

## OFFSHORE DRILLING WASTES DISPOSAL TECHNIQUES AND REDUCTION OF ECOLOGICAL IMPACT IN DRILLING OPERATION

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### ABSTRACT

*This paper explored offshore drilling waste disposal techniques and reduction of ecological impact in drilling operation. Offshore drilling industry has been working to reduce its environmental impact by implementing innovative waste reduction technology and best practices. The techniques explored here include zero policy, Seabed injection and Bioremediation techniques as well as innovative techniques such as Robotic and Automation, Advanced treatment and Biodegradable techniques. The intent of this paper therefore was to assess these various offshore drilling waste disposals techniques and advice on the best practice that is cost effective as well as the one that reduces impact most on the ecosystem. The questions that comes to mind are why is it important to dispose offshore drilling waste adequately, what positive impact has proper waste disposal, how is proper waste offshore disposal carried out and incorporation of 3R to offshore disposal technique. The study scope is majorly analyzing Zero discharge policy, Subsea injection and Bioremediation techniques by evaluating their strength and weaknesses to the objective of ensuring no effect on the ecosystem as well as cost effectiveness. In conclusion, synergizing with literature reviews such as Norwegian oil company Equinor implemented zero policy Technique and achieved a 99.9% reduction in offshore waste disposal and Nigeria enforcement and monitoring forcing most offshore companies to comply to Zero policy technique by Nigerian Marine time administration and Safety agency (NIMASA) made zero policy techniques as best in control of offshore waste disposal. It was then recommended that Offshore Drilling waste disposal should be prohibited or regulated without compromise. All environmental agencies should ensure that new developed techniques on offshore drilling waste disposal embarked by organizations meet regulatory requirements, adhered to and strictly enforced. The three-tiered waste management hierarchy, wastes minimization, waste treatment and waste disposal should be followed by all the operatives to control and manage drilling waste in the most eco-friendly manner possible.*

**Keywords: Drilling, Ecological Impact, Offshore, Techniques and Wastes Disposal,**

### INTRODUCTION

The offshore drilling industry has been working to reduce its environmental impact by implementing innovative waste reduction technology and best practices. Environmental Impact of Offshore Drilling Waste is quite disastrous to the ecosystem; the aquatic life is very much affected as well as the human health. Offshore drilling waste can cause significant harm to marine ecosystems, with long-lasting impacts. Drilling fluids and cuttings, for example, can smother benthic habitats, reducing biodiversity and affecting fish and invertebrate populations. Produced waste water can also be toxic to marine life, as it often contains chemicals used in the drilling process. According to the International Association of Oil & Gas Producers, offshore drilling waste accounts for around 5% of the total waste generated by the oil and gas industry globally. This figure highlights the need for continued efforts to reduce the environmental impact of offshore drilling waste. Current Waste Reduction Techniques has been embarked on by offshore drilling industry as significant strides in reducing its environmental impact through the implementation of waste reduction technologies and techniques. Several case studies demonstrate the effectiveness of waste reduction techniques in offshore drilling. Equinor's zero discharge policy is one of the most successful examples, achieving a 99.9% reduction in waste. Another case study is the Gulf of Mexico Research Initiative funded project, which developed an environmentally friendly drilling mud made from agricultural waste. A

Survey of offshore oilfield drilling wastes and disposal techniques to reduce the ecological impact of sea dumping; stating that most of major ingredients of drilling fluids have a low toxicity to marine organisms. Only chrome and ferrochrome linosulphates and sodium hydroxide are slightly toxic. Also that few special chemicals sometimes added to drilling fluids to solve certain problems are toxic. They include diesel fuel, chromate salts, surfactants and paraformaldehyde biocide. This innovation has the potential to reduce waste and improve drilling efficiency. Despite the challenges and limitations, the oil and gas industry is constantly developing and innovating new waste reduction technologies and techniques.

Offshore drilling is the process of boring holes in the ocean floor to extract gas and oil. When companies locate a potential site, they start by installing high-tech drilling equipment and machines to drill wells on the ocean bed. Three primary drilling phases enable companies to extract natural gas and oil from the ocean floor. Renegade Wire line Services contributes crucial support during offshore drilling operations by providing specialized wire line solutions that enhance efficiency, safety, and precision in down hole operations, ensuring optimal extraction of this valuable resources. They account for 50 percent of energy needs worldwide. They help burn electrical current, power transportation by air, land, and sea, and manufacture plastic, road oil, synthetic materials, asphalt, and chemicals. Gas comes in liquid and solid forms and lies at the bottom of some of the world's oceans. Offshore exploration is the driving force to tap into these resources. It is a mechanical process where a wellbore is drilled below the seabed which is typically carried out in order to explore for and subsequently extract petroleum that lies in rock formations beneath the seabed. The term offshore is used to describe drilling activities on the continental shelf, but can also be applied to drilling in lakes, inshore waters and inland seas. It presents environmental challenges, both offshore and onshore from the produced hydrocarbons and the materials used during the drilling operation. There are many different types of facilities from which offshore drilling operations take place. These include bottom founded drilling rigs (jackup barges and swamp barges), combined drilling and production facilities either bottom founded or floating platforms, and deepwater mobile offshore drilling units (MODU) including semi-submersibles or drill ships. These are capable of operating in water depths up to 3,000 meters. In shallower waters the mobile units are anchored to the seabed; however, in water deeper than 1,500 meters, the semi-submersibles and drill ships are maintained at the required drilling location using dynamic positioning.

Offshore drilling is a vital component of the global energy industry, providing a significant source of oil and gas. However, it also has a significant impact on the environment due to the production of waste. Offshore drilling waste refers to the byproducts generated during oil and gas exploration, including drilling fluids, cuttings, and produced condensate water. These wastes can have detrimental effects on marine ecosystems, including damage to coral reefs, fish populations, and other marine life thus destroying the ecosystem. Offshore oil production involves environmental risks, most notably oil spills from oil tankers or pipelines transporting oil from the platform to onshore facilities, and from leaks and accidents on the platform. Produced water is also generated on the surface along with the oil and gas; it is usually highly saline and may include dissolved hydrocarbons. Offshore drilling industry has been working to reduce its environmental impact by implementing innovative waste reduction technologies and best practices.

However, many of the environmental problems arising from the oil and gas industries and their related services have contributed to the degradation of habitats, biodiversity, water quality, air quality, and climate change. Environmental impacts include ambient air quality, marine ecology, and biodiversity such as soil and groundwater contamination. These industries have also brought opportunities for improving the offshore drilling operations to standards of producing countries and enhanced the world's industrial economy by reducing ecological impact. Therefore a balanced approach is necessary between maintaining environmental quality, controlling climate change, sustaining aquatic life of aquatic organisms and hydrocarbon production through adherence to best practices of drilling waste management in offshore drilling operations. The rapid increase of oil and gas industry, exploration, offshore drilling and extraction has increased concerns over environmental

issues, where the challenge to cope with stringent environmental regulations is mounted and pressure from local and international community's is increasing towards the need to reduce the impact on the ecosystems and human lively hood of such activities at all levels. Further oil and gas expansion and developments will depend on investors' ability to develop sustainable, cleaner, more innovative, and efficient equipment, optimized unit operations, and processes that can generate fewer emissions, minimal liquid discharges, and optimum waste generation and control to comply with environmental regulations and standards, as well as meeting the corporate social responsibility principles. Oil and gas industry production and operations necessitate the best practice in control and management of emissions, discharges, and disposal strategies for avoiding, eliminating, or minimizing impacts and related consequences. It is equally crucial to develop an integrated emergency and rescue plan, response, recovery and mitigate contaminant facilities, and maximize reuse of treated condensate industrial water and waste generated or minimize release into the environment and disposal into water ways.

There is no doubt that oil Exploration and Production industry provides an important energy source for the world. However, there is a worldwide concern about the environmental impacts of the drilling fluids disposal activity and more disastrous on offshore as it imposes danger to the aquatic life of the ecosystem. Spent drilling fluid is one of the drilling wastes generated by the oil and gas industry's activities that compose of drilling fluid and drilling cuttings together form the second-largest volume of residues generated by the Exploration and production industry. Drilling fluids are responsible for many important functions in the well drilling process such as cooling the drilling bits, maintain temperature and pressures thereby strengthen the viscosity and reduce blow out. They are re-circulated between the well and the platform several times during the drilling of an oil well. When the drilling fluid reaches the reservoir phase, spent drilling fluid return to the surface contaminated with oil and drill cuttings. The resulting residue has several compounds containing potential pollutants, which if incorrectly disposed off can pose several risks to terrestrial, aquatic, and aerial environments, including reducing soil fertility, affecting negatively the flora and fauna and causing climate change leading to human health problems due to the volatilization of hazardous oil components such as benzene, toluene, ethylbenzene and xylene organic compounds into the atmosphere. In this sense, regulators have established that the disposal of non-water based and water-based drilling fluid containing free oil as well as free fatty acid is not allowed above 1% in volume. Therefore, the treatment of oily residues generated in Exploration and drilling activities is an essential task to manage adequately to mitigate the hazard to zero minimum.

Studies around the world presented a variety of physical, chemical, and biological methods to treat drilling waste: bioremediation, thermal, physicochemical, supercritical fluid, electrokinetic and stabilization/solidification treatment. All these methods showed promising results while presenting a series of advantages and limitations. It is also important to note that most treatment methods can recover and/or recycle oil, the main contaminant of the wastes generated. In choosing the best method, some relevant factors need to be considered, such as the drilling waste's characteristics and the costs to implement the process on a large scale. It was observed that only bioremediation and stabilization/solidification proved to be easy to apply on a large scale. However, the bioremediation treatment process is of long duration, and high biodegradation efficiency is difficult to be achieved in uncontrolled environments. In the stabilization/solidification treatment, in turn, encapsulating all contaminants from the waste is difficult. Therefore, the development of new physicochemical methods for the large-scale treatment of drilling waste have been proposed, as the physicochemical treatment presented the highest treatment efficiency when compared with other methods, while also enabling the recovery and reuse of all separated phase.

#### **Statement of the Problem:**

This thesis addresses the offshore oil and gas facility development with emphasis on the central processing platform components, impact of drilling offshore techniques, exploration and production

to reduce drilling waste on the environment and off shores of water. Moreover, it identifies key related regulations and legislation and highlights safety and risk management approaches, relevant sustainability impact identification and definitions, impact mitigation mechanisms, and monitoring requirements. In this thesis, we will explore the latest developments in offshore drilling techniques waste reduction, successful case studies, and mention future innovations. The intent of this thesis therefore is to assess the various offshore drilling waste disposals techniques and advice on the best practiced that is cost effective as well as the one that reduces impact most on the ecosystem. Research shows that offshore drilling companies invest billions of dollars in labor and equipment each year to mine for these valuable fuels by utilizing several conventional and unconventional resources to help extract the oils. At the same time, they also try to protect the marine environment from pollution and other hazards.

### **Aim and Objectives of the study**

This work is aimed at exploring and evaluating the offshore drilling wastes disposal techniques and reduction of ecological impact in drilling operation. Specifically, the study tends to:

1. identify the importance of disposing offshore drilling waste properly.
2. assess the positive impact proper offshore disposal has on the ecosystem.
3. know how offshore drilling waste is been disposed of properly.
4. assess the importance of 3R in mitigating offshore drilling waste disposal

### **Research Questions**

The following research question guided the study:

1. Why is it important to dispose offshore drilling waste properly?
2. What positive impact has proper offshore drilling waste disposal on the ecosystem
3. How offshore drilling waste dispose properly carried out.
4. How do 3R incorporated into offshore drilling waste disposal.

### **Review of related literature**

This study is anchored on by Technological Determinism Theory. These theories are discussed below: **Diffusion of Innovations Theory** (DIT) explains the process by which innovations are adopted by users.

### **Technological Determinism Theory**

Technological determinism theory was developed in 2001 by an American sociologist and economist named Thorstein Veblen. This theory assumes that a society's technology determines the development of its social structure and cultural values. The technological determinism theory argues that the emergency of technology and technological changes are the critical factors responsible for the changes in society. This theory explains how the emergence of technology has impacted on human thoughts and actions. It has changed the way people do things including the way we communicate with one another and see our environment. Technological determinism theory tends to explain how the introduction of technology and the changes comes alongside with it (technological innovation) has influenced the way people perform a given task as well as the way they communicate with each other in an organizational setting. The theory shows that technological emergency drives environmental factor such as social, economic, political, ecological and organizational change (Green, 2001). The theory sees technology as the basis for modernizing the way human beings perform a given task and relate with others within an organization.

The basic idea behind the technology determinism theory is that technology changes determine social change i.e. the way people see things as well as the way they communicate with each other in a polluted environment. It is believed that social progress with respect to the way we communicate is driven by technological development (Croteau & Hoynes, 2003).

Technological determinism theory argues that technological change in inevitable and as such society needs to keep up with the changes in technology to improve their environmental pattern and solve

other social problems (Adler, 2006). The theory questions the degree to which human thoughts and actions are influenced by technology. It tries to explain the degree to which technology has influenced human affairs to the extent that it has been applied in our communication pattern. As technology is introduced, its application tends to dictate users' behaviour. However, once a technology is introduced into an organization's culture, what follows next is the continuous improvement of that technology. As technology is continuously improved, society embraces the new development and applies them to solve social problems including those related to environment (Adler, 2006).

Commenting on technological determinism theory, Karl Marx, the distinguished economist, remarked that technological advancement has led to a new ways of production in a society and this has greatly influenced the political, social, economic, ecological and cultural aspects of a society, thereby changing society itself. Karl Marx buttress his point with an example of how a feudal society that makes use of hand mill in production gradually turned into a technological driven society with the introduction of stream mill. In support of Karl Marx point of view, Dafoe (2015) noted that technology is a great influencer of society behaviour and action. According to him, technology has changed the way we do things including the various choices we make as well as our methods of cleaning our environment.

The technological determinism theory is on the right path when it proposes that technology has a great influence on society. According to the theory, a changed society can be traceable to a changed technology. History has shown numerous examples of how technology determines the way we live, think and act.

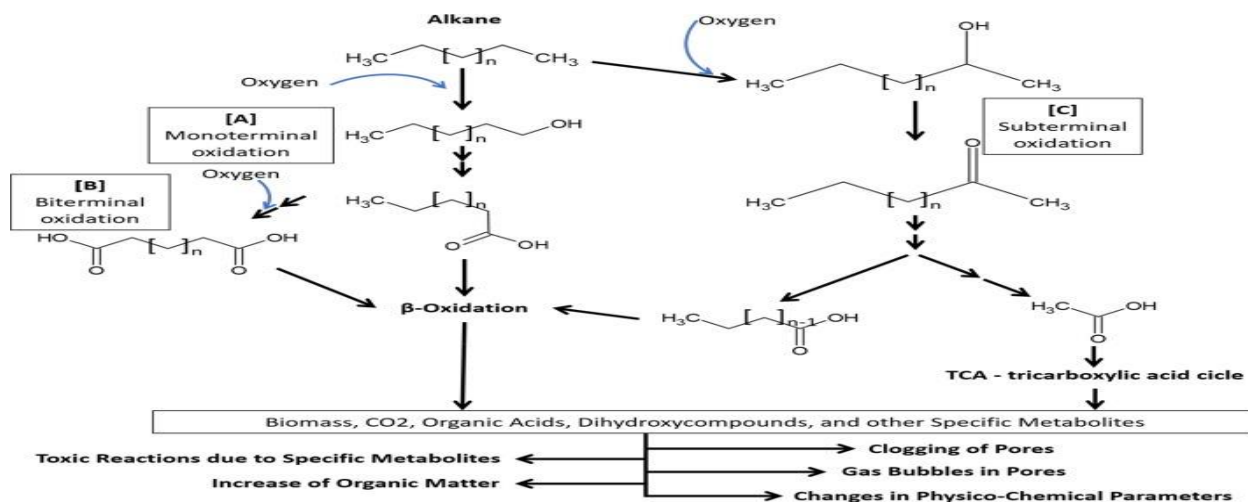
### **Conceptual Review**

**Positive impact of Seabed injection Technique of offshore drilling waste disposal on ecosystem:** The main implication of seabed injection technique on offshore drilling waste disposal includes:

- Environmental protection – from pollution or contamination.
- Money generation – companies may buy recyclable materials due to their value. Additionally, the waste management industry creates employment opportunities.
- Safety – irresponsibly disposed of waste can harm people.
- Exploring alternatives – where innovative solutions to waste disposal have been found, great strides have been made i.e. composting.
- Business philosophy – as consumers become more environmentally conscious, it is important for businesses to promote their 'green' strategies and environmental promise.

### **Bioremediation**

Bioremediation is used to treat several types of wastes, including drilling fluids. This treatment method consists of an organic matter biodegradation process that converts the organic matter present in the waste into humus and other components into CO<sub>2</sub> and H<sub>2</sub>O, illustration below shows the aerobic degradation of n-alkane (an aliphatic chain hydrocarbon)



It was possible to observe that the degradation reactions are typically reduction, oxidation, hydroxylation, and dehydrogenation. These reactions require an energy stimulus, which is generally provided by enzymes, for example, NADH (Nicotinamide-Adenine-Dinucleotide) and monooxygenase. The biodegradation process can occur through aerobic and/or anaerobic pathways, i.e. with or without oxygen, respectively.

Considering that oil is one of the main contaminants of drilling fluid wastes, there are some types of microorganisms efficient at degrading hydrocarbons. Iman et al. (2019) reported about 25 hydrocarbon-degrading microorganisms, and most of them shown an efficiency above 80% in hydrocarbon biodegradation

The main advantages of using bioremediation to treat oily residues are its low cost and ability to biodegrade large volumes of waste. However, improving biodegradation rates in-situ is a challenge, because there are several factors to be controlled, such as temperature, salinity, pH, nutrients and oxygen levels. However, there are some strategies to improve it. The most common are biostimulation and bioaugmentation, which consist of nutrient enrichment and the addition of microorganisms, respectively.

Several researchers are studying this method to treat drilling fluid wastes. Li et al. (2011) studied the bioremediation of oily drilling fluid waste using biochemical treatment. The authors obtained satisfactory results, achieving more than 98% of hydrocarbon degradability using three strains pre-selected for their oil-degrading ability.

Fan et al. (2012) compared the bioremediation of drilling fluid waste with and without biostimulation and bioaugmentation. They proved experimentally that the enrichment with nutrients improved hydrocarbon degradation.

Agwu et al. (2013) isolated four hydrocarbon-degrading microorganisms from diesel oil-polluted soils, which were identified as *Pseudomonas luteola*, *Pseudomonas alcaligenes*, *Pseudomonas aeruginosa* and *Actinomyces*. The authors reached hydrocarbon-degrading levels above 92% in the oil-based drilling fluid.

Adekunle et al. (2013) evaluated the efficacy of a nanotechnology based bioremediation technique (CNB-Tech) in the biodegradation of hydrocarbons in oil-based drilling wastes generated by an oil company in Nigeria. Their results showed that the Total Petroleum Hydrocarbon (TPH) level which initially was  $79,200 \text{ mg}\cdot\text{kg}^{-1}$  decreased after the application of CNB-Tech products to  $1,888.87 \pm 161.20 \text{ mg}\cdot\text{kg}^{-1}$  in a short period of six days. Furthermore, they achieved a reduction in heavy metals of 46% for As, 70% for Pu and 100% for Hg. The authors also presented alternatives for using the remediation end-product, such as material for road and building construction.

Lirong et al. (2015) performed tests with soil microorganisms associated with the treatment of drilling fluid wastes. They did experiments in the Danqian 001–8 and Lianhua 000-X8 wells, increasing the rate of bacteria per soil area unit to obtain greater efficiency in microbial degradation.

They also assessed the viability of plant growth in the treatment site. After three months of treatment, the authors found that it was possible to achieve a degradation rate of more than 90%, based on the chemical demand indicators for oxygen and oil. They also observed that the levels of heavy metals were within the limits established by the National Environmental Quality Standard for Soil and that there was no harmful transfer of heavy metals to plants.

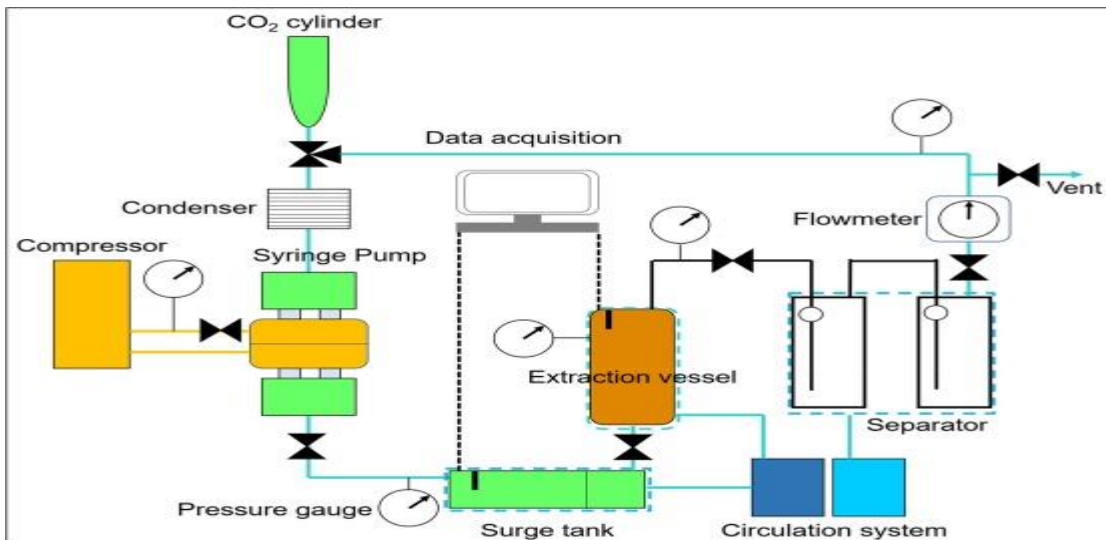
It was possible to observe from the studies presented above that bioremediation is an efficient method for the treatment of drilling wastes, turning a residue potentially dangerous to the environment into harmless compounds, besides being a cost-effective method. High oil-degradation rates are an important advantage presented in the studies. The researchers pointed out the importance of controlling the conditions to ensure a high degradation efficiency, mainly the type of microorganism, the type of substrate and equally important, these microorganisms' tolerance to hydrocarbons. According to Kostenko et al. (2013), microorganisms' tolerance to hydrocarbon is poorly studied, despite its importance to achieve high oil-degradation efficiency in complex emulsions like drilling fluids. The degradation time is also important in this treatment method. Adekunle et al. (2013) achieved the mark of six days, but it is common to find studies showing longer degradation times, mainly in uncontrolled environments, i.e. bioremediation in situ, as in the study by Lirong et al. (2015)'s.

Tang et al. (2017) adopted physicochemical methods to treat oil-based drilling fluid waste from a well in the JiDong oilfield, China. The authors made experimental tests with demulsifiers, mechanical mixing and gravitational sedimentation to promote oil-water-solid separation. After separation, the oil recovery rate reached 90% and an analysis of its properties indicated that it could be recycled to prepare new drilling fluid. The researchers also treated the wastewater (flocculation oxidation method) and solids (solidification method) to meet the requirements of "The National Integrated Wastewater Discharge Standard."

Another important point about physicochemical treatment is the possibility to recover and recycle each separated phase, thus drastically reducing the environmental impacts associated with drilling wastes with no generation of by-products. Tang et al. (2017) promoted oil, water and solid separation from oil-based drilling wastes using the physicochemical method. They then proposed oil reuse in new drilling fluid formulations. They also treated the wastewater using the flocculation oxidation method and solids using the chemical solidification method to meet the requirements of local legislation.

Supercritical fluids are defined as a solvent in the liquid or gas state that is submitted to critical pressures and temperatures when characteristics of both phases can coexist. Among the several types of supercritical fluids, carbon dioxide (CO<sub>2</sub>) is one of the most used in supercritical fluid technologies, accounting for more than 90% of published studies on the topic, due to its non-toxic, non-flammable and non-explosive properties, even in critical conditions, which are relatively low (74 bar and 305 K). Moreover, CO<sub>2</sub> has a linear and small-sized structure that increases its permeability.

Case study below shows a scheme of the SC-CO<sub>2</sub> extraction process laboratory apparatus. This scheme shows the laboratory apparatus to extract hydrocarbons from oil-based drilling mud waste used by Ma et al. (2019) The sample is placed in the extraction vessel and mixed with SC-CO<sub>2</sub> under constant pressure and controlled temperature. After that, the extracted fluid flows out to the extraction vessel together with SC-CO<sub>2</sub>. The flow rate in the dynamic phase is controlled until the mixture flows to the first vial, when the system is depressurized and the CO<sub>2</sub> becomes gaseous. The extracted fluid then precipitates in the first vial and the CO<sub>2</sub> is collected in the second vial.



Goodarznia & Esmailzadeh (2006) used SC-CO<sub>2</sub> to extract oil from drilling cuttings. The experiment was carried out at a pressure range of 160 to 220 bar and a temperature range of 328 to 353 K. The authors used a flow-type apparatus to extract the oil, the extraction process lasted about 2 h and the solvent flow rate used ranged from 34.44 to 110.56 cm<sup>3</sup>/s<sup>-1</sup>. The results showed that it was possible to extract 49.1% of oil from drilling cuttings at 200 bar, 353 K and a SC-CO<sub>2</sub> flow rate of 56.02 cm<sup>3</sup>/s<sup>-1</sup>. Considering their results, the authors concluded that increasing temperature and pressure improve extraction efficiency. On the other hand, increasing the SC-CO<sub>2</sub> flow rate has the opposite effect.

Street et al. (2009) used SC-CO<sub>2</sub> to treat synthetic-based drilling waste. They optimized the process of changing pressure and temperature levels to improve oil extraction from the waste. First, a known mass of drilling waste was placed in the stainless steel extraction vessel. During the static phase, drilling waste was mixed with SC-CO<sub>2</sub> for 15 min. Next, hydrocarbons were extracted and SC-CO<sub>2</sub> flowed out to the vessel for 90 min with pressure and controlled flow rate (maintained between 0.5 and 0.67 cm<sup>3</sup>/s<sup>-1</sup>). Finally, the mixture was depressurized and SC-CO<sub>2</sub> turned into gas, causing the SC-CO<sub>2</sub> solubility with hydrocarbons to decrease, leading to phase separation. The results presented by the authors were promising, with 97% of the oil extracted in optimized conditions of pressure and temperature (145 bar and 313.2 K). The results also suggested the use of the recovered oil in the drilling process.

Khanpour et al. (2014) also investigated the SC-CO<sub>2</sub> potential for extracting contaminants from drilling mud waste by varying pressure (100–200 bar), temperature (313–338 K), SC-CO<sub>2</sub> flow rate (0.05–0.36 cm<sup>3</sup>/s<sup>-1</sup>) and static time (20–130 min). A scanning electron microscopy was used and an X-ray diffraction analysis was performed to verify the viability of using carbon dioxide to remove contaminants. From the results obtained, the authors observed that a static time of 110 min, SC-CO<sub>2</sub> flow rate of 0.1 cm<sup>3</sup>/s<sup>-1</sup>, pressure and extraction temperature of 180 bar and 333 K, respectively, are ideal conditions for removing contaminants from drilling mud waste.

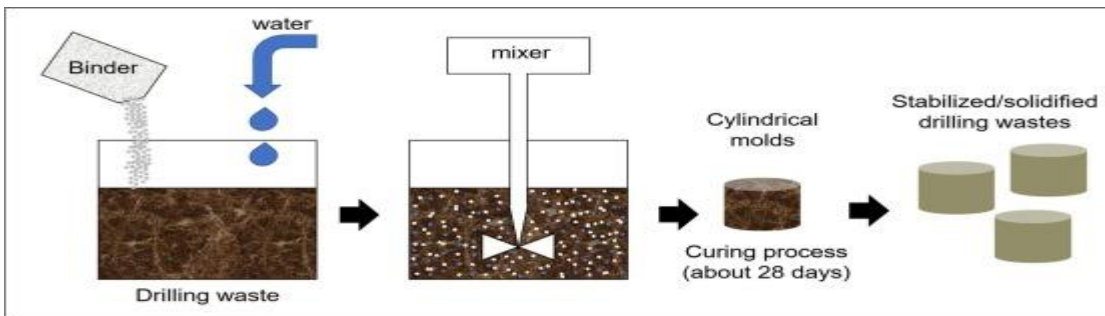
Ma et al. (2019) studied the SC-CO<sub>2</sub> efficiency in extracting oil from oil-based mud waste with an oil content of around 25 wt% under different parameters. The experiment time was evaluated, with results showing that from 10 to 60 min the extraction efficiency increases dramatically, and between 60 and 240 min the increase was not relevant. They also evaluated the impact of pressure variation in extraction efficiency. They observed that with increasing pressure, the extraction efficiency also increases, but only up to 220 bar. Above that pressure the extraction efficiency decreases. The same behavior was observed with temperature increase. Initially, the extraction efficiency increased considerably until 308 K was reached. The authors thus concluded that 60 min, 200 bar and 308 K were the best parameters to ensure the most efficient extraction of oil from oil-based drilling mud wastes, which reached 98.6 wt%.

As seen above, the researchers showed that the treatment of drilling wastes using SC-CO<sub>2</sub> is a promising alternative. It is worth emphasizing that the pressure, temperature and flow rate parameters are extremely important to determine the extraction efficiency. In the experiment by Goodarznia&Esmailzadeh (2006) , for example, the flow rate used was higher than in other studies, which could explain why they achieved only 49.1 wt% of extraction efficiency. With regard to pressure, 145 bar was the lowest pressure that achieved satisfactory results in terms of extraction efficiency, and 200 bar was the highest. The ideal temperature ranged between 308 and 333 K. SC-CO<sub>2</sub> thus proved to be an excellent method for treating drilling wastes due to its high oil extraction efficiency, highlighting the possibility of oil recovery. Moreover, SC-CO<sub>2</sub> is considered a clean technology, as it does not use toxic solvents nor generates by-products. Another case study shows a scheme of an experimental electro kinetic cell used by Adhami et al. (2021) in the treatment of oil-based drilling fluid waste (OBDF waste). In the conventional electro kinetic method, distilled water was used as an electrolyte in the anode and cathode reservoirs, and the electrodes were made of acid-resistant graphite.



As said before, Adhami et al. (2021) used the electrokinetic process to treat oil-based drilling wastes. Furthermore, they enhanced the electrokinetic method by using the Fenton technique (EK-Fenton) to remove total petroleum hydrocarbons (TPH) from oil-based drilling waste. The authors made three experiments to select the best method to remove TPH from the waste. The experiments differed in the process, oxidant and electrode used. The first experiment used the conventional electro kinetic method, with water (H<sub>2</sub>O) as the oxidant and graphite as the electrode. The second was used EK-Fenton, Hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) and Iron. And the last one also used EK-Fenton and H<sub>2</sub>O<sub>2</sub>, but used copper as the electrode instead. The experiment lasted 7 days and used 18 V of electric potential difference. The authors reported that the best results were achieved with EK-Fenton using copper as the electrode, which achieved 77% of TPH removal. Finally, they concluded that the combination of the electrokinetic method with the Fenton technique and the use of copper electrodes are suitable to remove TPH from oil-based drilling wastes efficiently. Moreover, according to the authors, the process is an environmentally friendly method that does not generate byproducts.

Again a schematic stabilization/solidification process is as shown below. The experimental procedure of Al-Ansary and Al-Tabbaa (2007) was used to illustrate the process.



Al-Ansary and Al-Tabbaa (2007) treated synthetic-based drilling cuttings using stabilization/solidification. The drilling cutting samples used in the experiments contained 4.20 and 10.95% of hydrocarbons. The authors tested different types and quantities of binders. Drilling cuttings, basic soil constituents of drilling cuttings (paraffin oil, sodium chloride and sodium hydroxide) and binders were mixed and placed in cylindrical molds. Next, the mixture was left to cure for 28 days at  $21 \pm 2$  °C. The results presented showed that the stabilization or solidification technique was able to immobilize about 99% of the oil content of drilling cuttings. In addition, the authors concluded that the stabilization/solidification treatment could turn drilling cutting wastes into a stable non-reactive waste, while also reducing their chloride content to levels in accordance with the local legislation.

## METHODOLOGY

The research adopts an inter preventivist philosophy and abductive logic (inductive and deductive approach) of strength and weakness method and a case study approach to examine the valuation and verisimilitude between production and safety practice when faced with the challenge of offshore drilling waste disposal. The research method is abductive and descriptive reasoning - by fact finding and reporting what is happening in production in correlation to impact on the environment ecosystem with comparison of best practiced for future research.

It is an empiricism theory through inductive method that is more of comparing and evaluating the various techniques of offshore waste disposal that is cost effective, easy to operate and harmless reducing risk to as low as reasonably practicable.

The study therefore aimed at concentrating on the most successful offshore drilling waste techniques, which are Zero Discharge Policy Technique, Subsea Injection Technique and Bioremediation Technique. They are compared and evaluated on their importance of offshore drilling waste disposal properly; assessing the positive impact of proper offshore disposal technique on the ecosystem; how the offshore drilling waste disposal technique is been operated adequately to mitigate the impact and assess the importance of Reduce, Recycle and Reuse (3Rs) in mitigating the hazard to ecosystem.

## DISCUSSIONS

### **Incorporation of Recycle, Reuse and Reduce (3R) in zero policy technique in offshore drilling waste disposal:**

This publication provides an overview of the reasons and ways to better manage garbage or other household waste. While "recycle" may be a buzzword for an environmentally friendly way to manage waste, a more comprehensive approach to doing so is summarized by the "Three Rs":



**I. Reduce:** Buy only what you need because a better way to reduce waste is by not creating it.

**II. Reuse:** If you have to acquire goods, try getting used ones or obtaining substitutes.

**III. Recycle:** When discarding your waste, find ways to recycle it instead of letting it go to landfill.

**The "Three Rs" (Reduce, Reuse, and Recycle)** effort to promote better waste management needs to be done in an effective manner. If converting an old pair of jeans into a shopping bag that needs continuous repair, you are better off donating the jeans in the first place and purchasing reusable shopping bags. Some efforts may involve a steep learning curve and require time to get used to. Sorting out recyclable items may be challenging in the beginning, but once you get the hang of the system the related chores will become like effortless habits. The oil and gas industry in Nigeria has always tried to meet the challenges of providing environmental protection. Admittedly, the exploitation of oil and gas reserves has not been without some ecological side effects including oil spills, and air and water pollution. Drilling fluids and drill cuttings are the largest waste streams generated in global drilling operations. Regulations ensure minimal damage is done to the environment and protect marine life offshore.

These protections are not limited to Nigeria; most oil and gas countries have similar legislation and regulations to protect the environment. There are also regional legislations like OSPAR, Helsinki, Barcelona and Kuwait, and international groups such as the International Finance Corporation and the World Bank Group also has the Environmental, Health & Safety Guidelines for Offshore Oil & Gas Development. All these are efforts aimed at protecting the environment along with workers health and safety.

#### **Zero Discharge Policy Technique:**

**Strength:** This policy involves treating and reusing all drilling fluids and cuttings, resulting in a significant reduction in waste. Norwegian Oil Company Equinor has implemented this policy and achieved a 99.9% reduction in waste. In US Gulf of Mexico waters, the Environmental Protection Agency (USEPA) discharge limit is 6.9% OOC for synthetic-based drilling fluid. Zero discharge is the restriction for operations less than 3 miles from shore. For Mexico, ASEA & AMEXHI are the regulatory agencies. The Mexico discharge limit in deep water was zero discharge; however, they have recently adopted some part of USEPA regulation allowing 6.9% OOC discharge limit on case-by-case basis. A seabed study is a requirement for the 6.9% OOC limitation. In the Caribbean, Trinidad & Tobago – the discharge regulation is 5% OOC. Brazil has the IBAMA regulation which ranges from zero discharge to 5.9% OOC depending on the field. The Department of Petroleum Resources (DPR) is the regulator of the oil and gas industry in Nigeria. The Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN) outlines environmental and safety standards that must be comply with by oil operators. Since 1991, the EGASPIN has been updated and revised to be at par with 6.9% OOC. For Thailand & Malaysia, the discharge limit is 5% OOC. With the zero discharge techniques most offshore drilling operators industry in the world has made lots of progress with the development of new drilling fluid systems that are more environmentally

friendly. Use of diesel-based mud has been stopped offshore and greatly reduced onshore. The industry has continued to engage with regulators and industry stakeholders to create awareness on best practices and develop and implement new technology to move the industry in the direction of greater safety and protection of the environment.

**Weakness:** Pressure from government growing environmental regulations and constraints put pressure on drilling operations thereby slow down operation activities by way of monitoring and paying of penalties for defaults.

### **Subsea injection Technique**

This technique involves injecting produced water and other wastes directly into the seabed, where they are naturally biodegraded. This technique has been shown to be effective in reducing the environmental impact of produced water.

**Strength:** For a safe operation re-injection operations from mobile offshore drilling units are reviewed first in paper. Lessons learned from that and other system design and operational experience including detailed study and careful engineering as well as adequate communication to handle emergency, adequate quality control in place and good slurry injection procedures. But challenges and best practice guidelines for waste injection operations from subsea well heads are given minimize failure and maximize success. It is environmentally preferred when rock formations allow it.

**Weakness:** The primary disadvantage of this option is the possibility of freshwater contamination due to casing failure. Often, offshore waste re-injection technique may re-inject the waste or send it to onshore for treatment. Onshore treatment and logistics are expensive and involve a large emission of carbon dioxide into the environment. It is also difficult to have reliable logistics to bring offshore drilling waste to onshore. Although, offshore drilling waste re-injection operations have been conducted in an environmentally acceptable manner, system design and operational experience are limited. Also offshore re-injection of disposal of drilling waste is quite applied since 1980, but the operation is mostly been restricted to fixed platforms; annular re- injection into subsea well, where drilling operations in progress, had not been feasible until early 1993.

### **Bioremediation offshore drilling waste disposal technique**

This technique involves using bacteria to break down drilling waste, including drilling fluids and cuttings. This method has the potential to significantly reduce waste and improve environmental outcomes.

#### **Strength:**

Bioremediation's most significant benefit is its environmental contribution. The bioremediation process allows nature to repair itself with help from experienced people and specialized equipment. Since it's a primarily natural process, it is the least invasive and safest groundwater and soil cleaning method. Bioremediation can remove contaminants such as the following: Fluoride, Pathogens, Arsenic, Nitrate, Metal, Volatile organic compounds, Pollutants such as phosphates and ammonia, Insecticides, Herbicides, Saltwater intrusion. The benefits of bioremediation include the following:

- i. **An eco-friendly solution:** Bioremediation is an entirely natural process with little to no damaging side effects.
- ii. **In situ application:** Most bioremediation applications can occur in situ, eliminating the risk of dangerous transport.
- iii. **Quick turnaround time:** With bioremediation, soil and water can return to being useful faster than with other cleaning methods.
- iv. **Minimal equipment requirement:** The bioremediation process requires minimal equipment.
- v. **Positive reputation:** Since it is a natural process, bioremediation is a publicly acceptable process.

- vi. **Cost-effectiveness:** Implementing the bioremediation process is an economical solution, and its maintenance needs are cost-effective.
- vii. **Decreased liability:** When companies implement bioremediation, contaminants are less likely to escape. This lowers a company's liability.
- viii. **Energy efficiency:** Bioremediation consumes less energy compared to land filling and incineration.

**Weakness:**

Bioremediation offshore drilling waste disposable technique, though has the potential to significantly reduce waste and improve environmental outcomes but it is more expensive to operate in the mode of Procuring equipments, experimenting with micro-organisms, how efficient and effective, adherence to standard procedure, the culturing media as well as equipment monitoring and maintenance.

**Summary:**

Oil and Gas Exploration & Production industry provides an important energy source for the world with great concern on the environmental impacts of their activities. Drilling fluids application is an activity responsible for many important functions in the well drilling process. They are recirculated between the well and the platform several times during the drilling of an oil well. When the drilling reaches the reservoir phase, spent drilling fluid return to the surface contaminated with oil. The resulting residue has several compounds containing potential pollutants, which if incorrectly disposed of can pose several risks to terrestrial, aquatic, and aerial environments, including reducing soil fertility, affecting negatively the flora and fauna and causing health problems due to the volatilization of hazardous oil components such as benzene, toluene, ethylbenzene and xylene into the atmosphere. In this sense, regulators have established that the disposal of non-water based and water-based drilling fluid containing free oil is not allowed above 1% in volume. Therefore, the treatment of oily residues generated in E&P activities is an essential task. Spent drilling fluid is one of the drilling wastes generated by the oil and gas industry's activities. This waste forms the second-largest volume of residues generated by the E&P industry.

Studies around the world presented a variety of physical, chemical, and biological methods to treat drilling waste: zero policy, subsea injection, bioremediation, thermal, physicochemical, supercritical fluid, electrokinetic and stabilization/solidification treatment. All these methods showed promising results while presenting a series of advantages such as stabilization/solidification and easy to apply on a large scale. However, the bioremediation treatment process is of long duration and high biodegradation limitations. It is also important to note that most treatment methods can recover and/or recycle oil, the main contaminant of the wastes generated. In choosing the best method, some relevant factors need to be considered, such as the drilling waste's characteristics and the costs to implement the process on a large scale. It was observed that only bioremediation efficiency is difficult to be achieved in uncontrolled environments. In the stabilization/solidification treatment, in turn, encapsulating all contaminants from the waste is difficult. Therefore, the development of new physicochemical methods for the large-scale treatment of drilling waste have been proposed, as the physicochemical treatment presented the highest treatment efficiency when compared with other methods, while also enabling the recovery and reuse of all separated phases through injection.

Zero policy led to Environmental standards and regulations compliance requirements. It is common that investors in the oil and gas industry, in general, tend to establish a comprehensive and effective management system to protect their commercial interests, maintain the marine ecosystem, and sustain healthy air, soil, and groundwater environment. Community engagement and protection of human health and safety are considered essential to ensure compliance with International Fund Corporation (IFC), World Bank (WB) (World Bank Group, 2007), and State Environmental Regulations. For purposes of national environmental protection in Qatar, for example, the key binding environmental regulations are overseen by the Ministry of Environment and Climate Change

and include: The Environment Protection Law issued via the Decree-Law No. 30 of 2002. Environmental Protection Standard, 2005 (the executive by-laws for Law 30 of 2002). The Environmental Societal Health Impact Assessment (ESHIA) and Risk Management study of projects usually identify the potential aspects and assess those risk management approach.

ESHIA and risk assessment studies, has Contributed to reduction of the serious and irreversible environmental impacts during the different stages of offshore drilling processes. Ensure system reliability and high control of process incidents and personal injury, thereby increasing operation time and minimizing associated cost. Conduction of risk on produced water and effluent discharge limits; Environmental regulations encourage oil and gas production companies to comply with legal effluent discharge requirements and improve the produced water treatment efficiency.

## **CONCLUSION**

Environmental impacts of offshore oil and gas exploration, drilling, production, and operation are the main threats to marine ecosystem; if addressed and the importance of controlling and managing emissions and discharges, and disposal strategies maintained to avoid, eliminate, or minimize impact and consequences emphasized, controlled and adhered stringently to the environmental regulation Agencies by enforcement, monitoring, not compromised and compliance will ensure adequate offshore drilling waste disposal and set the environment and ecosystem free from impacts of contaminants in offshore drilling waste disposal.

## **RECOMMENDATIONS**

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

1. Offshore Drilling waste disposal should be prohibited or regulated without compromise.
2. All environmental agencies should ensure that new developed techniques on offshore drilling waste disposal embarked by organizations meet regulatory requirements, adhered to and strictly enforced.
3. The three-tiered waste management hierarchy, wastes minimization, waste treatment and waste disposal should be followed by all the operatives to control and manage drilling waste in the most eco-friendly manner possible.
4. Operators should prioritize capacity building on offshore drilling waste disposal techniques due to the chronic impact it has on the ecosystem.

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