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Greenhouse-Scale Lab Techniques Used to Optimize Removal of Chlorides from Drill Cuttings and Qualify the Feasibility of Beneficial Reuse in the Field

Kayli Clements, M-I SWACO; Gary Fout M-I SWACO; Will Marchbanks, M-I SWACO; Dorsey Rogers, Cimarex

Abstract

There has been increasing interest in the land application of cuttings during the recent decade; however, the primary focus has been placed on the recovery of hydrocarbon-impacted soils. There are other components present in the drilling fluid or introduced by the formation into the mud and cuttings that may cause problems in the environment if allowed to come in contact with the topsoil or seep into ground or surface waters.

Operators in New Mexico (NM) have become particularly interested in beneficial reuse as they move away from the traditional method of open horseshoe pit systems in favor of closed-loop systems. Closed-loop drilling generates less waste, releases fewer toxins into the environment and eliminates the need for large earthen pits dug into the landscape. An internal study of wells in this area indicated that rising costs of operations have made it difficult to drill economically in several zones using a closed-loop system. One way to alleviate the strain is to minimize haul-off costs by beneficially reusing water-based mud (WBM) and cuttings on site, but there are some areas in NM where salt in the formation makes it necessary to drill with saturated salt fluids. The result can be hundreds of barrels of salty drill cuttings and an increased disposal cost.

Salt-contaminated cuttings have made it necessary to research several new approaches of handling drilling byproducts onsite and make it possible for the operators in NM to continue drilling economically. This document will describe research of innovative methods to optimize removal of chlorides from drill cuttings and further research into their use as soil or construction material. These tests make it possible to qualify new technologies through greenhouse techniques to determine their feasibility and optimization in the field.

Introduction

For many years, operators in NM have been using open horseshoe reserve pits for solids control and disposal of mud and cuttings. Operators and service companies have been working together to eliminate the use of earthen reserve pits, thereby decreasing the amount of waste generated onsite. With the use of highly efficient solids-control equipment, a system has been developed and used in NM that can process water-based drilling fluid at the rig site with very high efficiencies and with relatively low fluid retention on the removed cuttings. Effluent volume decreases with increasing solids-control equipment and efficiencies; thus there is no need to dump large volumes of fluids. Records indicate that an average of 3,800 m^3 (24,044 barrels) of material intended for disposal was removed from each pit in the study area. A typical hole volume for each well is 177 m^3, representing a ratio of 21.6 times the hole volume. With the new solids-control process, the volume of cuttings estimated in the pile is 819 m^3, a ratio of 4.6 times the gauge hole volume. This is dramatically lower than the 21.6 ratio-to-hole volume for cuttings and fluid left in the pit for disposal under the previous operating mode.

While closed-loop systems significantly reduce waste volume, they do not completely eliminate waste. The typical well in New Mexico still has 819 m^3 of salty cuttings that need to be managed. Burial disposal is an option for the dry cuttings but is not desirable since the overall goal is to eliminate the need for a pit and thereby reduce the liability. Another option is to haul the cuttings to a landfill, but costs of hauling could, in some areas, eliminate the savings margin that closed-loop drilling provides to the operator.

Recent proposed modifications in NM oilfield regulations have presented an opportunity for alternative treatment and management options for salt-contaminated cuttings. Some of the alternative management techniques being considered include beneficial reuse as fill material or top soil. The purpose of this project is to develop economic and technical information to support the viability of new beneficial reuse options. The target for these treatment methods is to develop a lower cost structure and better environmental solution as compared to traditional onsite burial and haul-off options for residual cuttings from closed-loop systems.

One of the key concerns is maintaining cost-effective drilling operations while improving waste management techniques. The results of financial analysis indicate that eliminating the pit in NM is cost effective in areas where excavation is difficult and/or the water table is high. In other areas, such as Quail Ridge, excavation is easy due to high sand content instead of hard koliche clay and water tables located below 65 ft; thus, current economics favor the open horseshoe pit system. When solids can not be buried onsite and must be hauled for commercial disposal, eliminating the pit actually saves money. Operators in NM have already made significant strides toward waste minimization; the full benefits of these in combination with beneficial reuse options will form the basis for justification of the proposed management options.

Salt-Contaminated Cuttings

A major problem for operators is salt contamination of mud and cuttings. Saturated salt solutions are used to drill wells where salt in the formation is anticipated. This is the case for many wells in NM where salt stringers exist in the geology of the region. The result can be several thousand barrels of salty drill cuttings and a significant disposal cost since the presence of the salt eliminates the option to reuse the cuttings as fill material or soil. Most often the salt in the cuttings is sodium chloride (NaCl).

Salt is a major problem for many reasons. First, breaches in pit liners can leak salt into the soil below where it can migrate deep into the ground, sometimes creating a plume that must be chased down and removed by excavation. Time, equipment and haul-off costs to clean up salt plumes can be extremely expensive and counterproductive. Second, salt does not biodegrade. Once it has contaminated an area the only solutions are removal or dilution. Third, salt is highly mobile and dissolves quickly and completely in water. It can contaminate groundwater, which can carry the contamination for miles and resurface in unexpected areas. Finally, salt in the soil affects osmotic intake of water by plants and kills beneficial bacteria and other organisms in the same way. Sodium chloride salt increases the sodium absorption ratio (SAR) and ruins the soil structure. Most plants cannot grow in salt-contaminated soils and the result will be intense scarring on the land surface.

Traditional methods of salt management are simply to contain the problem in bermed and lined pits, burying the cuttings below the root zone in a non-permeable envelope or re-injection to the subsurface. There are problems with these techniques, including the previously mentioned cleanup costs caused by breached liners.

The migratory nature of salt is highly resistant to containment in a specified area, and if allowed to escape from the buried cell, the salt will quickly rise to the surface by evaporation and kill the plants growing there, or transversely, by hydrostatic pressure quickly find its way to groundwater. Second, landfills and re-injection sites are being filled with WBM that could easily be disposed of onsite if the chlorides had not been introduced into the mud system or leached from the formation during drilling operations. Harmful components, such as sodium and chloride, that find their way into the mud system can, in some cases, be leached or naturally attenuated to acceptable regulatory limits with clean water, thereby making the treated cuttings acceptable for land application. The challenge in NM is finding cost-effective solutions to minimize and remove the salt contamination from the mud and cuttings.

Hierarchal Approach to Minimizing Waste

The hierarchy of waste management was used to develop plans for removal of salt from the drilled cuttings. The first tier is waste minimization at the source; remove the salt from the mud system and there will be less waste created. Clearly, the application of closed-loop systems is a very significant step forward because it allows the water from the mud to be recycled and removes most of the residual water from the drilling process. The results are a dramatic 75 percent reduction in salty waste. Efforts have continued to look for other operational opportunities the eliminate salt from the mud and cuttings. One major operator in NM has reworked their drilling program and agreed to case off the section that contains the salt zone and drill only that interval with salt-saturated WBM. The sections above and below did not need the high amounts of salt in the drilling fluid to control fluid loss and washout as in the salt zone. The effluent and cuttings from this high-salt-content section should be separated from the rest of the drilled cuttings from the sections above and below so as to not contaminate a larger volume of cuttings through contact and seepage. In this manner, additional reductions in salty waste can be made before any treatment techniques are applied.

Once cuttings are created, reuse is the most effective and least expensive way to manage drill cuttings. If they can not be reused, burial or injection are the final and least preferred methods of treatment. Only the cuttings highly contaminated with salts should be sent to the landfill (such as centrifuge discharge) – or approximately ¼ to ½ of the entire waste stream. The drill cuttings are, for the most part, free of salt except for the portion of the waste from the salty interval; the volume that must be handled by a secondary salt removal process has been cut by at least half (Fig 1). The current research focus is to explore ways to treat and manage residual salty cuttings so that they do not have to be hauled off or buried onsite.

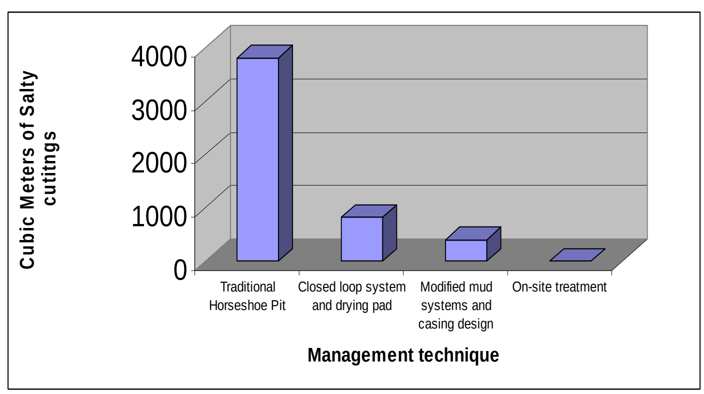

Fig. 1 – Cuttings management can reduce the volume of waste requiring treatment / disposal.

Physical and Chemical Treatment of Salty Cuttings

Previously, the only way to determine the potential of cuttings treatment was a full-scale field trial involving several hundred barrels of drill cuttings and a large area of the lease.

A field trial of this size can tie up manpower, time and money, and in the end, sometimes yield disappointing results. There is a need in this industry to develop a tool for determining the endpoints and qualify wastes to be used safely and responsibly onsite. It is useful to optimize the amendments and management of waste in the lab before applying the technology to the field. Just as labs develop and test the performance and quality of drilling fluids before introducing them to the clients, the same can be done with drilling waste before the operator expends valuable resources on an unproven theory with a full-scale project. Greenhouse-scale testing can be used to address the management and removal of several common contaminants that typically render drilling waste unsuitable for beneficial reuse.

To find the most cost-effective and practical treatment options, several approaches were considered for treating the salty cuttings to the point at which they could be beneficially reused. Some of the leading options are discussed below.

Mechanical Washing and Soil Amendments

The basic idea is to wash the cuttings using a mechanical system as part of the solids-control process. The mechanical washing device can be placed behind the traditional shakers and receive the cuttings coming over the screens. Freshwater is used to wash and soak the drilled cuttings. If the cuttings have been purged down to a regulatory approved level of chlorides, then the next step is to make amendments to improve the cuttings' functionality as soil. The batch can then be spread onsite. The primary advantage of mechanical washing systems is the ability to incorporate the process into the active mud system. The challenge of mechanical washing systems is managing the large volumes of water associated with removing the salt.

Leaching Pad

Another technique allows cuttings to be treated after they have been generated, using a drying pad to leach salt from the cuttings. The rate of salt removal from drilled cuttings depends on several parameters (1) concentration of salt (2) particle size, *i.e.*, clay content and (3) contact with freshwater. Several rounds of leachate testing using samples of drilled cuttings have allowed us to determine blends of additives and physical equipment (e.g. grinding equipment) to help increase water efficiency in removing salt ions from solid particles.

Salt is leached down to an acceptable level and collected in designated areas of the leaching pad. The salty water can then be either incorporated back into the mud system, depending on the salinity, or taken to a re-injection site for disposal. There may be some salt in solid form collected from the pile which can be incorporated into the active mud system. After the leaching process, drilled cuttings will be incorporated into the soil matrix below the regulatory limits, used as the base for tank batteries at the leased site, or incorporated into an aggregate material to be used as road bed for state highways.

Chlorides from the salt leaching process will be protected from entering ground and surface water with the use of liners and bermed areas around the leaching pad. Once the salt is removed from the cuttings, it is no longer the concern that large amounts of chlorides will leach out of the cuttings and become a hazard to the environment.

Addition of Calcium Ions

There are also ways to chemically enhance the removal of chloride ions from the drilled cuttings that are contaminated with sodium chloride salt. Montmorillonite, vermiculite, illite, and mica-derived clays are more sensitive to Na^+ than other clays. Adding calcium acetate or gypsum to the freshwater wash solution will promote a base exchange, swapping sodium ions for calcium ions. As a result, more chloride is free to dissolve into freshwater and be removed from the cuttings medium.

Beneficial Reuse

Once the cuttings are free of chlorides they can be disposed of beneficially. Drill cuttings have been used as both a soil and a soil enhancer in many areas. The texture of cuttings can sometimes enhance native soil structure when shale cuttings are added to sandy soils. Conversion of WBM drill cuttings to soil is an active project that has been pursued with customers operating on BLM land in Colorado, New Mexico, Texas, and Wyoming. To convert drill cuttings to soil, a process needs to be used that ensures an end result that meets an acceptable standard. By using a logical design and quality control system, the beneficial reuse of cuttings can be developed. Listed below are some of the basic process steps that are being pursued to develop beneficial reuse options.

Reuse as Soil

- Identify target properties and standards of beneficial reuse product.
- Design fluids, solids-control and treatment processes to meet appropriate standards and minimize contaminants and toxic materials.
- Conduct pitless drilling operation.
- Store cuttings on pad.
- Treat reuse material as a product and document design criteria achieved with QA/QC controls.
- Identify soil properties required to support plant life.
- Amend cuttings as needed to meet physical and chemical properties required to support plant life. Test product using standardized tests and record results.
- Monitor end products and ensure end-use market acceptability Use byproduct as soil and seed to prevent erosion. Monitor location to ensure that the target soil properties are effective.

Greenhouse-Scale Procedure for Salt Leaching

Several laboratory methods have been implemented to explore the options of removing chlorides.

Physical Salt Leaching

The first option is to design the leaching pad to efficiently remove salt from the drill cuttings. An experiment was designed to test the effectiveness of several amendment combinations, pad depth and washing cycles on cuttings sent from the field that contained anywhere from 15,000- to 50,000-ppm chlorides.

The test containers were 3-in. diameter acrylic tubes tied vertically to PVC scaffolding. Each tube was set down into a plastic pot 4½-in. in diameter. Gravel was poured 3 in. into the tube (Fig 2). The gravel in the pot anchors the tube and provides a filtering barrier for the contents inside the tube. One liter plastic tri-pour containers were suspended with hooks below each tube to collect the leachate that was discharged from the sample. The PVC tubes were filled with various combinations of drilling waste materials and amendments for a total of 500 cm³. The combinations are summarized in Table 1. The field samples of cuttings were provided from a well in southeast NM. The low, medium and high chlorides content reflect subsequent sections of the well and the introduction of chlorides at that level. The cuttings also displayed different physical properties with varying quantities of clay and sand content. The differences in leachabilty due to the physical aspects were also observed and will be discussed in the results section.

Water was flushed through the tubes and the leachate was collected in the suspended containers beneath the tubes. Each flush contained 250 mL of water; this volume was chosen arbitrarily and will qualify as a "wash" for all leachate Later, it was determined that the amount of water used per wash should create a 1:1 dilution after passing through the medium in adherence to LA 29-B procedure for chlorides testing. Therefore, in subsequent studies the amount of water in each "wash" is equal to the mass of drill cuttings present in that sample on a dry-weight basis. The "washes" were repeated until the leachate reached 300-ppm chlorides. The leachate was tested for chlorides using the titration method with silver nitrate and potassium chromate; the results were confirmed using a refractometer.

Fig. 2 – From left to right: first tube contains 50% gravel, second contains 50% peat, and third contains 100% cuttings.

Table1 - Amendment Combinations

Field Sample	Amendments (50% by vol.)	Total (cm³)
Low (27,000 ppm Cl^-)	None	500
Medium (29,000 ppm Cl^-)	None	500
High (34,000 ppm Cl^-)	None	500
Mix (low, med, high)	None	500
High	Hay	500
Mix	Peat	500
Mix	Hay	500
Mix	Gravel	500

Chemical Salt Leaching

Lab tests were performed to test the removal of chlorides through the addition of calcium acetate and gypsum. 20 g of Oxford cuttings were soaked in a 20 %NaCl solution for 8 hr. The cuttings were then removed from the salt solution and placed in a different chemical solution to soak for 16 hr in the chemical solution. The cuttings are then removed from the chemical solution and washed with 100 mL of DI water over a 60-mesh screen. The cuttings are then added to 100 mL of DI water and homogenized in a Waring blender. 15mL of this mixture is centrifuged for 5 min and the supernatant is analyzed for chlorides content.

Seed Germination and Root Elongation Test

The seed germination and root elongation test is used to demonstrate the reduction in plant toxicity. In addition to chemical contaminants of concern, seed germination studies ensure that soil structure and chemistry is appropriate to support plant growth. The procedure requires that twenty alfalfa (*Medicago sativa*) seeds be planted in each test container and allowed to grow for 14 days (Fig. 3); at the end of that time the germinated seeds were counted and their root lengths measured. This information was entered into statistical software that determines the concentration-response curves for seed germination and root elongation. This test determines the acute toxicity of drilling fluid systems and additives for onshore application. It is based on the procedure outlined in ISO 11269-1 and the EPA Seed Germination and Root Elongation test method. Positive seed germination results will attest to the potential for use as soil of the leached cuttings and amendment mixtures.

Fig. 3 – *Medicago sativa* in salt-leached drill cuttings after two weeks of growth.

Results

The nature of the cuttings (*i.e.*, clay, sand, silt) determines the accessibility that water has to the substance of concern. Drill cuttings that consist primarily of clay with very fine particles do not allow water to flow through all spaces to dissolve the offensive substance; likewise, an extremely clay-laden soil will be more likely to hydrate and pack off, thus keeping the water from penetrating through the pore spaces and reaching the root growth zone. Adding amendments can increase the leaching potential, and subsequently, the soil structure when it is time to recycle the material. Adding organic amendments increases the pore space and moisture holding capacity and improves the overall structure. The key is to find the balance between a material that holds water in contact with cuttings but allows the water to slowly drain out. This is an economic and a structural challenge because the end goal is to use amendments that will enhance the cuttings for the particular application for which they are intended, such as soil, roadbed or another form of beneficial reuse.

The tube leachate tests show how well the amendment allows water to percolate through and dissolve chlorides. By measuring the chlorides in the wash water, the effectiveness of the addition is determined. In the tubes and by analyzing the soil afterwards, four characteristics were identified that determine the success of the cuttings and amendment mixture: retention, drainage, resistance to pack off, and soil quality.

Retention is the amount of time that the water was held in contact with the cuttings. This is an important aspect because the water should be held in contact with the salt for several seconds to be able to dissolve it from the cutting.

Drainage. At some point it is also important that the chlorides are allowed to drain away from the cuttings and out of the tube; the material is rated on the drainage of water.

Resistance to pack off is determined by the clay content and the effect that the amendment has on breaking up the clay aggregates. When the sample packs off, water will not penetrate; in the field this would mean that the water would run down the sides of the pile and the wash would be useless.

Finally **soil quality** is important for the end use of the cuttings. For example, adding gravel would increase the potential of cuttings as roadbed but would inhibit the option of using the washed cuttings as soil. This was proven with the seed germination tests showing that alfalfa did not grow as well in soils containing a high percentage of gravel. Table 2 ranks the amendments in each category from 1-5, 1 being the best performance in that category and 5 being the worst. The amendments with the lowest overall total are the best choices for physical leaching amendments.

Amendment addition increased seed germination compared to the control and greatly increased germination and growth compared to the background soil levels. The mix of cuttings with peat produced the longest root lengths and greater than average germination. The native soil from that area did very poorly in both seed germination and root elongation; therefore, in this case the background target is low. The trend shows that increasing amounts of gravel negatively affected the growth of seeds in the soil. The results from the chemical salt leaching experiment indicate that about 1% gypsum and 3% calcium acetate is necessary for maximum enhancements of chloride removal compared to water without chemical amendments; these percentages outperformed higher additions. In the case of gypsum, higher additions could cause other problems with the soil structure that would decrease the productivity of any healthy soil.

Table 2 – Amendments Ranked on Performance Based on 4 Key Parameters

	Retention	Drainage	Resistance to Packoff	Soil Quality	Total Score
No Amendments	4	3	4	3	14
Peat	1	5	5	1	12
Hay	2	4	3	2	11
Gravel	5	1	1	5	12
Sand	3	2	2	4	11

Conclusions

Since the closed-loop system has been operational for some time, the focus of this project is to further develop the pathway to appropriate beneficial reuse.

The operational and economic targets have been identified as the closure alternatives to beneficial reuse for closed-loop systems. Using these targets as guidelines, the following elements will be pursued in project design and operation.

- Design and plan to reduce waste
- Minimize hazards associated with equipment and material usage
- Consider full environmental impacts, including air pollution, water pollution and habitat disturbance
- Move toward beneficial reuse

In many cases, the correct combination of mechanical and chemical treatment exists that can make it economically possible to leach the salt from the cuttings onsite making beneficial use possible.

Greenhouse-scale screening techniques are very useful in determining the outcome of physical and chemical treatments to the drilled cuttings before the techniques were applied in the field. Every formation is different; therefore the composition of the waste generated from each well will be different and the optimal treatment potentially differing. Physical analysis and amendment modification should be done for each sample to determine how to transform that material into a useful product capable of meeting regulations and functioning in the capacity for which it was intended.

This is the first of many trials which will be undertaken to refine and focus these testing procedures and applications of this and similar studies. These greenhouse trials have provided a wealth of information helping to understand the parameters involved in salt removal and beneficial reuse as soil and how to manipulate those parameters to increase efficiency and define limitations to this research. Beneficial reuse is the future in the oil and gas industry. Faced with increasing scrutiny on disposal methods and operations from private land owners, regulatory bodies, and the media, it is important to explore alternative management options in order to be prepared for change and to ensure the continuation of drilling in existing and developing fields.

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