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A COMPREHENSIVE LOOK AT OILFIELD DRILLING WASTE SOLID-LIQUID TECHNIQUES AND ITS EFFECTIVENESS IN ULTIMATE DISPOSAL AND RE-USE

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ABSTRACT

In oil and gas operations, waste drilling muds are considered the second most generated wastes next to produced water. Many experiments, trials and field operators have proposed several approaches and technologies in effectively managing wastes generated from drilling operations. Based on published literature, available data, and materials, this article comprehensively reviews the strategies and precisely outlines best practices on drilling waste solid-liquid separation techniques. Their operational mechanisms and effectiveness are also concisely stated. Effective solid – liquid separation techniques include the application of solid control and other techniques such as: centrifuges, thermal treatment, chemical treatment, biodegradation and electro-mechanical process. Centrifuge is usually accompanied by further separation techniques to ensure further solid liquid separation. According to literature, effective waste management program involves: Source reduction, reuse, recycle, recover and disposal.

INTRODUCTION

The vast importance of drilling fluids in oil and gas operations cannot be over emphasized. Drilling fluids, usually aqueous and non-aqueous, are designed to perform a wide range of functions which include: cooling and lubricating the drill string and bit, cleaning the bottom hole, carrying cuttings to the surface, providing counter pressure to prevent influx of fluids into the well, transferring hydraulic energy to the bit, ensuring cutting evaluation and so on (Li et al. 2017; Nwinee 2018; Imarhiagbe and Obayagbona 2019). Ensuring optimal performance of these functions have led to the design and synthesis of novel chemical additives with potentials of posing environmental concerns through waste generation (Okeke and Obi 2013; Zouboulis et al. 2016). During mud circulation, the drilling mud passes through the drill pipes, nozzles of the drilling bits and carries the drill cuttings through the annulus to the surface for disposal or reuse.

Recent technological advancements and optimization of oilfield chemicals have been a contributing factor in the increase in toxicity of drilling waste (Li et al. 2017). Most novel additives applied to base muds comprise of organic, inorganic and heavy metals which can be toxic and hazardous to the environment (Loducngi et al. 2016). Heavy metals commonly found in Drilling waste include: Cu, Zn, Ni, Ba, Pb, Hg, Cr and so on (Department of Petroleum Resources 2002; Kujawska and Wojciech 2017; Xu et al. 2018).

The past decade has witnessed a drastic shift in wellbore technological configurations. Studies has shown that large wellbore sizes contribute immensely to the generation of drilling waste at very large volumes. It was reported that concentration of drilling wastes generated from deviated, horizontal and extended reach well drilling was significantly higher than the wastes generated from the conventional vertical wells (United states environmental protection agency 2019).

Aside from produced water, drilling waste is considered the second most generated waste in oil and gas operations (Onwuka et al. 2018). According to the American Petroleum Institute survey of onshore and coastal exploration and production operations, about 150 million barrels of drilling waste was generated in 1995 (American Petroleum Institute 2000).

Yearly generation of such huge volumes of waste has led to the imposition of strict government regulations aimed at efficiently managing generated waste. Recently, in countries like Nigeria and Angola, the governing Oil and Gas regulatory body imposed a ban on operators in the use of toxic oil based drilling fluids in exploration operations (Department of Petroleum Resources 2002; Imarhiagbe and Obayagbona 2019; Sharma et al. 2020). Effective drilling waste management cuts across several areas of drilling operations. From mud selection, application of digital automation process, treatment of drilling waste to the lowest toxic level and safe disposal / reuse.

Current globally accepted waste management practices include: Waste injection into disposal wells, Waste treatment for reuse, disposal in landfills and mud pits. In the mud treatment process, several solid-liquid separation techniques have been implemented:

- Centrifugal separation
- Thermal treatment
- Chemical stabilization
- Biological
- Surfactant enhanced washing
- Electro-solid control

These separation processes have become captivating, judging from the amount of waste annually generated in drilling operations (Nwinee 2018; Pereira et al. 2018). This article elaborates on the best practices and achievements in the development and implementation of solid liquid separation techniques in drilling waste management.

Recent Advancements in Drilling Waste Solid Liquid Separation Techniques

Over the past years, the oil and gas industry has witnessed a remarkable shift in technological advancements in oil field waste management operations. This can be attributed to the strict environmental regulations imposed by governments across the globe. Studies and literature materials have recorded variations on the effectiveness of these separation technologies leading to an effective disposal or reuse of the drilling fluid for further drilling operations. By implementing processes such as flocculation, surfactant enhanced washing, thermal desorption, electro kinetics/mechanical pneumatics, high success rates have been achieved in mud treatment through solid liquid separation (Li et al. 2017; Sharif et al. 2017; Nejad 2018; step oil tools 2020). In field operations, drilling wastes pass through several solid-liquid separation processes to eventually achieve the optimal recovery of water, chemicals, oil and cutting disposal. The resultant effect of these separation processes is operational cost reduction, reduction in nonproductive time, reduction in regulatory environmental concerns and optimization of drilling operations. The table 1 below illustrates the commonly practiced solid liquid separation techniques.

Table 1 – Solid-liquid separation techniques

Method	Technology	Mechanism	Fluid Separation type	Additional comments from literature	References
Physical method	Centrifugal separation	Gravity separation under the influence of centrifugal force.	Water based muds, synthetic based muds, oil based muds.	Largely considered a pre-treatment process. Solid separated require further separation.	Wills and Finch 2016; Nejad et al. 2018; Laine et al. 2019.
	Supercritical fluid extraction	Extraction of fluids at ultra-high conditions	Oil-based muds	It has been successful in oil-based mud extraction	Khanpour et al. 2014; Nejad 2018; Ma et al. 2019
Thermal	Heat treatment	Thermal desorption, smoldering, incineration	Water Based Mud, Synthetic based muds, Oil Based Muds	Proven to be efficient in solid-liquid separation. Zero discharge recorded in field application.	Okeke and Obi 2013; Sharma et al. 2020; Thomas et al. 2020.
Chemical	Chemical treatment	Absorption bridging and sweep flocculation, Coagulation, precipitation	Water based muds, synthetic based systems, oil based muds	Organic and inorganic flocculants can lead to high level separation could be achieved	Li et al. 2017
	Surfactant Enhanced Washing	Roll-up, emulsification, solubisation mechanism	Oil- based muds, synthetic based systems	Achieving effective separation through effective interfacial tension reduction of immiscible materials	Nejad et al. 2018; Nwinee 2018.
Electro Mechanical	Electro separation cell	Electro kinetics/Mechanical Pneumatic process	Oil-based muds	97% percent accuracy in oil separation	Wilmans and Van Deventer 1987; Step Oiltools 2020;

1. Centrifugal Separation

In practice, centrifugal separation is largely considered one of the most cost effective processes in solid liquid separation (Wills and Finch 2016). However, studies have shown that this technique is inefficient in the removal of tiny contaminants usually attached to the drill cuttings as experience has shown that particles smaller than 10 µm are usually still found in the separated drilling fluid (Nejad 2018). The operational mechanism of centrifuge separation is gravity separation due to the fact that particles sediment under the presence of centrifugal force. Separation is largely performed by hydrocyclones and centrifuges. Due to its inefficiencies in separating ultrafine contaminants, it is widely considered as a pre separation process.

Laine et al. 2019 carried out an experiment on the recovery of oil from drilling cuttings. Results from his experiments outlined that an increase in temperature and centrifugal force eventually leads to an improved efficiency in the solid liquid separation. However, this experiment was supported by chemical separation through the use of polymers in ensuring total oil removal from the drilling waste.

Figure 1 – Solid control unit in X field located in Niger Delta Nigeria (Onwuka et al. 2018)

2. Supercritical Fluid Extraction

Research and field experience has recorded the successful application of supercritical fluid extraction in the separation of oil from oil-based drilling fluid waste. Common supercritical fluids applied in solid-liquid separation include CO_2, Propane and Butane (Saldana et al. 2005; Nejad 2018).

Khanpour et al. 2014 recorded positive experimental results on the application of supercritical CO_2 in solid liquid separation. In his report, maximum separation efficiency was achieved at temperature and pressure of 333 K and 180 bar, respectively, flow rate of lower than 0.1 cm3/s and the static time of 110 min. In a later date, Ma et al. 2019 reported results on the experimental study on harmless disposal of waste oil based mud using supercritical carbon dioxide extraction. Results from this experiment showed that under temperature of 35 ℃ and pressure of 20 MPa oil extraction efficiency could reach as high as 98%.

3. Thermal Treatment

This separation technique utilizes high temperature treatment unit in the treatment of oilfield waste. Implementation of heat treatment in solid-liquid separation has gained wide acceptance and field applications have been reported (Okeke and Obi 2013; Sharma et al. 2020; Thomas et al. 2020). The application of several heat treatment mechanisms such as thermal desorption, incineration and smoldering have recorded remarkable solid-liquid separation efficiency. Sharma et al. 2020 reported a field implementation and application of thermos-mechanical cutting cleaner in an offshore field in Angola. Owing to the success of its installation several advantages such as reduction in HSE risks, reduction in required crane lifts were recorded. Onwuka et al. 2018 reported a field study on the effectiveness of thermal desorption process in drilling waste treatment on an X-gas field. Figure 2 provides a workflow illustration of solid liquid separation with the installation of thermal desorption unit.

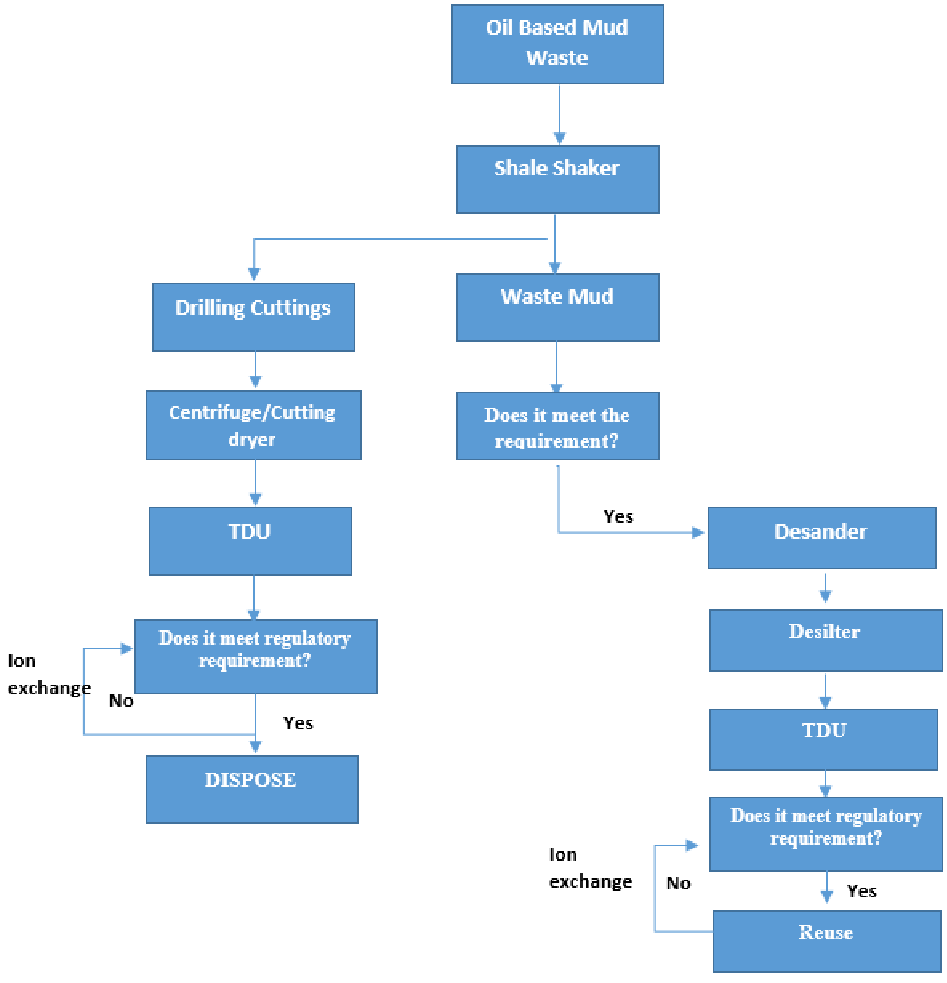

Figure 2 – A workflow chart depicting oilfield drilling waste management with installed thermal disruption unit (TDU)

4. Electro solid control

In practice, the electro solid control system has been implemented and proven to be highly effective in the separation of synthetic and oil based muds. Operational mechanism behind the electro solid controls process involves the destabilization of bonds and separation of the base oils from the mud additives and drill solids through the means of an electro kinetic / mechanical pneumatic process (https://frtr.gov/matrix2/section4/4-4.html). The Electro kinetic process which operates in sync with mechanical pneumatic vibration influences the movement of the various phases within the drill muds. Electric current provides the primary force in the form of electro kinetic phenomena and the mechanical hydraulic vibration to address the removal of the native clays / drill solids from the electro solid control unit (Wilmans and Van Deventer 1987). Three mechanisms are common in the electro solid control system:

- Electrophoresis
- Electro migration
- Electro osmosis.

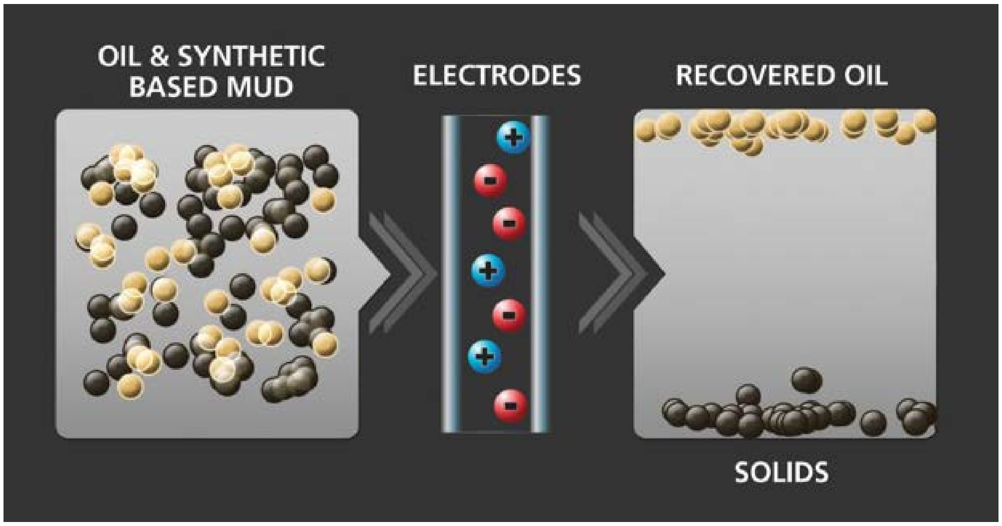

Figure 3 – Electro solid control mechanism

5. Surfactant Enhanced Washing

The action mechanism of surfactant involves the reduction of interfacial tension of miscible and immiscible materials. Through high level reaction of the hydrophobic and hydrophilic parts of surfactants, interfacial tension can be reduced in immiscible substances. Several successful studies on the use of surfactants and bio surfactants in the treatment of oil and gas drilling wastes have been reported (Nwinee 2018; Najed 2018). The washing mechanism of surfactants involves three processes: roll-up, emulsification, and solubisation.

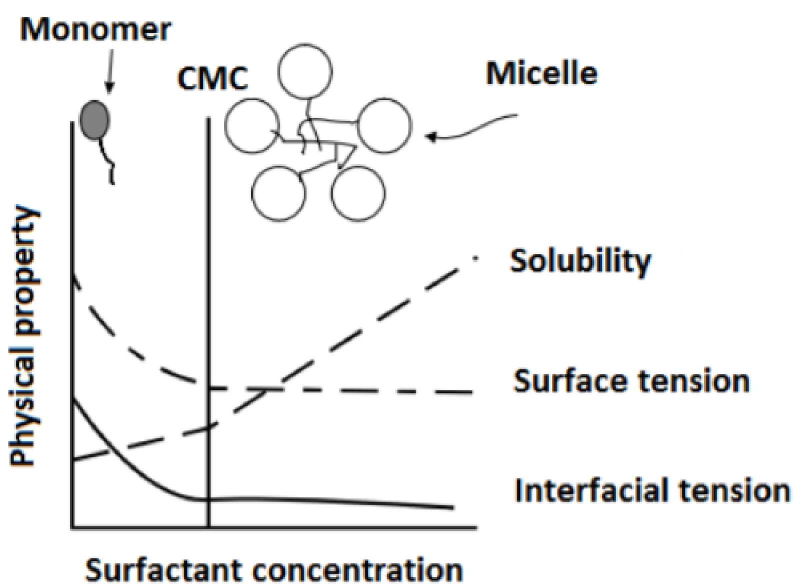

Figure 4 – Change in surfactant properties with change in concentration (Najed 2018)

In the roll-up process, adsorption of surfactant at the material interface leads to an increase in contact angle between the material phases thereby minimizing the interfacial tension effects.

Snap-off process usually takes place when the contact angle is not sufficient for the entire droplet to detach from the substrate, but a portion breaks off the deposited oil film.

Solubilisation mechanism is based on the partition of the oil molecules inside the hydrophobic core of micelles.

6. Chemical Treatment

A reliable practice in oil and gas drilling waste management system involves solid liquid separation techniques through processes such as: flocculation, coagulation, precipitation. Numerous researchers have reported positive results in the chemical treatment of drilling waste (Li et al. 2017). The procedure involves treating and separating the drill cuttings using organic and inorganic additives into aqueous and non-aqueous phases. The non-aqueous phase can be further converted into useful materials like soil for land fill, concrete for road constructions and so on. The aqueous phase is then sent back for further treatment and reuse.

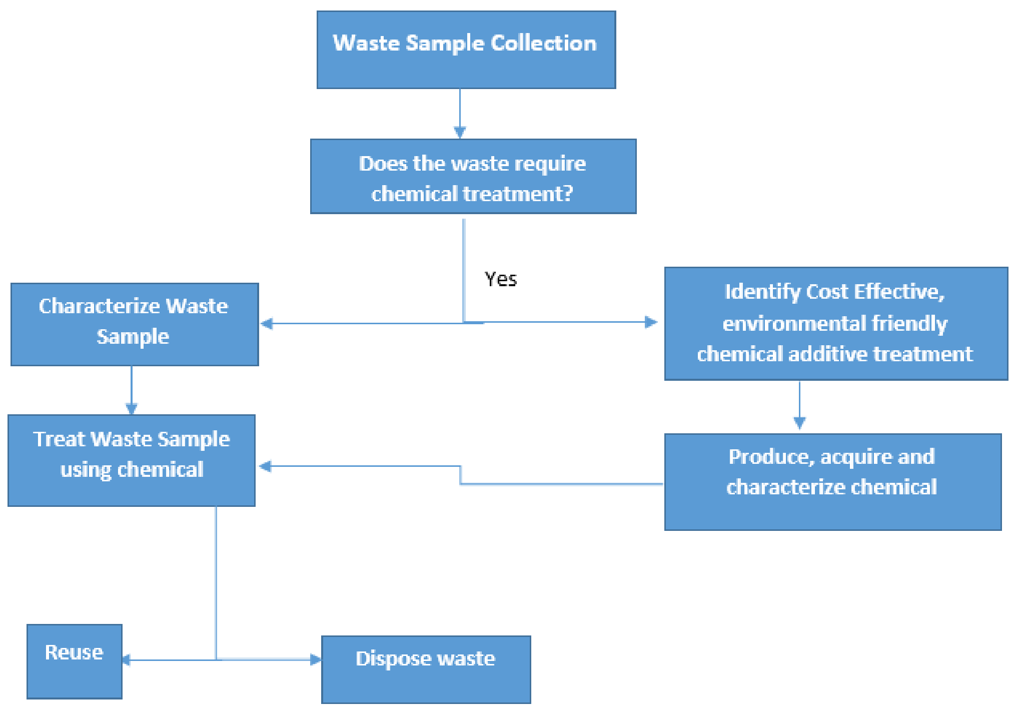

Figure 5 – A step by step experimental schematic in chemically treating oilfield drilling waste

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Effective Waste Minimization Strategy

It is known that oil based muds are more desirable than water-based muds due to its excellent lubricating properties, effect on fluid rock interactions, enhancement of wellbore stability and fluid loss control. However, the environmental concerns associated with oil-based muds are very enormous and hence the environmental regulations governing its use are usually very rigid. In order to maintain the desirable properties of oil-based mud with lower environmental impact, less toxicity and improved biodegradability is usually desired. An excellent candidate with such properties will be the synthetic based drilling mud. It is considered to be free of poly nuclear aromatic hydrocarbon, less toxic, biodegradable and poses lower bio accumulation potential. Globally, synthetic based muds have been utilized as a reliable replacement to the conventional oil based muds. This mud system reduces the amount of generated cuttings and eases the waste minimization and management process. Figure 4 illustrates an effective approach in oilfield drilling waste management.

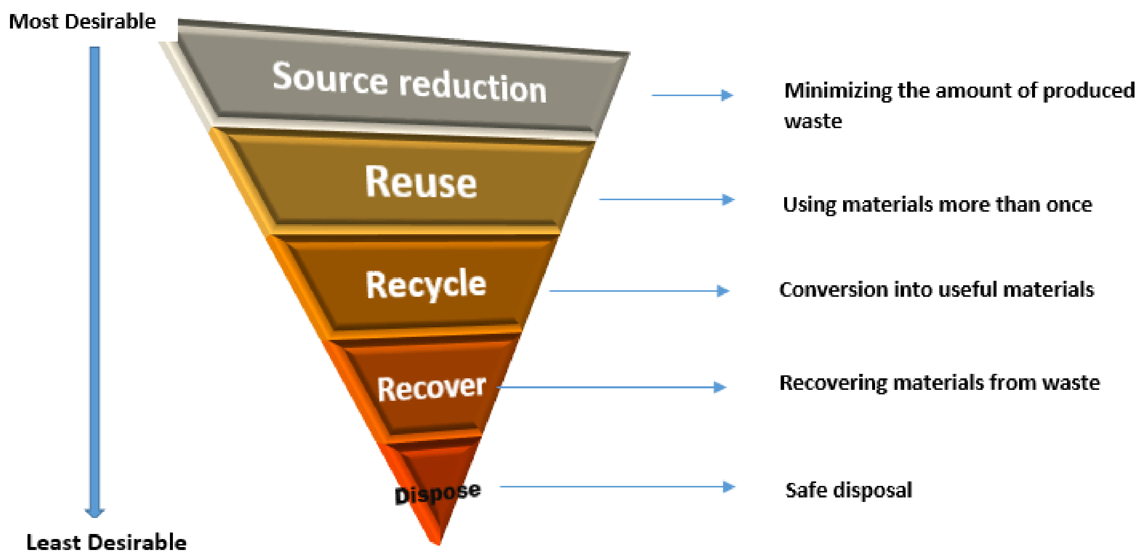

Figure 6 – Oilfield waste management strategic approach

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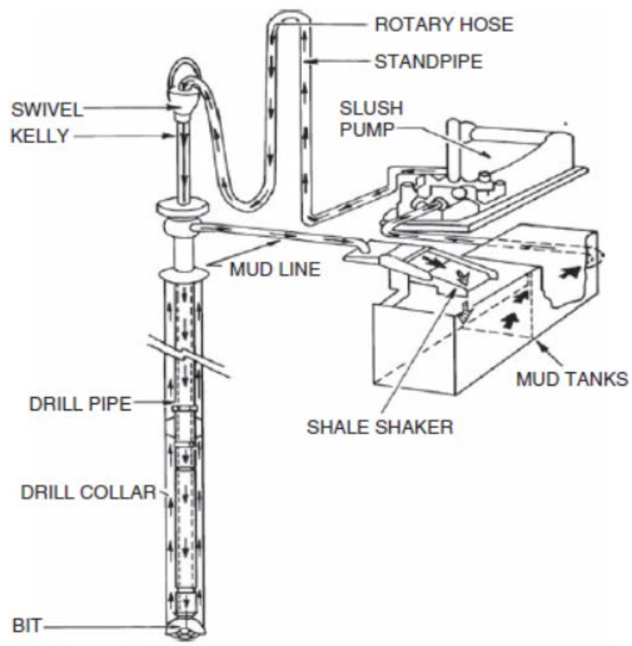

Figure 7 – Typical oilfield mud circulating system (

Discussions

Solid Management System consists of shaker shakers, centrifuges, Desanders, Desilters, and other mechanical, electro kinetic and thermal equipment installed at the surface. End result of effective solid liquid separation leads to either reuse or disposal of cuttings based on strict governmental regulations and environmental protection agencies. Operators, service providers and scholars are constantly studying and optimizing the technology behind oilfield waste solid-liquid separation. Although novel technologies have been recorded to be highly efficient separation materials, decision makers hold reserved attitude towards adoption of these technologies. Reason for this could be high cost of implementation of novel technologies. Further explanation could be unwillingness to change and adopt novel technological approaches since the old way is working. Application of new separation techniques must be strategically implemented at sites who need them the most. Reduction in risk exposure as an added advantage could be a further strategic approach and reason for the adoption of novel technologies in solid liquid separation.

In spite of the novel technological advancements in the development of solid liquid separation techniques, there is need for more research and development of more technologies. This will lead to high demand, reduction in waste management operational cost and equally boost the confidence of oil and gas operators in adopting these technologies in the offshore and onshore environment.

Current waste management techniques have proven to be effective but there is need to optimize available technology. A way to achieve this would be to enhance collaboration between the government regulatory bodies, environmental protection agencies, industry decision makers, oil and gas operators and research & development institutes.

Conclusion

Current oilfield drilling waste has proven to be highly effective, but there is still room for optimization of existing technologies and achieving minimal nonproductive time due to waste management operations. Observations have shown that majority of industry drilling waste management activities have been due to mechanical and chemical processes with minimal digital automation processes involved. As long as the technology behind drilling fluid selection, well configurations and drilling technology are continually evolving, there is need to optimize the waste management and solid-controls process through automation and digitalization.

With current advancements in the development of solid controls system, it can be categorically stated that the future seems bright in the development of enhanced and highly digitalized solid control systems.

Effective management and minimization of the volume of oilfield wastes begins from source reduction by selecting environmentally friendly drilling fluids. Solid-liquid separation techniques proven to be effective include: Installation of thermal desorption units, Electro separation cell installation, chemical treatment and biodegradation. These techniques together with the conventional surface solids controls system will further enhance drilling waste management program in onshore and offshore environments.

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