment with the sample fields with fixed soil characteristics.

The samples were tested and hence all the elements were measured by using EPA Digestion Method 3050B.

The results were as mentioned below:

1. EC levels in settling pond mud were very high about 6341 mg/kg, which indicates high salt levels in drilling fluid.
2. Na and Cl also tested very high about 5016 mg/kg and 6413 mg/kg, respectively.
3. The total N and extractable P levels, essential nutrients for plant growth, were low in all fields.
4. Settling Pond records total carbon values of almost 3.52% which is near to the high allotted scale end.
5. Ca levels were also tested over permitted limits.
6. Excess amounts of salt near the root zone can block the absorbing capacity of a plant which can instead increase the plant stress and is a negative sign for photosynthesis.
7. Hence fields like these will need special consideration and treatment like precipitation, supplemented by irrigation, to promote plant growth.

Case summary 2

With a similar intention, another important case study was carried out at Ploieşti, Romania in 2021 by Osama Sharafaddin 1 et al.

The main objective of that study was to review two major processes that tend to extract to remove total organic carbon efficiency. In other words, they were removing oils from cuttings.

Highlights:

1. Supercritical water oxidation and Superheated steam extraction are the two processes used for the experiment.
1. With Supercritical water oxidation, the total organic carbon content recovery is 98% with a minimum reading of 79% which is a significant percentage.
1. Carbon extraction is directly proportional to the rising temperature, reaction time, and oxidation coefficient.
2. Hence, the maximum carbon recovery is reached when the process temperature rises to 498 0C which is a high range to use for OBM cuttings.
3. Common limitations like corrosion, plugging, and salt deposition should be managed with particular consideration.
4. Another remarkable factor about superheated steam extraction is that it can be used for even flowing water.
5. Because it uses water and hence it is meant to be a green process. But on the same page, it requires high energy to operate due to working at high temperatures.

CHAPTER 8

Mitigation and Discussion

Drilling fluids are mainly, Water-based mud (WBM), Oil-based mud (OBM), and Synthetic mud (SBM) which is also a part of OBM but a further processed one. To escape or reduce the adverse impact of OBM and on the other hand to benefit the higher performance efficiency of OBM, the following few possible steps might prove fruitful,

- Re-using OBM
- Utilize treatment techniques that can minimize the amount of oil retained on cuttings before disposing of
- Dispose of excess OBM in an environmentally sound manner
- Use more water-based mud (optional)

8.1 Handling Oil-Based Mud

8.1.1 Mud Treatment Plant

All possible efforts have been executed just to ensure the main focus is to free waste from oil using solid equipment methods. The spent OBM was used at least three times before being it to the discharge injection well.

Figure 29: A View of Liquid Mud Plant

OBM is passed through the centrifugal tank from the primary tank to remove barite followed by the removal of low-gravity solid through a high-speed centrifuge. It is then stored in the mix tank after this solid removal where it is further subjected to the addition of diesel and other chemicals until it reaches to the desired composition and characteristics. After final testing, it is then transferred to the rig for use, as shown in the labeled diagram below, Figure No. 30.

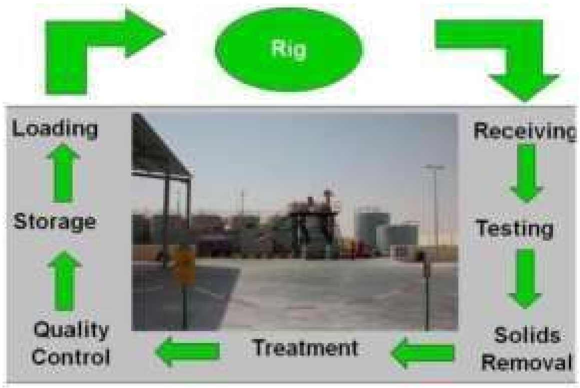


Figure No.30: Liquid Mud Treat Plant Process (LMP)

Advantages:

1. Efficient reconditioning
2. Minimizes mixing & treatment on the rigs
3. Maximizes the amount of OBM reused
4. Reduces rental storage tank

8.1.2 Indirect Heat Thermal Desorption

Oily muds are heated at a high temperature till its vapor point and condensed back for the removal of hydrocarbons from the mud and has advantages over the other available options because it produces cuttings containing TPH below environmental limits for disposal and can effectively recover the fluid from cuttings.

This is the first large-scale technology in the Middle East that is used for OBM recycling and has an efficiency of about 99% (Figures No. 31 & 32). Due to the success of the plant, expansion is planned to meet the growing requirements. Because of such incredible performance efficiency, companies are planning the wide establishment of this unit. It is successfully able to treat 150 Tons a day which is an excellent result for mass waste treatments.

Figure No. 31: View of Thermal Desorption Plant (TDP)

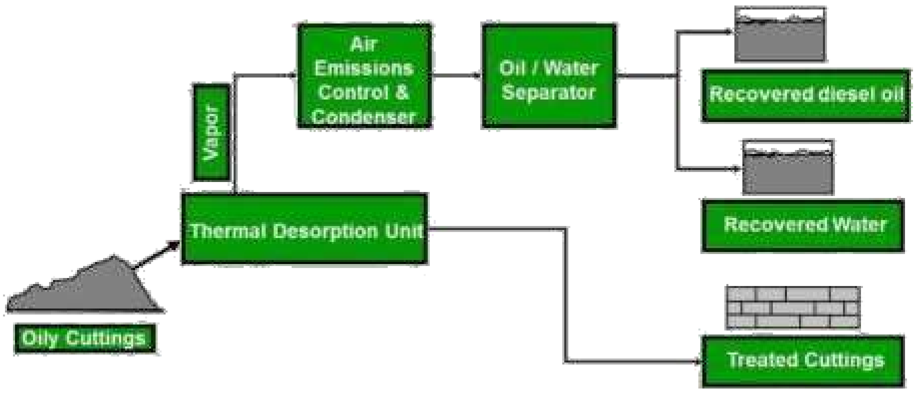


Figure No. 32: The Simplified Process of Thermal Desorption Plant Drilling wastes

Through this treatment plant, it is possible to reduce the Total Petroleum Hydrocarbon (TPH) level to 0.5 % which is below the environmental regulations. Fig 33 shows an incredible graph explaining the reduction of THP after the treatment as we can see.

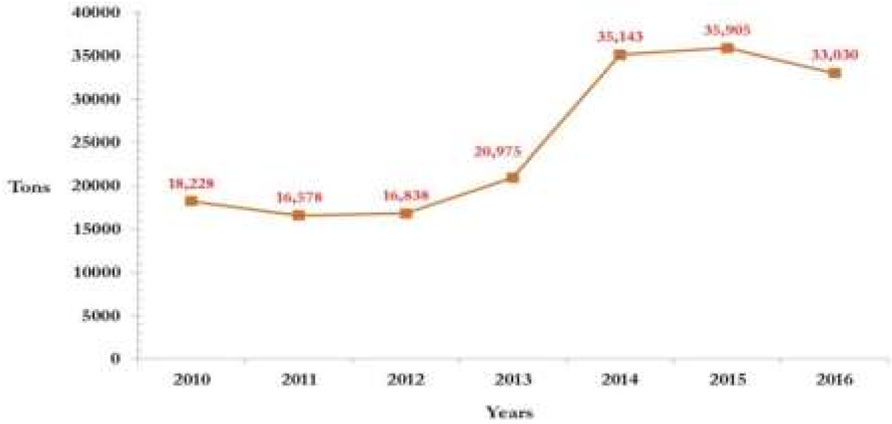


Figure No. 33: Cuttings treated at TDP

8.2 Handling Water Based Mud

WBM is considered more environmentally friendly than OBM. Although WBM lacks petroleum hydrocarbons it does contain additives, barites, water-soluble organic polymers, and other dissolved solids. WBM may contribute to the Chemical Oxygen Demand (COD) of the receiving water if directly discharged. WBM is more suitable and is in practice reused multiple times before being it for disposal. WBM is only discharged to the land if;

- The fluid does not contain hydrocarbon or toxic chemicals
- The discharge area is not environmentally sensitive

Usually drill cuttings from WBM are spread over on the site itself but checking the salinity level is always important in any case for safety reasons.

8.2.1 Downhole Injection

To eliminate the issue of surface dumping, this downhole injection of spent drilling mud can be a good option. This practice has its limitations before 2002. In 2002, it was planned to drill two dedicated wells they were drilled waste injection started in 2003. That is to ensure that one well is always in operation. (Figure No. 34).

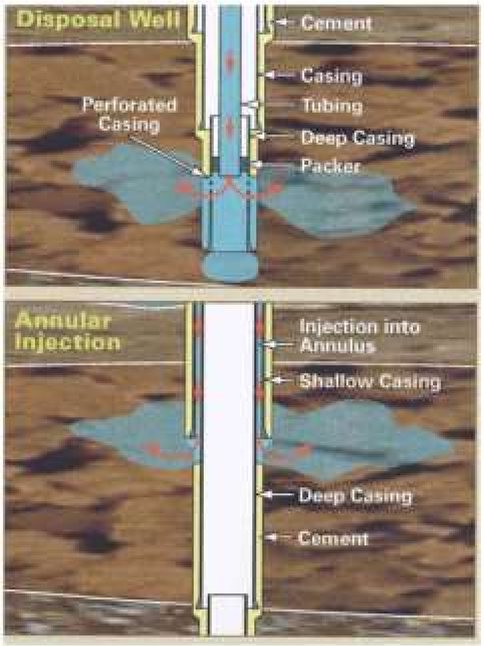


Figure No. 34: Schematic of Disposal Well

8.3 Discussion

8.3.1 Selection of Drilling Mud

A. Nano-based drilling fluids applications:

Unique Characteristics such as huge surface area, high thermal conductivity, and pollution resistance are the key features of Nanotechnology. The recent generation of drilling fluids must possess enhanced rheological properties to form high-quality mud cake, improve the wellbore stability, and provide advantages like wettability alteration, advanced drag reduction and sand consolidation along with superior thermal and filtration control properties, and high anti-pollution power that meet complicated requirements during drilling. Hence, Nano-base drilling fluid is recommended in the application of current and future high-temperature high-pressure (HTHP) drilling operations, unconventional drilling conditions, and deep water drilling operations.

The benefits of using Nano-base drilling fluid;

Increases drilling fluid stability in the HPHT Environment

The cooling system enhancement of the drilling fluids due to the nanoparticle interaction with the rocks because of its high surface area to volume ratio helps in smooth and efficient drilling operations.

Reducing torque and drag problems and increasing the rate of penetration hence reducing the drilling time.

Decreasing the environmental impact of drilling fluids

Nano-particles reduce the composition of additives up to less than 1% which is an excellent sorting compared to the conventional agents. Thus, it is also flexible to drill in any sensible locations.

Removal of Toxic Gases:

Under the same operating conditions, compared to other possible compounds, nano-particle omits hydrogen sulfide gas from drilling mud in just 15 minutes which is an escape for the workers at the rig from a continuous life threat risk.

B. Applications of bio-products in drilling fluids to minimize environmental footprint

1. Date Seed: it consists of chemicals like Potassium, Magnesium, phosphorus, Sodium, and Iron with almost 298 Micro-meter morphology and is suitable for HPHT (High-Pressure high-temperature) conditions.
2. Bio-products like simple grass and grass ash also contain chemicals like Potassium, phosphorous, calcium, magnesium, and acid detergent of the same 298 micro-meter morphology and are also suitable for HPHT conditions.
3. Similarly, cellulose from ground nuts is engrossed with carbohydrates, minerals, and lipids.
4. Furthermore, other bio-products like mango starch ester consist of calcium, magnesium, manganese, zinc, and barium which is also suitable for HPHT conditions with morphology of about 5 – 12 micro-meter

C. Effect of bio-products in rheological properties of drilling fluid

Grace M3600 Fann G Viscometer is used to check the plastic viscosity, yield point, and gel strength to make additives from the bio-products to mix up into the mud.

The concentrations of 0.25, 1.5, and 2.0 ppb of each additive (i.e. date seed, grass, and grass ash) in a WBM (water base mud) of 22.5 g of bentonite in 350 ml of water come up to good additives as per prescribed by Wajheeuddin and Hossain, 2017. The consistency curve of bentonite mud with date seed, grass, and grass ash in 35a, 36a, and 37(a); Date seed helps in increasing PV and gel strength. Grass particles aid in increase but PV remains constant. In the case of the grass ash, viscosity, YP, and gel strength increases with increasing concentration.

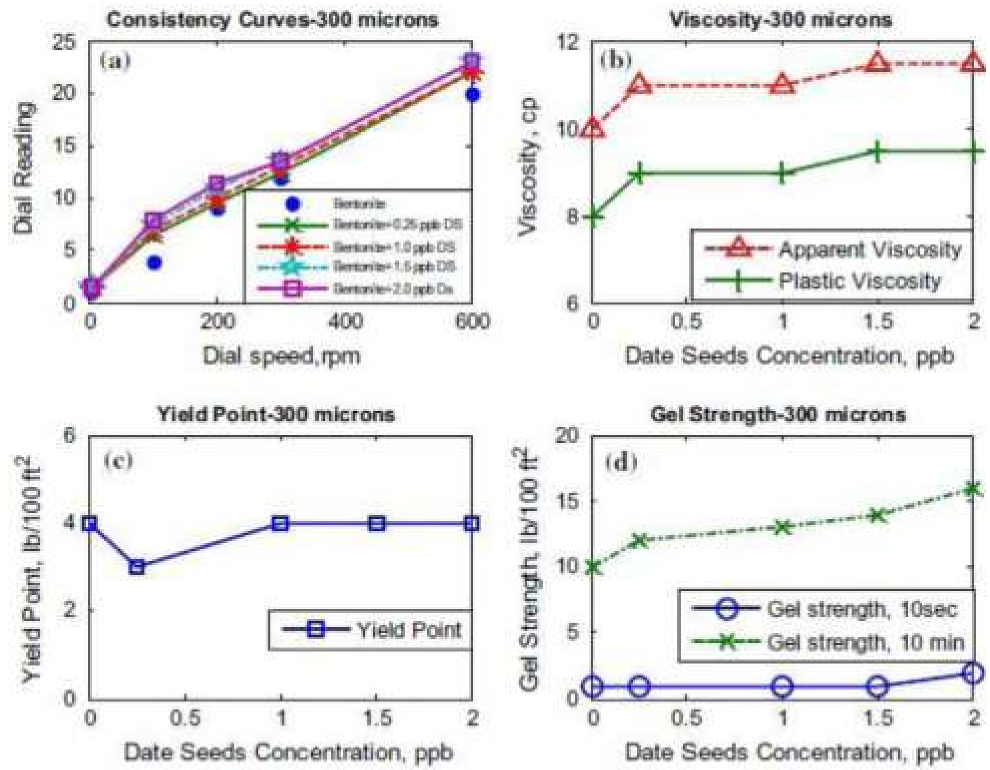


Fig. 35. Plot of rheological parameters for drilling fluids formulated with date seeds particles

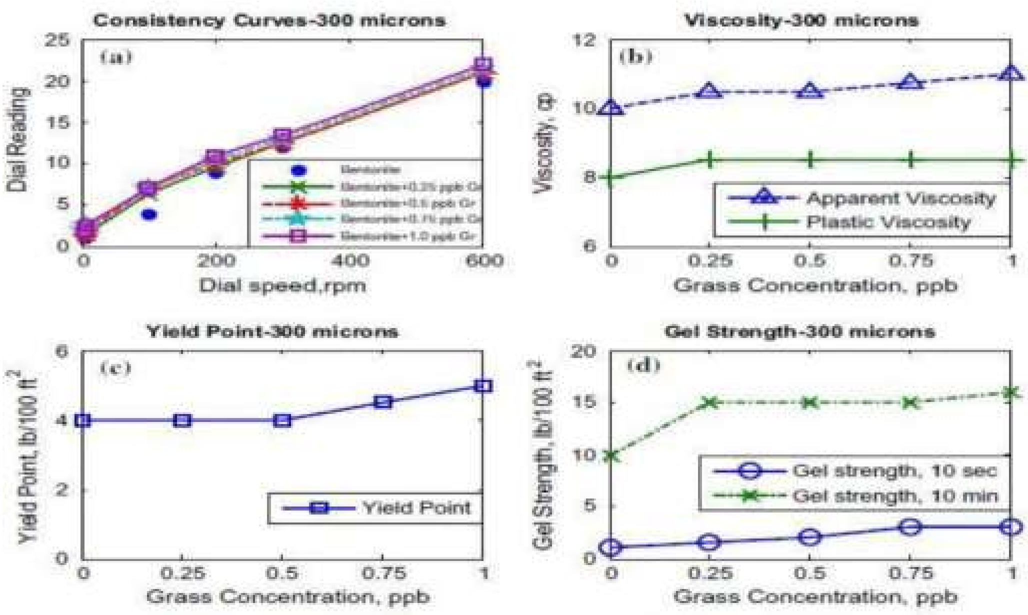


Fig. 36. Rheological parameters for muds formulated with grass particles

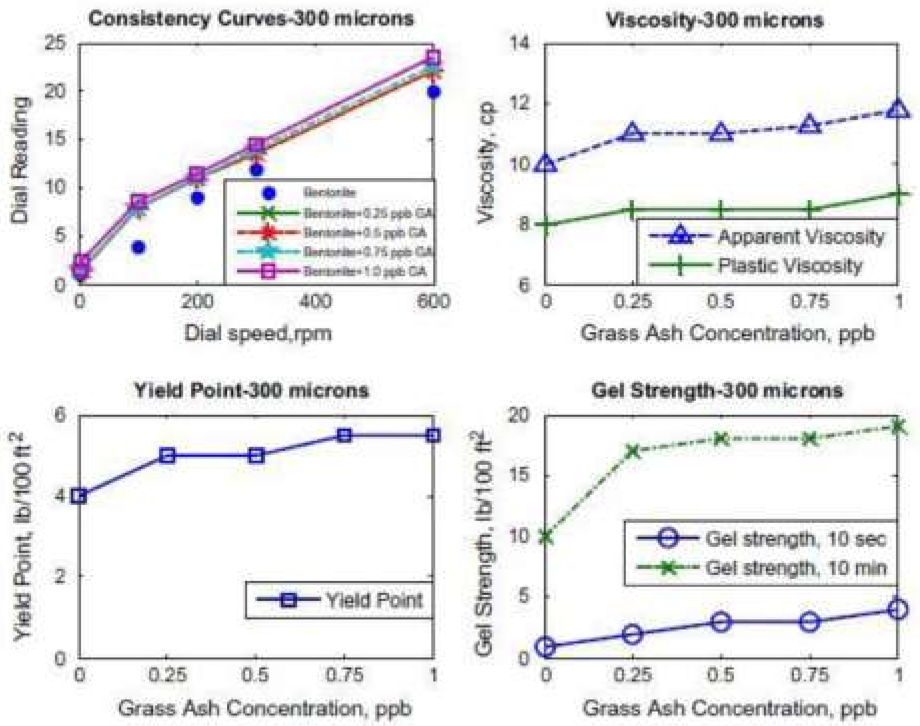


Fig. 37. Rheological parameters for muds formulated with grass ash

Conclusion

1. Bio-products such as date seeds, grass, mango starch, potato peel, sunflower seed, wheat husk, olive pulp, soya bean, sugarcane, coconut shell, eucalyptus bark, etc. work as a good rheology modifier for drilling muds.
2. Bio-products like potato peel, cottonseed, mandarin leaf, palm leaf, rice husk, and avocado pear pulp sow incredible fluid loss-controlling agents.
3. Banana ash, plantain ash, burnt palm head sponge ash, olive peel, wheat husk, etc are favorable for maintaining the pH level in the additives.
4. Many seashells can be used as LCM and rheology modifiers and hence attract the researchers also because of their goof range of mud properties and stability under high pressure and temperature.

Thus, there are almost a lot of bio-products available of which proper utilization can provide us an excellent property holing additives which is fruitful by cost, maintenance, and environmental risk. Plus it has higher drilling efficiency with net zero side harms and demands.

8.3.2 New Environmental-Friendly Synthetic Fluid for Preparing Synthetic-Based Drilling Fluid

1. Use of synthetic-based fluid with NSF can favours not to have swelling damage to the reservoir, and saves the cost of drilling fluid. The sulphur and aromatic content in it is less than 0.5mg/l so it's proven to be environment friendly.

2. Laboratory verification supports the NSF with its efficient properties compared to other synthetic fluids. Some major features of NSF are;
    1. High permeability recovery value(95.2), and
    2. Excellent suspension property

3. This new synthetic-based drilling fluid is not only environmentally friendly but also its performance is superior and economic because it can improve the rate of penetration without inducing borehole problems.

8.3.4 Techniques that use less drilling fluid:

- From all aspects, oil-based mud performs better than water-based mud.
- Managed Pressure Drilling is one of the most effective method which prevents fluid loss to the formation resulting less fluid to use.
- 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.
- Air drilling (Pneumatic drilling) may be favours over drilling using water-base or oil-base fluids when the underlying formations are hard and dry or in shallow locations where the use of fluids to maintain subsurface pressures is not required

CHAPTER 9

Conclusion

1. Regarding energy consumption worldwide, oil, coal, and natural gas will remain the primary energy sources for the upcoming decades.

2. From selection, choosing additives not enriching the nature of the formation, drilling mud will be used, to the improper handling of spent drilling fluids and drill cuttings raise enormous pollution and damage to both marine and terrestrial ecosystems on a big scale.

3. Petroleum products directly or indirectly are being used for making almost every product we are using in our everyday life. Without oil, we can’t imagine the luxuries we are experiencing today.

4. Despite such approaches, environmental concerns voices are against oil and gas producing companies because of the high and severe level of pollution they cause.

5. Drilling waste management Amendment, Acts, and Regulatory Compliances have been made throughout the world to minimize the environmental footprints made by it:

    a. Environmental Protection Agency (EPA)
    b. Oil Pollution Act (OPA)
    c. Clean Water Act (CWA)
    d. Oslo-Paris Convention (OSPAR)
    e. EU Offshore Safety Directive

6. Various hydrocarbons and chemical additives used to prepare drilling muds are the major factors to be analyzed conditionally to prepare a less effective for the environment but suitable for drilling functionality.

7. A significant improvement in the gel strength was obtained by adding bentonite to the commercial calcium carbonate drilling fluid formulation.

8. A high Yield Point implies a non-Newtonian fluid, one that carries cuttings better than a fluid of similar density but a lower Yield Point.

9. The viscous nature of the drilling fluid should align with the size of the cuttings for better transport and efficiency. But it also should be accounted that viscosity should not be very high to avoid high energy consumption.

10. Bioremediation treatment for drill cuttings along with the thermal treatment is the best-suited remedy concerning environmental and economic friendly, and hence drilling waste can be utilized.

11. Road Spreading and construction material as of the drilling cuttings are the widely impactful mitigating measures to reuse drill cuttings into sustainable acts.

12. After treatment of oil-based drilling cuttings through X-ray diffraction and scanning electron microscopy examination, oil contents noticeably diminished which resulted in a reduction of hazardous impact on the environment and can be considered as non-hazardous wastes. These methods not only extract hydrocarbon content but also other hazardous components.

13. Selection of nano-based drilling fluids helps:

    a. Reducing torque and drag problems and increasing the rate of penetration hence reducing the drilling time.

    b. Remove toxic gases

    c. Increasing drilling fluid stability in the HPHT environment

14. Bio-products such as date seeds, grass, mango starch, potato peel, sunflower seed, fenugreek leaves, mandarin leaves, palm tree leaves, plantain peel, wheat husk, olive pulp, corn cob,

pomegranate peel, peach pulp, soya been peel, sugar cane, coconut shell, eucalyptus bark, orange peel, etc. work as a good rheology modifier for drilling fluids.

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