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A review of treatment methods for oil-based drill cuttings

Zhiqiang Huang[1, 2,*], Ziyang Xu[1, 2], Yinhu Quan[3], Hui Jia[1], Jianan Li[1], Qianchun Li[3], Zhen Chen[1, 2] and Kailun Pu[1, 2]

[1]Key Laboratory of Oil and Gas Equipment, Ministry of Education, Chengdu, China
[2]School of Mechatronic Engineering, Southwest Petroleum University, Chengdu, China
[3]CCDC Drilling &Production Technology Research Institute, Xi'an, China

*Corresponding author e-mail: huangzq@swpu.edu.com

Abstract. Globally, the operation of oil and gas exploration is increasing, which results in a large number of hazardous oil-based drill cuttings. These oil-based drill cuttings are bound to pose a serious threat to the environment and human health, so a series of oil-based drill cuttings disposal methods are urgently required. However, due to the complicated composition of oil-based drill cuttings and increasingly stringent emission policies, few methods that can fully handle oil-based drill cuttings which are generated under various complex conditions. Therefore, this paper illuminates different emissions policies for oil-based drill cuttings in various places. What's more, several treatment methods are comprehensively compared, and the development trend of treatment methods is discussed by combining the oil-based drill cuttings practical treatment examples in offshore and shale gas exploration.

1. Introduction

With the increase of oil & gas exploration in conventional and unconventional resources, the output of oil-based drill cuttings (a by-product of drilling operations) has increased significantly. Taking the UKCS (United Kingdom Continental Shelf) as an example, every year, more than 80,000 t of oil-based cuttings are produced in offshore [1]. At the same time, oil-based drill cuttings are regarded as hazardous waste by many countries. Not only are they difficult to handle, but improper treatments of them will pose a serious problem to the environment and human health [2]. Therefore, the treatment of oil-based drill cuttings has become a worldwide problem [3].

Currently, a series of oil-based drill cuttings treatment methods, such as thermal desorption, solvent extraction, solidification or stabilization and bioremediation, have been developed [4]. However, due to the complexity composition of oil-based drill cuttings and increasingly stringent emission policies, few technologies can deal with oil-based drill cuttings which are generated under a variety of complex conditions.

Therefore, this paper firstly illuminates different emissions policy for oil-based drill cuttings in the major regions around the world. Then, a variety of oil-based drill cuttings treatment methods are summarized and compared. Finally, the development trend of treatment methods is discussed by combining the oil-based drill cuttings practical treatment examples in offshore and shale gas exploration.

2. Oil-based drill cuttings emission policies

Emission standards for oil-based drill cuttings vary from one to another country. For instance, “zero emissions” standards are enforced in the Caspian Sea region of Kazakhstan, while in many regions of Southeast Asia, the oil content of cuttings is regulated to be less than 10% [1]. But the emission policy is a key factor in limiting and selecting oil-based drill cuttings treatment methods. Therefore, it is necessary to analyze the oil-based drill cuttings policy in major oil and gas production areas [5].

China's discharge requirements (represented by concentration limits) for oil-based drill cuttings in offshore are classified into three levels with different discharge sea area: First-grade area (oil content is less than 1%), second-grade area (oil content is less than 3%), and third-grade area (oil content is less than 8%). Oil-based drill cuttings can be discharged with the permission, but the Bohai Sea area completely bans the discharge of those cuttings [6]. However, there are some differences in inland emission requirements, such as the Sichuan Province's policy which requires no discharge of oil-based drill cuttings.

The United States Environmental Protection Agency (USEPA) prohibits the release of oil-based drill cuttings in all regions.

Norway stipulates that the cuttings with less than 1% oil can be discharged, but there implements a zero discharge policy in the Barents Sea.

Brazil does not allow emissions of oil-based drill cuttings and low-mineral oils, but it allows to discharge the enhanced mineral oil-based muds approved by IBAMA (the Brazilian Institute of Environment and Renewable Natural Resources).

The North Sea's emissions policy is developed by the OSPAR (Oslo and Paris Commissions), which specifies that oil-based drill cuttings not only need to contain less than 1% oil, but also pass toxicity tests to determine whether they are hazardous substances. The cut-off values for the toxicity test parameters are as follows:

1) Persistency: Half-life of 50 days;

2) Liability to Bio-accumulate: log octane-water partition co-effective ≥4 or bio-concentration factor ≥500;

3) Toxicity: acute LC50 (Lethal Concentration 50) or EC50 (Effective Concentration 50) ≤1 mg/l, long-term NOEC ≤0. Mg/l.

3. Treatment methods of oil-based drill cuttings

The drill bit will generate a large amount of cuttings while breaking the formation. The drill cuttings are carried to the ground with the oil-based drilling fluid, as shown in Fig.1.

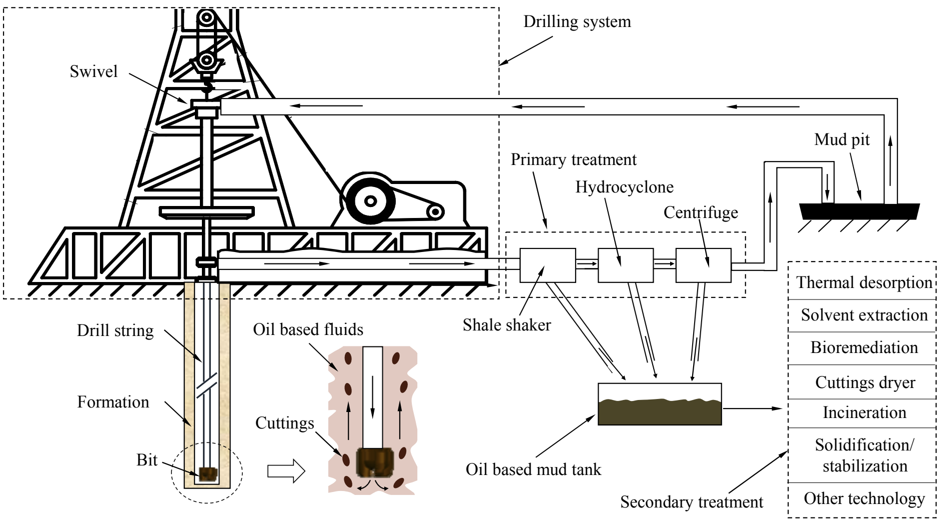

Figure 1. Schematic of oil-based drill cuttings treatment

The treatment of drill cuttings is divided into primary treatment and secondary treatment [5]. The purpose of the primary treatment is to remove the solid phase of the drilling fluid, so as to recover and reuse the drilling fluid. While the solid waste (the so called oil-based drill cuttings) separated from the oil-based drilling fluid is then discharged into the oil based mud tank. Generally, the oil content of cuttings ranges from 15% to 20% after primary treatment [1].

However, most regional emission policies require that the oil-based drill cuttings contain less than 1% oil. Therefore, the drilling site must adopt the necessary secondary treatment of oil-based cuttings in accordance with the emission policy requirements. The main purpose of the secondary treatment is to realize the harmless treatment of waste and the recovery and reuse of the base oil. The two most important technical indicators are the oil content of Residue after treatment and the base oil recovery efficiency [7].

The primary treatment equipment mainly includes a series of solids-control equipment, and the secondary treatment methods include thermal desorption, solvent extraction, bioremediation, chemical washing, Incineration, solidification/stabilization, and other technologies.

At present, the drilling site has equipped with proven primary treatment equipment, and the secondary treatment method is under development. Therefore, this section will focus on clarifying and analysing the above-mentioned multiple secondary treatment methods.

3.1. Solids-control equipment

Solids-control equipment contains a series of proven products, it mainly includes shakers, hydro cyclones, and centrifuges, as shown in Table 1. According to the control and processing requirements of solid particles, the drilling site shall be equipped with appropriate solid-control equipment.

Table 1. Characteristic of solids-control equipment

Equipment	Field products a	Working principle	Optimum cut points
Shaker		A periodically changing centrifugal inertial force is produced to force vibrate continuously, and the solid particles are sieved.	>74 μm
Hydro cyclone		Under the action of gravity and centrifugal force, the solid phase is separated from the liquid phase by utilizing the density difference between solid and liquid phases.	Desander:40-74 μm Desilter:20-40 μm
Centrifuges		Centrifuges can generate very large centrifugal forces (over 2000G) in order to remove very fine solid particles from the drilling fluid.	2~20 μm

a Source: MI-SWACO 2008

3.2. Thermal desorption

The thermal desorption technology separates and condenses most of the liquid phase oil in drill cuttings under anaerobic heating conditions. During the thermal desorption, water evaporates first, and forms steam to reduce the boiling point of the oil. Therefore, the thermal desorption will happen at a temperature lower than the theoretical evaporation value of the oil.

The commonly used thermal desorption system method includes indirectly heated drum type units (It heats the rotating drums which relies on the heat generated by the heating of the fuel.), screw type units (It circulate a hot fluid in the hollow screw), and directly-heated TCC units (thermal-mechanical cutting clean units that use friction to heat cuttings). All the units above can reduce the oil content of solid residue to less than 1%, and can recover the oil by condensation.

On the other hand, it also can be classified into a low temperature system and a high temperature system with the operating temperature. Low temperature systems (such as TCC) typically operate at 250°C to 350°C, while high temperature systems (such as indirect thermal desorption) can reach a temperatures of 520°C. The low temperature system are mainly used to treat wastes containing light oil, while the high temperature system can reduce the oil content of heavy oil-containing wastes. And the low temperature system has the following advantages:

1) If the oil in drill cuttings can be removed at a low temperature, not only can keep the ROC (retention on cuttings) to be less than 1%, but also a large amount of energy can be saved;

2) Compared to the high temperature system, the basic physicochemical properties of the recovered oil under low temperature environment are almost unchanged [8].

An indirect thermal desorption system requires a large heating area, which makes the system bulky, and it also consumes a lot of heat, as shown in Fig.2 (a). The TCC system not only solves these problems well, but also breaks the solid particles with hammer grinding, which reduces the diffusion of the oil, and recover the oil as much as possible. TCC has dealt with more than 15,000 t of oil-based cuttings in the UKCS region, it works with a treatment temperature of 240-260°C and an average throughput of 6t/h, which is sufficient among most drilling operations, as shown in Fig.2 (b). Nowadays, the TCC system operated by MI-SWACO is currently processing about 50,000 tons of oil-based mud every year in Kazakhstan [9].

(a) Indirect thermal desorption

(b) TCC applied in offshore oil field

Figure 2. Field application of thermal desorption.

Source: 1) Jacques Whitford, 2002 and 2) Gregoire, 2013.Rotomill experience. Report

3.3. Solvent extraction

Generally, supercritical fluids are selected as extract ants for oil-based drill cuttings, such as CO2, propane, and so on. A supercritical fluid is a state that exists between gas and liquid. It has a strong penetrating power as gas and a large density and solubility as liquid. In practice, cuttings are mainly extract with supercritical CO2 technology. The basic method of supercritical CO2 extraction technology is to mix waste oil-based drilling fluid with supercritical fluid, and the oil is extracted into supercritical fluid. After the decompression and desorption of the oil, so the solvent and the extracted oil both can be used again. But the process needs to be implemented under a high pressure of 14.5MPa, and a relatively high temperature of 40°C.

For the difficult conditions (the high pressure and temperature) of supercritical CO2 extraction technology, a method for replacing CO2 with liquefied gas (such as propane and butane) has been developed, which is named as Liquefied Gas Extraction. There are experiments that use the butane as a solvent to treat ester/olefin on cuttings. It works at 500psi pressure and room temperature, which can effectively reduce the oil content of cuttings from 21% to 0.24%. And the analysis of the recovered base fluid shows that its quality won’t be changed, and it can be reused in drilling operations [10].

3.4. Bioremediation

Bioremediation technology takes advantage of the organisms degradation (such as bacteria, plants, fungi, etc.) to degrade hydrocarbons in oil-based drill cuttings. Bioremediation includes composting, land farming, land spreading and bioreactors. And it is a natural process that fundamentally realizes the harmless treatment for oil-based drill cuttings. However, bioremediation needs a long treatment cycle (the duration ranges from several weeks to several years, and the shortest one is bioreactors), and the rate of repair depends mainly on: 1) the repair environment, 2) the composition of oil-based drill cuttings, and 3) the processing type. In addition, bioremediation is sensitive to external factors such as ambient temperature. Therefore, the robustness of this method is poor. Besides, bioremediation requires a large area of land, and it can’t recover the energy and material in oil-based drill cuttings.

3.5. Incineration

The incineration technology is to oxidize the organic components in the oil-based drill cuttings at a high temperature of 1200-1500°C, and converts the contaminants to inert residues. Incineration technology can dispose almost any waste, and avoids the waste pollution to the environment, also it can dispose a huge number of cuttings. However, incineration has following disadvantages:

1) Inability to treat inorganic components in oil-based drill cuttings, such as metals;
2) Extra dust removal equipment is required to remove metals from the steam;
3) It consumes too much energy;
4) Large amounts of carbon dioxide and nitrogen oxides are generated.

3.6. Solidification/stabilization

The USEPA defines solidification/stabilization as follows:

1) Solidification refers to techniques that encapsulate the waste in a monolithic solid of high structural integrity. The encapsulation may be a fine waste particles or a large container of wastes (micro encapsulation);

2) Stabilization refers to those techniques that reduce the hazard potential of a waste by converting the contaminants into their least soluble, mobile or toxic form.

Generally, it is required to ensure the oil-based drill cuttings remain in it by the coordination of solidification and stabilization. The use of solidification/stabilization techniques can greatly reduce the effect of harmful ions and organic matter on the soil, and the resulting product can be used for paving, backfilling or building. However, the cost of this technology and the agential is high, and it needs a large space, also there are some potential safety hazards.

3.7. Cuttings dryer

The cuttings dryer is a transformation from the coal industry. It is based on a high-speed rotating centrifugal mechanism to remove oil from oil-based drill cuttings [10]. According to the axial direction of the centrifugal, drill cutting dryers are divided into horizontal and vertical types. For example, MI-SWACO's Vertis GTM cuttings dryer is a vertically mounted dryer, while the Hutchison-Hayes Dusters is horizontal [11].

The oil recovered from the drill cuttings dryer can be used to compound a new oil-based drilling fluid. Drill cutting dryers are used extensively in the Gulf of Mexico. A number of studies have reported their treatment effects. For example, the study by Melton et al. showed that drill cutting dryers reduced ROC from 11.8% to 2.1% [12]. Cannon et al. reported the efficiency of drill cuttings dryer treatment in 23 wells, and the data shows that the average ROC was decreased from 11.47% to 3.99%, while the ROC of a single well was between 2% and 6% [11].

4. Discussion and conclusions

From the summary and comparison of the major method to dispose the oil-based drill cuttings, it is known that when selecting treatment methods, the government legislation, operator environmental standards, cost, safety, logistics and other factors should be taken into consideration.

A single method won't be applied to all oil-based drill cuttings processing conditions, because the method needs to be selected according to the requirements of field applications. For example, when dealing with oil-based drill cuttings produced by offshore drilling operations, because of the limitation of the deck area, large-area processing methods cannot be used. Therefore, the offshore oil-based drill cuttings always use TCC technology.

In addition, the combination of multiple treatment methods can not only improve the processing efficiency of oil-based cuttings, but also meet the stringent emission policy requirements. For example, such as Weiyuan and Changing in Sichuan, shale gas development areas requires "zero emission". Thus, firstly thermal desorption or solvent extraction are usually used to reduce the oil content of oil-based drill cuttings and recover the oil, finally the solidification/stabilization or incineration is used to dispose solid residues to meet regulatory requirements.

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