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A systematic review on composition, effect and remediation methods of petroleum hydrocarbon contaminated waste drilling mud

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ABSTRACT
The worldwide oil and natural gas extraction sector has a significant and dynamic role to play in the world's energy system. The phases of petroleum operations where waste is produced the most are drilling and production. Drilling mud is a condensed liquid that is cycled through the drilling pipe to carry out a range of tasks. Water-based muds (WBMs) are complex mixtures of bentonite and water, while mineral oils, barite, and chemical additives make up oil-based muds (OBMs). How to reduce petroleum wastes and their long-term effects is the current petroleum operating problem. The current management techniques are not integrated with other activities around the development site and are primarily directed at achieving sectoral success. The review article aims to focus on the use of water based mud for petroleum drilling as well as remediation methods for waste drilling muds. If improperly disposed of, waste drilling mud can pose threats to terrestrial, aquatic, and aerial habitats, including decreasing soil fertility, negatively altering flora and fauna, and causing health issues owing to the volatilization of hazardous oil components into the atmosphere. As a result, this review article recommends bioremediation as the best method for degrading hydrocarbons from waste contaminated drilling mud and recovering residual crude oil from waste drilling mud at greater depths. Following treatment, solid waste can be used as an alternative aggregate, building material, or cement production, promoting a valuable and sustainable solution based on the circular economy concept.
Keywords: Petroleum hydrocarbon exploration, Water based mud (WBM), Bentonite, Petroleum hydrocarbon contamination, Remediation, Solid waste.

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INTRODUCTION

Petroleum drilling is the process of drilling a wellbore to extract oil or gas from underground reservoirs. It is a complex and costly operation that involves several stages, including drilling, completion, and production. One critical aspect of petroleum drilling is the use of drilling fluids, or muds, which are essential for successful drilling operations. However, drilling fluids can also generate waste materials that pose significant environmental challenges. In this overview, we will discuss petroleum drilling, drilling fluids, and drilling waste generation, including their impact on the environment and potential solutions. Petroleum drilling involves the use of drilling rigs, which are machines designed to bore into the earth's surface and reach reservoirs containing oil or gas. Drilling rigs come in different sizes and configurations, depending on the depth and location of the reservoir. Once the rig is in place, the drilling process begins, and the drill bit is rotated to create a borehole. The drilling process generates rock cuttings, which are transported to the surface using drilling fluids. Drilling fluids, or muds, are essential components of the drilling process, as they help to maintain wellbore stability, control pressure, and lubricate the drill bit. They also aid in transporting rock cuttings to the surface, where they can be analysed to determine the quality of the reservoir. Drilling fluids are typically composed of a mixture of water, clay, and various chemicals, such as biocides, lubricants, and weighting agents. However, drilling fluids can also generate waste materials that can be harmful to the environment. Drilling waste includes drill cuttings, spent drilling fluids, and other materials generated during the drilling process. The waste materials can contain toxic substances, such as heavy metals, hydrocarbons, and chemicals used in the drilling process. These materials can contaminate soil, water, and air if not handled and disposed of correctly. To address the environmental impact of drilling waste, regulatory agencies have implemented strict regulations for waste management and disposal. The most common methods of drilling for waste disposal include landfills, injection wells, and thermal treatment. Several remediation methods are available for the treatment of petroleum hydrocarbon-contaminated waste drilling fluid, including physical, chemical, and biological methods. Physical methods include excavation, soil washing, and air sparging. Chemical methods include oxidation, reduction, and solvent extraction. Biological methods include bioremediation, phytoremediation, and microbial-enhanced oil recovery. Each remediation method has advantages and disadvantages, and the selection of a remediation method depends on the specific characteristics of the contaminated waste drilling fluid. However, each method has its own advantages and disadvantages, and some methods may not be suitable for certain types of waste. In recent years, there has been an increasing interest in developing new technologies and methods for drilling waste management. For example, some companies are exploring the use of bioremediation, which involves using microorganisms to break down and degrade drilling waste. Other approaches include the use of nanotechnology and electrochemical processes to treat drilling waste more efficiently and effectively. Petroleum hydrocarbon-contaminated waste drilling fluid is a significant environmental problem that has serious effects on soil and groundwater. The discharge of contaminated waste drilling fluid into the environment may cause soil contamination, damage ecosystems, and harm human health. The waste drilling fluid contains a range of hydrocarbons, including aliphatic and aromatic hydrocarbons, which are persistent in the environment and can cause significant environmental damage. The management of drilling waste is a crucial aspect of the oil and gas industry, and the disposal of contaminated drilling waste is a challenging task. The composition of petroleum hydrocarbon-contaminated waste drilling fluid, its effect on the environment, and the remediation methods for contaminated waste drilling fluid have been extensively studied in recent years. Petroleum hydrocarbon-contaminated waste drilling fluid is a significant environmental problem that requires effective management and remediation. This systematic review provides a comprehensive understanding of the composition, impact, and remediation methods available for petroleum hydrocarbon-contaminated waste drilling fluid. The findings of this review can assist in the selection of appropriate remediation methods for specific types of contaminated waste drilling fluid and can contribute to the development of sustainable waste management practises for the oil and gas industry. Future research should focus on the long-term effectiveness of different remediation methods and the potential environmental impacts of these methods.

MATERIAL AND METHODS

Drilling fluid and its composition

Drilling fluid, also known as mud, plays a crucial role in the drilling process. It serves several purposes, such as cooling and lubricating the drill bit, carrying rock cuttings to the surface, and providing support to the borehole wall. The composition of drilling fluid can vary depending on the drilling environment and the specific requirements of the drilling operation. In this review, we will explore the different components of drilling fluid and their effects on the drilling process.

One of the most important components of drilling fluid is the base fluid. Water-based fluids are commonly used in drilling operations due to their low cost and availability. However, other base fluids, such as oil-based fluids and synthetic-based fluids, are also used in certain drilling environments where water-based fluids are not suitable [1]. To improve the properties of the base fluid, various additives are added to the drilling fluid. These additives include weighting agents, viscosifiers, fluid loss control agents, and lubricants. Weighting agents such as barite and hematite are added to increase the density of the drilling fluid, which helps to control formation pressures [2]. Viscosifiers such as bentonite and polymers are added to increase the viscosity of the drilling fluid, which helps to suspend and transport the rock cuttings to the surface [3]. Fluid loss control agents such as starches and cellulose derivatives are added to reduce fluid loss into the formation, which helps to maintain wellbore stability [4]. Lubricants such as fatty acids and esters are added to reduce friction between the drill string and the borehole wall, which helps to prolong the life of the drill bit [5]. The percentages of individual chemical constituents are shown in Figure 1. Another important consideration in the composition of drilling fluid is the pH level. A pH level that is too high or too low can lead to problems such as corrosion, emulsion formation, and clay swelling. To maintain the desired pH level, buffers such as caustic soda and sodium bicarbonate are added to the drilling fluid.

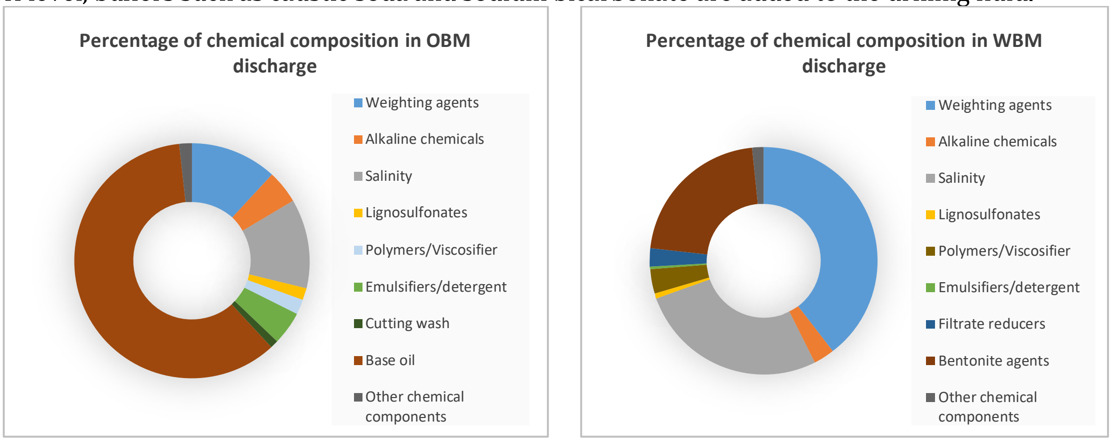

Figure1 Percentage of individual chemical constituents (Hudgins and Charles, 1994) [6].

In addition to the above components, other additives such as biocides and surfactants may be added to the drilling fluid to prevent bacterial growth and improve the stability of the fluid, respectively [7]. Overall, the composition of drilling fluid is a complex mixture of various components that are carefully selected and blended to meet the specific requirements of each drilling operation. The choice of base fluid, additives, and their concentrations depends on factors such as the formation being drilled, the drilling environment, and the drilling objectives.

Petroleum hydrocarbons

Petroleum hydrocarbons are a group of compounds derived from crude oil and natural gas that are widely used as fuels and raw materials in many industrial processes. These hydrocarbons are composed mainly of carbon and hydrogen atoms and can be divided into four major groups as per figure 2: alkanes, alkenes, alkynes, and aromatic compounds. Each group has its own unique physical and chemical properties, which determine its usefulness and environmental impact.

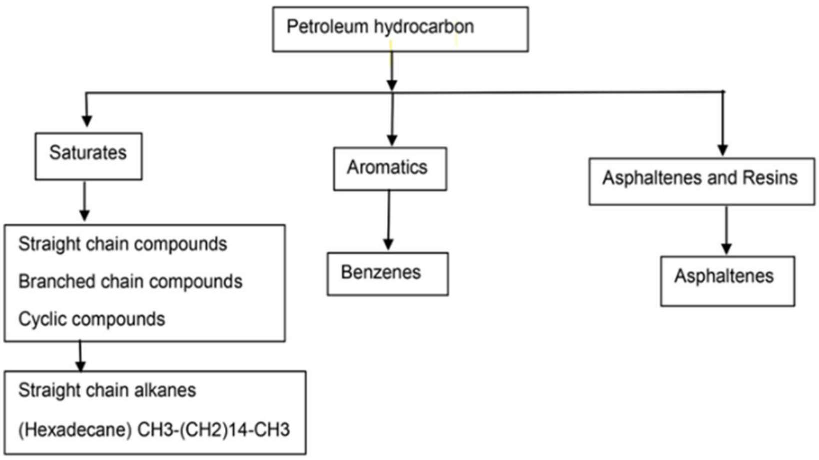

Figure 2 Types of petroleum hydrocarbon

Alkanes, also known as paraffins, are the simplest hydrocarbons and have a straight or branched chain structure. They are widely used as fuels, solvents, and raw materials in the petrochemical industry. Alkanes are relatively non-reactive and are considered to be less harmful to the environment than other types of hydrocarbons. Alkenes, also known as olefins, have one or more double bonds in their carbon chain structure. They are used as raw materials in the production of plastics, rubber, and other chemicals. Alkenes are more reactive than alkanes and can easily form reactive intermediates that can be harmful to human health and the environment. Alkynes, also known as acetylenes, have one or more triple bonds in their carbon chain structure. They are used in the production of solvents, pharmaceuticals, and other chemicals. Like alkenes, alkynes can form reactive intermediates that can be harmful to human health and the environment. Aromatic hydrocarbons, also known as arenes, have a ring structure and are widely used in

the production of plastics, detergents, and other chemicals. Aromatic compounds are highly reactive and can easily form reactive intermediates that can be harmful to human health and the environment.
The harmfulness of petroleum hydrocarbons depends on several factors, including their physical and chemical properties, their concentration in the environment, and the duration of exposure. Some hydrocarbons, such as benzene and toluene, are known to be toxic and can cause a variety of health problems, including cancer, reproductive and developmental disorders, and neurological damage [8]. Exposure to petroleum hydrocarbons can occur through inhalation, ingestion, or skin contact. Workers in the petrochemical industry and people living near oil refineries, pipelines, and other industrial facilities are at higher risk of exposure to these compounds. However, spills and leaks during the transportation and storage of petroleum products can also lead to environmental contamination and human exposure [9]. Petroleum hydrocarbons are a diverse group of compounds that are widely used in many industrial processes. While some hydrocarbons are relatively non-toxic, others can be harmful to human health and the environment. It is important to monitor and regulate the production, transportation, and use of petroleum products to minimize the risks associated with these compounds.

Amount of waste generated

The amount of waste drilling fluid generated during drilling operations varies depending on several factors, including the type of drilling fluid used, the depth of the well, the size of the borehole, and the drilling technique. A study found that the amount of drilling fluid required to drill a well depends on the borehole diameter, the depth of the well, and the type of drilling fluid used. They reported that a typical 6-inch diameter borehole drilled to a depth of 3,000 m using a water-based drilling fluid can generate up to 1,000 m^3 of waste drilling fluid. In comparison, an oil-based drilling fluid generates less waste, about 600 m^3 for the same well. The amount of waste drilling fluid generated can also be affected by the drilling technique used. For example, the amount of waste drilling fluid generated during directional drilling is higher than that of vertical drilling due to the higher mud requirements and the use of a larger borehole. One study reported that the amount of waste drilling fluid generated during directional drilling can reach up to 3,000 m^3 for a 6-inch diameter borehole drilled to a depth of 3,000 m.

Factors influencing waste generation rates:

1. Drilling depth: The deeper a well is drilled, the more drilling fluids will be required, and the more waste will be generated. A study by Zhao, et al. (2017), found that drilling depths of over 4,000 m resulted in much higher rates of waste generation compared to shallower wells [10].
2. Drilling fluid composition: Different types of drilling fluids have varying waste generation rates. For instance, oil-based drilling fluids are known to generate more waste than water-based drilling fluids. A study by Grant et al. (2022), found that oil-based drilling fluids produced twice as much waste as water-based fluids [11].
3. Formation properties: The properties of the formation being drilled can also affect waste generation rates. Soft formations require less drilling fluid, and thus, generate less waste than hard formations [12]. Additionally, formations with higher permeability may require more drilling fluids and generate more waste than less permeable formations.

Strategies for minimizing waste generation:

1. Proper drilling fluid management: Proper management of drilling fluids can help minimise waste generation. This includes proper selection of drilling fluids, proper maintenance of drilling fluids, and proper handling and disposal of waste drilling fluids.
2. Recycling and reuse of drilling fluids: Recycling and reusing drilling fluids can reduce waste generation rates. A study found that recycling drilling fluids reduced waste generation rates by up to 70%.
3. Use of non-toxic drilling fluids: Non-toxic drilling fluids, such as biodegradable fluids, can reduce the environmental impact of drilling operations and minimise waste generation rates. A study by Al-Hameedi et al. (2020) found that the use of biodegradable drilling fluids reduced waste generation rates by up to 50% [13].
4. Optimisation of drilling parameters: Optimisation of drilling parameters, such as drilling speed and drilling fluid flow rate, can reduce the amount of drilling fluid required and thus minimise waste generation rates. A study found that optimising drilling parameters reduced waste generation rates by up to 45%.
5. Implementation of waste management plans: Developing and implementing waste management plans can help ensure that waste drilling fluids are handled and disposed of properly, minimising their impact on the environment. This includes proper storage, treatment, and disposal of waste drilling fluids.

Managing waste drilling fluid is critical to protecting the environment and ensuring compliance with environmental regulations. There are several methods used to manage waste drilling fluid, including treatment, reuse, and disposal. The choice of the method used depends on the type of drilling fluid used, the amount of waste generated, and the environmental regulations at the drilling location.

Effect of Spent drilling fluid

Spent drilling fluids, also known as drilling muds, are mixtures of chemicals, water, and solids used in the oil and gas industry to facilitate drilling operations. The discharge of spent drilling fluids can have significant environmental and public health effects. In this review, we will discuss the potential impact of spent drilling fluids on the environment and human health and explore strategies for reducing these impacts. One of the primary environmental impacts of spent drilling fluids is the contamination of soil and water resources. The chemicals and heavy metals present in drilling fluids can leach into soil and groundwater, leading to long-term environmental degradation. According to a study by Ugochukwu, et al. (2012), the discharge of spent drilling fluids has been found to cause soil and water pollution in oil and gas-producing areas in Nigeria [14]. Similarly, a study by Kinigoma, et al. (2001) found that the discharge of drilling fluids in the Niger Delta region of Nigeria had a significant impact on the quality of the surrounding water resources [15]. According to Dantas, A. P. T. et al. (2014), drilling fluids contain various chemical additives, including barite, bentonite, and polymers, which can cause significant environmental damage if not handled properly [16]. The disposal of these waste fluids can lead to soil and water pollution, which can harm both plant and animal life. In addition, drilling fluids can also contain heavy metals, such as lead, cadmium, and mercury, which can be toxic to humans if ingested or inhaled. Exposure to these toxins can cause long-term health problems, including cancer, liver damage, and neurological disorders.

Similarly, another study by Oghenekohwo, et al. (2010) also highlighted the potential adverse effects of waste drilling fluids on the environment [17]. The authors noted that the disposal of drilling fluids can lead to contamination of surface and groundwater sources, which can impact aquatic life and biodiversity. The accumulation of drilling fluid waste in soil can also lead to soil degradation and loss of fertility, which can affect agricultural productivity. Furthermore, a study by Njuguna, et al. (2022) suggested that the improper disposal of drilling fluids can also lead to air pollution [18]. The authors found that the evaporation of drilling fluids can release volatile organic compounds (VOCs) into the atmosphere, which can contribute to the formation of ground-level ozone and smog. Exposure to these air pollutants can lead to respiratory problems and other health issues.

In addition to soil and water contamination, spent drilling fluids can also have negative effects on aquatic life. The discharge of drilling fluids can lead to the death of fish and other aquatic species, as well as the destruction of their habitats. A study by Mearns et al. (2017) found that the discharge of drilling fluids in the Bohai Sea in China had a negative impact on the growth and reproduction of marine organisms [19]. The public health effects of spent drilling fluids are also a major concern. Exposure to the chemicals and heavy metals present in drilling fluids can have a range of negative health effects, including respiratory and neurological problems. According to a study by Islam and Mostafa et al. (2021), people living in oil and gas-producing areas in Bangladesh are at risk of exposure to toxic chemicals from spent drilling fluids [20].

The discharge of spent drilling fluids can have significant environmental and public health impacts. To mitigate the environmental and public health impacts of spent drilling fluids, various strategies have been proposed. One approach is to reduce the use of drilling fluids through the development of alternative drilling technologies. Another approach is to improve the treatment and disposal of spent drilling fluids. Table 1 provides an overview of some of the potential environmental effects that can result from hydrocarbon-contaminated waste drilling mud.

Table 1: Environmental effects due to petroleum hydrocarbon contamination

Environmental Effect	Description	Reference
Contamination of Soil and Groundwater	Hydrocarbon contaminated spent drilling fluids can seep into the soil and groundwater, leading to contamination of these resources.	(Swigart, et al., 2021) [21]
Damage to Aquatic Ecosystems	If the contaminated fluid is not properly contained, it can enter nearby bodies of water, such as rivers, lakes, or streams.	(Bashir, et al., 2020) [22]
Air Pollution	Hydrocarbon emissions from contaminated drilling fluid can contribute to air pollution, which can lead to respiratory problems for humans and animals.	(Macey, et al., 2014) [23]

Contamination of Sediment	Contaminated drilling fluid can settle on the bottom of bodies of water, leading to contamination of sediment.	(Srungavarapu, et al., 2018) [24]
Ecological Disruption	The introduction of hydrocarbon-contaminated drilling fluid into an ecosystem can cause disruption to the natural balance of that ecosystem.	(Truskewycz, et al., 2019) [25]
Human Health Impacts	If people come into contact with hydrocarbon-contaminated soil, water, or air, they can experience negative health effects, including skin irritation, respiratory problems, and more serious illnesses.	(Bloomdahl, et al., 2014) [26]
Economic Costs	Cleaning up hydrocarbon-contaminated sites can be expensive and have long-term impacts on industries such as agriculture, tourism, and fishing.	(Ahmed, et al., 2022) [27]

Remediation methods

Drilling operations generate a significant amount of spent drilling fluid, which contains contaminants that may cause environmental damage. Thus, various remediation methods have been developed to manage spent drilling fluid. This review discusses the various remediation methods for spent drilling fluid and their effectiveness in removing contaminants.

One of the commonly used methods for spent drilling fluid remediation is thermal treatment, which involves heating the fluid to high temperatures to remove contaminants. Thermal treatment has been found to be effective in removing hydrocarbons, heavy metals, and other contaminants [28]. However, this method is energy-intensive and can be expensive.

Another method is bioremediation, which is a biological process that involves the use of microorganisms to degrade organic contaminants in the environment. In the case of spent drilling fluid, bioremediation can be used to break down the hydrocarbons in the waste. The microorganisms used in bioremediation include bacteria, fungi, and algae. Studies have shown that bioremediation is an effective method of reducing hydrocarbon concentrations in spent drilling fluid [29, 30]. Several studies have reported the effectiveness of bioremediation in the remediation of hydrocarbon-contaminated waste drilling fluids. For example, Shetaia, Y. M. H. et al. (2016) reported that bioremediation using a bacterial consortium resulted in a 68.3% removal of total petroleum hydrocarbons (TPH) from waste drilling fluids [31]. Similarly, Chang, Y., et al. (2014) reported a 91.7% removal of TPH from oil-based drilling fluids using a bacterial consortium [32]. Other studies have reported similar results, indicating that bioremediation is an effective method for remediating hydrocarbon-contaminated waste drilling fluids [33, 34, 35, 36].

Physicochemical remediation involves the use of chemical and physical methods to treat spent drilling fluid. Some of the physicochemical methods include coagulation, flocculation, electrocoagulation, adsorption, and membrane filtration. These methods are effective in reducing the concentrations of contaminants in spent drilling fluid. For instance, adsorption using activated carbon has been found to be effective in reducing the concentrations of polycyclic aromatic hydrocarbons (PAHs) in spent drilling fluid [37]. Electrocoagulation has also been found to be an effective method of treating spent drilling fluid [38]. However, it requires a significant amount of energy and can be expensive.

Chemical treatment is also an option for spent drilling fluid remediation. This method involves the use of chemicals to neutralise or separate the contaminants from the fluid. Various chemicals, such as oxidants, acids, and bases, have been used in chemical treatment [39, 40]. However, the use of chemicals can have adverse effects on the environment.

Physical separation is another remediation method that involves the use of physical processes such as filtration, centrifugation, and sedimentation to separate the contaminants from the fluid. This method has been found to be effective in removing solid contaminants such as drill cuttings [41]. However, it may not be effective in removing dissolved contaminants.

Thermal remediation involves the use of heat to treat spent drilling fluid. The method involves heating the waste to high temperatures to vaporise the contaminants, which are then collected and treated separately. The residual solid is then disposed of appropriately. Thermal remediation is effective in treating spent drilling fluid contaminated with organic compounds [42, 43].

Phytoremediation is a process that involves the use of plants to absorb and accumulate contaminants from the environment. In the case of spent drilling fluid, plants can be used to absorb the hydrocarbons in the waste. Some of the plants that have been used in phytoremediation of spent drilling fluid include ryegrass, clover, and mustard [44]. Studies have shown that phytoremediation is effective in reducing hydrocarbon concentrations in spent drilling fluid.

Other methods such as adsorption, ion exchange, and reverse osmosis have also been used for spent drilling fluid remediation. These methods have varying degrees of effectiveness in removing contaminants and require careful monitoring to ensure their efficiency [45, 46].

The choice of the remediation method should consider the contaminants present in the spent drilling fluid, the efficiency of the method, and the potential impact on the environment. A combination of remediation methods may also be required to achieve efficient and effective spent drilling fluid remediation.

Application

Wastes from petroleum drilling have been added as new types of waste that can be treated and used in a positive way. These wastes could be used in construction and building materials, like making roads [47], pavement made of asphalt [48], as a total in cool blend black-top [49], Hot-mixed asphalt [50], the production of cement [51], real-world [52], sandcrete blocks [53], blocks [54], and ceramics for construction [55] have been proposed as of late. Solid drilling cuttings contain reactive calcium, silicon, aluminium, and iron oxides that can be used in the cement industry as natural fine aggregate to replace limestone and clay. They either serve as an active component to enhance the technical behaviour of cement in small quantities or as a filler and constituents of the finished product [56]. Additionally, as construction materials, pre-treated drill cuttings (i.e., thermally treated cuttings without a hydrocarbon fraction) and screened or filtered cuttings with less liquid mud are potential aggregates or fillers [57]. Untreated cuttings are moderately difficult to reuse for development purposes [58].

CONCLUSION

In conclusion, the systematic review on composition, effect, and remediation methods of petroleum hydrocarbon contaminated waste drilling fluid has provided valuable insights into the current state of knowledge on this topic. The analysis has emphasized the intricate characteristics of waste drilling fluid contaminated with petroleum hydrocarbons. This fluid contains a diverse array of organic and inorganic compounds, which can have detrimental impacts on the environment and human health.

The review has also provided a comprehensive overview of the different remediation methods that are available for treating petroleum hydrocarbon contaminated waste drilling fluid, including physical, chemical, and biological methods. Each of these methods has its own advantages and disadvantages, and the choice of remediation method will depend on a number of factors, including the extent of contamination, the type of hydrocarbon, and the desired end-use of the treated waste.

Overall, the systematic review has emphasized the need for continued research and development of effective and sustainable remediation methods for petroleum hydrocarbon contaminated waste drilling fluid. It is hoped that the findings of this review will help to inform future research and development efforts in this area, as well as guide policy and decision-making related to the management of petroleum hydrocarbon contaminated waste drilling fluid.

FUTURE SCOPE

In recent years, several studies have focused on the remediation of petroleum hydrocarbon-contaminated waste drilling fluid. However, there is still a lack of understanding of the long-term effectiveness of different remediation methods and the potential environmental impacts of these methods. Therefore, there is a need for further research on the selection of appropriate remediation methods for specific types of petroleum hydrocarbon-contaminated waste drilling fluid.

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COMPETING INTERESTS

"The authors have declared that no competing interest exists".

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REFERENCES

1. Khodja, M., Khodja-Saber, M., Canselier, J., Cohaut, N., & Bergaya, F. (2010). Drilling Fluid Technology: Performances and Environmental Considerations.
2. Ibrahim, D. S., Sami, N. A., & Balasubramanian, N. (2017). Effect of barite and gas oil drilling fluid additives on the reservoir rock characteristics. Journal of Petroleum Exploration and Production Technology, 7(2), 281-292. https://doi.org/10.1007/s13202-016-0258-2.
3. Nabiyev, K. (2018). The impact of different concentrations of viscosifiers on rheological properties of invert emulsion mud.
4. Gautam, S., Guria, C., Rajak, V. K., (2022). A state of the art review on the performance of high-pressure and high-temperature drilling fluids: Towards understanding the structure-property relationship of drilling fluid additives. Journal of Petroleum Science and Engineering, 213, 110318. https://doi.org/10.1016/j.petrol.2022.110318.
5. Al-Hameedi, A. T., Alkinani, H. H., Dunn-Norman, S., Al-Alwani, M. A., Alshammari, A. F., Albazzaz, H. W., Alkhamis, M. M., Alashwak, N. F., & Mutar, R. A. (2019). Insights into the application of new eco-friendly drilling fluid additive to improve the fluid properties in water-based drilling fluid systems. Journal of Petroleum Science and Engineering, 183, 106424. https://doi.org/10.1016/j.petrol.2019.106424.
6. Hudgins Jr, C.M., 1994. Chemical use in North Sea oil and gas E&P. J. Petrol. Technol. 46 (01), 67–74.
7. Fenibo, E. O., Ijoma, G. N., Selvarajan, R., & Chikere, C. B. (2019). Microbial surfactants: The next generation multifunctional biomolecules for applications in the petroleum industry and its associated environmental remediation. Microorganisms, 7(11), 581. https://doi.org/10.3390/microorganisms7110581.
8. Masekameni, M. D., Moolla, R., Gulumian, M., & Brouwer, D. (2018). Risk assessment of benzene, toluene, ethylbenzene, and xylene concentrations from the combustion of coal in a controlled laboratory environment. International Journal of Environmental Research and Public Health, 16(1), 95. https://doi.org/10.3390/ijerph16010095.
9. Axiak, V., & George, J. J. (1987). Effects of exposure to petroleum hydrocarbons on the gill functions and ciliary activities of a marine bivalve. Marine Biology, 94(2), 241-249. https://doi.org/10.1007/BF00392936.
10. Zhao, Y. S., Feng, Z. J., Xi, B. P., Yang, D., Liang, W. G., & Wan, Z. J. (2017). Limit of crustal drilling depth. Journal of Rock Mechanics and Geotechnical Engineering, 9(5), 989-992. https://doi.org/10.1016/j.jrmge.2017.05.006.
11. Grant, Stephanie & Germack, David & Haslam, Beth. (2022). Drilling Fluid Composition and Method for Making. RG ResearchGate.
12. Bageri, B.S., Benaafi, M., Mahmoud, M. et al. (2020). Effect of Formation Cutting's Mechanical Properties on Drilling Fluid Properties During Drilling Operations. Arab J Sci Eng, 45, 7763–7772. https://doi.org/10.1007/s13369-020-04424-7.
13. Al-Hameedi, A.T.T., Alkinani, H.H., Alkhamis, M.M. et al. (2020). Utilizing a new eco-friendly drilling mud additive generated from wastes to minimize the use of conventional chemical additives. J Petrol Explor Prod Technol, 10, 3467–3481. https://doi.org/10.1007/s13202-020-00974-6.
14. Ugochukwu, C. N. & Ertel, J. (2012). Negative impacts of oil exploration on biodiversity management in the Niger Delta area of Nigeria. Journal of Biodiversity and Environmental Sciences, 2(2), 139-147.
15. Kinigoma, B.S. (2001). Effect of Drilling Fluid Additives on the Niger Delta Environment: A Case Study of the Soku Oil Fields. Journal of Applied Sciences and Environmental Management, 5(1).
16. Dantas, A. P. T., Leite, R. S., Nascimento, R. C. A. M., & Amorim, L. V. (2014). The influence of chemical additives in filtration control of inhibited drilling fluids. Brazilian Journal of Petroleum and Gas, 8, 97-108. https://doi.org/10.5419/bjpg2014-0009.
17. Oghenekohwo, J., Oviri, E., & Onojake, C. (2010). Environmental aspect of oil and water-based drilling muds and cuttings from Dibi and Ewan off-shore wells in the Niger Delta, Nigeria. African Journal of Environmental Science and Technology, 4(5), 284-292.
18. Njuguna, J., Siddique, S., Kwroffie, L. B., Piromrat, S., Addae-Afoakwa, K., Ekeh-Adegbotolu, U., Oluyemi, G., Yates, K., Mishra, A. K., & Moller, L. (2022). The fate of waste drilling fluids from oil & gas industry activities in the exploration and production operations. Waste Management, 139, 362-380. https://doi.org/10.1016/j.wasman.2021.12.025.
19. Mearns, Alan, Reish, Donald, Oshida, Philip, Morrison, Ann, Arthur, Courtney, Rutherford, Nicolle, & Pryor, Rachel. (2017). Effects of Pollution on Marine Organisms. Water Environment Rese\\\arch, 89(12), 1704-1798. https://doi.org/10.2175/106143017X15023776270647.
20. Islam, Md. Ph.D., & Mostafa, Md. (2021). Environmental Hazards of Petroleum Refinery in Bangladesh: A Review. Petroleum, Coal, and Natural Gas, 3(1). https://doi.org/10.33140/PCII.03.01.

21. Swigart, J., Heo, J., & Wolf, D. (2021). Soil Contamination Assessments from Drilling Fluids and Produced Water Using Combined Field and Laboratory Investigations: A Case Study of Arkansas, USA. International Journal of Environmental Research and Public Health, 18(5), 2421. https://doi.org/10.3390/ijerph18052421.
22. Bashir, I., Lone, F. A., Bhat, R. A., Mir, S. A., Dar, Z. A., & Dar, S. A. (2020). Concerns and Threats of Contamination on Aquatic Ecosystems. In K. Hakeem, R. Bhat, & H. Qadri (Eds.), Bioremediation and Biotechnology (pp. 1-23). Springer. https://doi.org/10.1007/978-3-030-35691-0_1.
23. Macey, G. P., Breech, R., Chernaik, M., Cox, C., Larson, D., Thomas, D., & Carpenter, D. O. (2014). Air Concentrations of Volatile Compounds Near Oil and Gas Production: A Community-Based Exploratory Study. Environmental Health, 13, 82. https://doi.org/10.1186/1476-069X-13-82.
24. Macey, G. P., Breech, R., Chernaik, M., Cox, C., Larson, D., Thomas, D., & Carpenter, D. O. (2014). Air Concentrations of Volatile Compounds Near Oil and Gas Production: A Community-Based Exploratory Study. Environmental Health, 13, 82. https://doi.org/10.1186/1476-069X-13-82.
25. Truskewycz, A., Gundry, T. D., Khudur, L. S., Kolobaric, A., Taha, M., Aburto-Medina, A., Ball, A. S., & Shahsavari, E. (2019). Petroleum Hydrocarbon Contamination in Terrestrial Ecosystems-Fate and Microbial Responses. Molecules, 24(18), 3400. https://doi.org/10.3390/molecules24183400.
26. Bloomdahl, R. Y., Abualfaraj, N., Olson, M., & Gurian, P. L. (2014). Assessing Worker Exposure to Inhaled Volatile Organic Compounds from Marcellus Shale Flowback Pits. Journal of Natural Gas Science and Engineering, 21, 348-356. https://doi.org/10.1016/j.jngse.2014.08.018.
27. Ahmed, I. B., Nwaichi, E. O., Ugwoha, E., Ugbebor, J. N., & Arokoyu, S. B. (2022). Cost Reduction Strategies in the Remediation of Petroleum Hydrocarbon Contaminated Soil. Open Research Africa, 5, 21. https://doi.org/10.12688/openresafrica.13383.1.
28. Piña, J., Merino, J., Errazu, A. F., Bucalá, V. (2002). Thermal treatment of soils contaminated with gas oil: influence of soil composition and treatment temperature. Journal of Hazardous Materials, 94(3), 273-290. https://doi.org/10.1016/S0304-3894(02)00081-X.
29. Antizar-Ladislao, B., Lopez Real, J. M., Beck, A. J. (2004). Bioremediation of Polycyclic Aromatic Hydrocarbon (PAH)-Contaminated waste using composting approaches. Critical Reviews in Environmental Science and Technology, 34, 249-289.
30. Paladino, G., Arrigoni, J. P., Satti, P., et al. (2016). Bioremediation of heavily hydrocarbon-contaminated drilling wastes by composting. International Journal of Environmental Science and Technology, 13, 2227-2238. https://doi.org/10.1007/s13762-016-1057-5.
31. Shetaia, Y. M. H., El khalik, W. A. A., Mohamed, T. M., Farahat, L. A., ElMekawy, A. (2016). Potential biodegradation of crude petroleum oil by newly isolated halotolerant microbial strains from polluted Red Sea area. Marine Pollution Bulletin, 111(1-2), 435-442. https://doi.org/10.1016/j.marpolbul.2016.02.035.
32. Chang, Y., Wang, X., Han, Y., Wang, M., Zheng, C., Wang, Y., & Huang, Z. (2014). The Removal of Crude Oil in Waste Drilling Muds by a Constructed Microbial Consortium. Lecture Notes in Electrical Engineering, 250, 1245-1257. https://doi.org/10.1007/978-3-642-37922-2-134.
33. Kostenko, V., Martinuzzi, R., Hareland, G. (2013). Impact of Oil-Based Drilling Fluids Emulsification on Tolerance and Hydrocarbon-Degrading Potential of Ralstonia pickettii and Alcaligenes piechandii. Journal of Petroleum & Environmental Biotechnology, 4. https://doi.org/10.4172/2157-7463.1000140.
34. Rasti, A., Ameri, A., Riahi, M. A. (2021). Aerobic degradation of oil-based mud drilling fluid by in situ bacteria in the Hawizeh Marshes. Journal of Petroleum Exploration and Production Technology, 11. https://doi.org/10.1007/s13202-021-01263-6.
35. Geetha, S. J., Joshi, S. J., Kathrotiya, S. (2013). Isolation and Characterization of Hydrocarbon Degrading Bacterial Isolate from Oil Contaminated Sites. APCBEE Procedia, 5, 237-241. https://doi.org/10.1016/j.apcbee.2013.05.041.
36. Varjani, S. J., Rana, D. P., Jain, A. K., Bateja, S., Upasani, V. N. (2015). Synergistic ex-situ biodegradation of crude oil by halotolerant bacterial consortium of indigenous strains isolated from on shore sites of Gujarat, India. International Biodeterioration & Biodegradation, 103, 116-124. https://doi.org/10.1016/j.ibiod.2015.03.030.
37. Tang, C., Xie, S. X. (2017). Resource recovery and harmless treatment of waste oil-in-water drilling fluid. Environmental Engineering Research, 22(3), 277-280. https://doi.org/10.4491/eer.2016.151.
38. Elnenay, A. M. H., Nassef, E., Malash, G. F., Abdel Magid, M. H. (2017). Treatment of drilling fluids wastewater by electrocoagulation. Egyptian Journal of Petroleum, 26(1), 203-208. https://doi.org/10.1016/j.ejpe.2016.03.005.
39. Zhu, M. J., Liu, H. J., Yao, J., Luo, Q. H. (2014). Chemical demulsification-ultrasonic recycle oil from oil-based drilling fluid using response surface methodology. Advanced Materials Research, 955-959, 2653-2657. https://doi.org/10.4028/www.scientific.net/AMR.955-959.2653.
40. Zhu, Z., Li, J., Xie, S., Yuan, G. (2011). Research and application on resource utilization technology of oily waste drilling fluid. Petroleum Science and Technology, 29(14), 1470-1481. https://doi.org/10.1080/10916466.2010.490818.
41. Pereira, L. B., Sad, C. M. S., Silva, M., Corona, R. R. B., Santos, F. D., Gonçalves, G. R., et al. (2019). Oil recovery from water-based drilling fluid waste. Fuel, 237, 335-343. https://doi.org/10.1016/j.fuel.2018.10.007.
42. Drzewicz, P., Nałe¸cz-Jawecki, G., Drobniewska, A., Zgadzaj, A., Smolinski, A., Krzan, M., et al. (2019). Toxicological Evaluation of Thermal Treatment of Drilling Waste from Shale Gas Exploration in Poland. Ecological Chemistry and Engineering S, 26, 45-57. https://doi.org/10.1515/eces-2019-0004.

43. Robinson JP, Kingman SW, Snape CE, Barranco R, Shang H, Bradley MSA, et al. Remediation of oil-contaminated drill cuttings using continuous microwave heating. Chem Eng J (2009); 152(2-3):458–63. https://doi.org/10.1016/j.cej.2009.05.008.
44. Wang A, Fu W, Feng Y, Liu Z, Song D. Synergetic effects of microbial-phytoremediation reshape microbial communities and improve degradation of petroleum contaminants. J Hazard Mater. (2022); 429:128396. ISSN 0304-3894. https://doi.org/10.1016/j.jhazmat.2022.128396.
45. Xie S, Ren W, Qiao C, Tong K, Sun J, Zhang M, et al. An electrochemical adsorption method for the reuse of waste water-based drilling fluids. Nat Gas Ind B. (2018); 5(5): 508-512. ISSN 2352-8540. https://doi.org/10.1016/j.ngib.2018.03.005.
46. Chen G, Wang Z, Nghiem LD, Li XM, Xie M, Zhao B, et al. Treatment of shale gas drilling flowback fluids (SGDFs) by forward osmosis: Membrane fouling and mitigation. Desalination. (2015); 366:113-120. ISSN 0011-9164. https://doi.org/10.1016/j.desal.2015.02.025.
47. Tuncan A, Tuncan M, Koyuncu H. Use of petroleum-contaminated drilling wastes as sub-base material for road construction. Waste Manag Res. (2000), 18(5), 489-505. DOI: https://doi.org/10.1177/0734242X0001800511.
48. Dantas, A. P. T., Leite, R. S., Nascimento, R. C. A. M., & Amorim, L. V. (2014). The influence of chemical additives in filtration control of inhibited drilling fluids. Brazilian Journal of Petroleum and Gas, 8, 97-108. https://doi.org/10.5419/bjpg2014-0009.
49. Allen B, Day D, Armstrong S, Page PW, Murdoch K, Beardsley R. The development and trial use of oil exploration drill-cutting waste as an aggregate replacement in cold-mix asphalt. In: E&P Environmental and Safety Conference. (2007) Society of Petroleum Engineers.
50. Xie S, Ren W, Qiao C, Tong K, Sun J, Zhang M, et al. An electrochemical adsorption method for the reuse of waste water-based drilling fluids. Nat Gas Ind B. (2018); 5(5): 508-512. ISSN 2352-8540. https://doi.org/10.1016/j.ngib.2018.03.005.
51. Aboutabikh, M., Soliman, A. M., & El Naggar, M. H. (2016). Properties of cementitious material incorporating treated oil sands drill cuttings waste. Construction and Building Materials, 111, 751-757. https://doi.org/10.1016/j.conbuildmat.2016.02.163.
52. Nabiyev, K. (2018). The impact of different concentrations of viscosifiers on rheological properties of invert emulsion mud.
53. Monteiro, S. N., Vieira, C. M. F., Ribeiro, M. M., & Silva, F. A. N. (2007). Red ceramic industrial products incorporated with oily wastes. Construction and Building Materials, 21(11), 2007-2011. https://doi.org/10.1016/j.conbuildmat.2006.05.035.
54. Robinson JP, Kingman SW, Snape CE, Barranco R, Shang H, Bradley MSA, et al. Remediation of oil-contaminated drill cuttings using continuous microwave heating. Chem Eng J (2009); 152(2-3):458–63. https://doi.org/10.1016/j.cej.2009.05.008.
55. Mostavi, E., Asadi, S., & Ugochukwu, E. (2015). Feasibility Study of the Potential Use of Drill Cuttings in Concrete. Procedia Engineering, 118, 1015-1023. https://doi.org/10.1016/j.proeng.2015.08.543.
56. Bageri, B.S., Benaafi, M., Mahmoud, M. et al. (2020). Effect of Formation Cutting's Mechanical Properties on Drilling Fluid Properties During Drilling Operations. Arab J Sci Eng, 45, 7763–7772. https://doi.org/10.1007/s13369-020-04424-7.
57. Bashir, I., Lone, F. A., Bhat, R. A., Mir, S. A., Dar, Z. A., & Dar, S. A. (2020). Concerns and Threats of Contamination on Aquatic Ecosystems. In K. Hakeem, R. Bhat, & H. Qadri (Eds.), Bioremediation and Biotechnology (pp. 1-23). Springer. https://doi.org/10.1007/978-3-030-35691-0_1.
58. Okoh, N. B. (2015). Engineering Properties of Drill Cuttings Recycled Towards Construction Applications.