THE TREATMENT OF DRILL CUTTINGS USING DISPERSION BY CHEMICAL REACTION (DCR)

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ABSTRACT

Drill cuttings consist of various rocks, particulates and liquids from geologic formations in the drill hole. These cuttings are coated with drilling fluid. The drilling fluids are suspensions of solids and dissolved materials in base oil or water that are used to maintain hydrostatic pressure control in the well, lubricate the bit, remove drill cuttings from the well, and stabilize the walls of the well during drilling or work over operations. The drilling fluids with the cuttings from the well are discharged to a rig shell shaker where the cuttings are separated from the drilling fluid. The separation step does not completely remove drilling fluid from the cuttings, as such; some drilling fluid and additives remain on the drill cuttings.

The Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGSPIN) Revised Edition, 2002, stipulated the drill cuttings discharge limitations for inland / near-shore and offshore deep water in order to minimize the adverse impact on the surrounding environment. Drilling inland and near shore within 12 nautical miles and 200 feet of water depth, the limitation is zero discharge, and for the offshore / deep waters various limitations are stipulated for different types of mud systems. These requirements therefore had called for an appropriate drill cuttings treatment prior to disposal in order to meet the stipulated conditions.

The drill cuttings treatment methods recommended in the Second Edition of the Environmental Guidelines and standards for the Petroleum Industry in Nigeria include: thermal desorption, re-injection, incineration and solidification. This paper reviewed the advantages and disadvantages of these treatment methods and studied an efficient and effective solidification and stabilization method that could be a preferred method for the treatment and disposal of drill cuttings. This treatment method is "Dispersion by Chemical Reaction (DCR).

In addition to solidification and stabilization, this method encapsulates too. The non-aqueous fluid phases are transformed into solid preparation, while with respect to the aqueous phases, their solubilities are made insoluble through an irreversible chemical and physical fixation of the water-leachable constituents of the waste material. Essentially, the DCR technology involves the treatment of the cuttings with hydrophobized Calcium Oxide to form a dry, soil-like material. The resulting immobilized solid mass can then be used as construction material.

The efficacy of treating drill cuttings by DCR technology was demonstrated by bench test. A leachate test conducted of the DCR treated drill cuttings gave values of parameters, including heavy metals, far below the EGSPIN stipulated limitation levels. The resulting mass was successfully moulded to form interlocking bricks that can be used in road construction. The unconfined comprehensive strength tests value obtained for the DCR treated drill cuttings was 37psi, while the DPR minimum standard for the solidified material is 20psi. A control test using natural sand to produce similar construction interlocking bricks gave a test result of 38psi.

From the results of the treatment of drill cuttings by DCR process, when qualitatively compared with other treatment methods, the technology can be preferred for treating drill cuttings. The process has a value-added end-product, which can successfully be used in construction. The raw materials in the treatment process can be locally sourced and the re-usable end-product is non-polluting and therefore, environmentally safe to be put into other uses. The paper concluded by recommending DCR process for treating drill cuttings.

INTRODUCTION

In order for damage to be caused in biological system, there has to be a physiological interaction between a toxic substance and a living organism. For this purpose, a potentially dangerous material has to be introduced to the biological system in a biologically "available" form. The mobility and bioavailability of toxic compounds determine their concentration in the environment at which they have an adverse effect on living organisms.

A variety of treatment methods have been proposed and tried in a bid to convert toxic liquids and sludges into harmless solid materials thereby rendering them biologically unavailable. Most of these processes involve the application of inorganic materials with high absorption capacities and/ or pozzalanic characteristics. Accordingly, the long-term properties of stabilized and solidified wastes depend on the characteristics of the corresponding absorption / desorption equilibrium and on the mechanical stability of the monolithic systems involved. Typically, these methods have been based on producing a hardened matrix to incorporate the contaminant using pozzalans as additives

These methods, however, fall short of requirements when used for certain waste materials that have certain inorganic compounds or high concentrations of organic matter. The compounds retard and even prevent the solidification of mixtures, for instance, when cement was used to solidify PCB-contaminated oily soil. Treatments like these may form' monolithic' solids at the time of treatment but, as experience has shown, will disintegrate spontaneously in the course of a few years.

Additionally, some of these techniques have failed under test conditions after wet/dry cycles, as the deposited materials would have to withstand in the natural environment. Similar mechanical breakdown have also occurred with respect to attempts at sealing mobile phases as a whole in landfills lined with concrete and impermeable plastic foils. These materials unexpectedly lose their initial optimum chemical and mechanical properties after long-term contact with solid or fluid substances and spontaneously disintegrate. Also cracks often occur as a result of inhomogeneous setting properties due to different constituents in waste materials.

Indefinitely long-term costs of maintaining such systems including drainages, treatment of seepage water, and transfers in-between new sites emphasizes the inefficacy of these numerous stabilizing waste treatment methods

Dispersion by Chemical Reaction (DCR) is an advanced solidification, stabilization and encapsulation method for waste treatment [(1)]. DCR results in a complete and irreversible immobilization of non-aqueous fluid phases by transforming them into solid preparation, and with respect to aqueous phases by removing their solubility, through an irreversible chemical and physical fixation of water-leachable harmful substances.

A real and complete detoxification of organic contaminants is achieved through DCR supported chemical and biological processes. Dispersion by chemical reaction involves the use of a dispersing chemical agent, in this case, calcium oxide (CaO) in a chemical reaction with toxic wastes in aqueous or non-aqueous solutions to form an extremely and finely dispersed pulverulent solid preparation. Drill cuttings generated from E & P activities can be successfully treated using the DCR process.

Drill cuttings consist essentially of inorganic materials like sand, gravel, clay, rock, etc, characteristic of the geology of the drilling location interspersed with organic phase from the drilling fluid used in the drilling.

The objective of the DCR technology is to treat the drill cuttings in such a way that the organic contents or contaminants in the cuttings matrix are stabilized and the heavy metals are encapsulated and the entire mass solidified into solid mass. In the DCR process, it is required that all the organic contaminants in the drill cuttings or contaminated soil be “reached” or treated without leaving any residues. The drill cuttings must be homogeneously transformed into a finely dispersed form for this process to be effected.

With the aid of a pre-treated calcium oxide, the dispersed form is converted in a DCR system into a dry pulverulent solid preparation. The CaO treatment agent plays a double role in the treatment of drill cuttings or oil contaminated soil. It assures, first, the complete incorporation and dispersion of the organic phase in the DCR process, and then, the chemical fixation of heavy metals in the drill cuttings. The dispersion chemical reaction results in the formation of a water-insoluble (non-bioavailability) product, which in the form of limestone, is a natural and harmless basic component of our environment.

The solid and finely dispersed DCR reaction product can without any difficulty be incorporated in both, a water-impermeable body of soil and in pozzolanic systems.

Accordingly, the product can be used as an earth construction material for refilling and road construction, embankment fill, and also, can be used in forming cement and concrete blocks for curbstones, roads and foundations. It is important to add that the re-use of DCR treatment materials improves the economy of the whole treatment process significantly. These numerous advantages of DCR treatment technology emphasizes its potential in managing wastes generated from oil exploration and production activities.

Examples of the application of DCR technology for various waste materials are shown in Table 1. From the table, it is shown that the DCR stabilized waste materials find their use as construction material for road and parking site, construction back fill, embankment fill, land reclamation for cultivation, etc.

Table 1: DCR Technology Selected Applications And End Use of DCR Stabilized Materials [(2)]

LOCATION	TYPE OF WASTE	END USE
MOBIL OIL AG Bremen	DIESEL FUEL IN SOIL	Reuse as an earth construction material (soil stabilization)
BEB ERDGAS U. ERDOL GMBH. Hannover	OILY DRILLING MUD	Reuse as an earth construction material for road construction.
TRICIL Montreal	OILY MUD	Reuse as an earth construction material (stabilization of surfaces)
GERMAN TEXACO AG Hamburg	DRILLING MUD Hankesbuttel Site	RECULTIVATION Through DCR supported biological degradation (arable land, pasture)
GBS FRANKENTHAL Ingelheim	OILY MUD AND ACID TAR	RECULTIVATION Through DCR supported biological degradation (arable land, pasture)
KUWAIT PETROLEUM Rotterdam Euro	HAZARDOUS WASTE PIT Including oil contaminated soil and bituminous residues	Reuse as an earth construction material (stabilization o surfaces, parking site)
PREUSSAG AG Edemissen	HAZARDOUS WASTE PIT Including oil contaminated soil	Reuse as an earth construction material (backfill)
Imhoff waste treatment digest tank	Sludge and Ash	Reuse as an earth construction material
AG WESER Shipyard Bremen	HAZARDOUS WASTE And oil contaminated soil	Reuse as an earth construction material for a parking site
KLOCKNER-HUTTE Iron and steel works Bremen	HAZARDOUS WASTE And soil contaminated with Diesel fuel	Reuse as an earth construction material
MOBIL OIL Wedel	WASTE EMULSIONS	Reuse as an earth construction material for soil stabilization
NOW PIPELINE Wihelmshaven	PIPELINE ACCIDENTS (broken pipelines at different sites)	RECULTIVATION through DCR supported biological degradation (arable land, pasture)
DEPARTMENT DU FINISTERE Brest	TANKER ACCIDENT "AMOCO CADIZ" (oil contaminated sand- crude oil)	Construction of an industrial area in the harbour of Brest
NAPHTACHIMIE Marseille	OIL LAGOON With residues from the petrochemical industry	Reuse as an earth construction material (backfill)

LEGAL & REGULATORY REQUIREMENTS FOR CUTTING TREATMENT

Drill cuttings consist of various rocks, particulates and liquids released from geologic formations in drill hole. These cuttings are coated with drilling fluid resulting from the incomplete separation of drilling fluids from the cuttings in the rig shale shaker.

Consequently, the Department of Petroleum Resources (DPR), in its Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN), Revised Edition, 2002[(3)] outlined the following discharge limitations for drill cuttings:

a) Cuttings contaminated with water based mud may be discharged offshore / deep waters without treatment, provided the discharged does not contain free oil as determined by a visual sheen on the receiving water surface.

b) There is zero discharge of cuttings contaminated with water / oil based muds and / or esters in inland and hearshore areas.

c) Cuttings contaminated with oil from Low Toxic Mineral Oil Based Mud System shall not be discharged into offshore discharge zone unless treated to residual oil content less than 10g/kg cuttings; i.e. 1% oil on cuttings.

d) Cuttings contaminated with oil from synthetic / pseudo oil based mud system, containing linear alpha olefins (LAO), isomerized olefins (L0), $\wedge$ - paraffin and polyalpha olefins (PAO), shall not be discharged into offshore discharged zone unless treated to a residual oil content of less than 50g/kg, i.e. 5% oil on cuttings.

e) Cutting contaminated with esters may be discharged in offshore discharged zone only when the residual oil content is less than 100g/kg, i.e. 10% ester-on-cuttings.

f) Oil contaminated solids e.g. sand, shall be discharged into offshore discharged zone, unless the oil content is less than 10g/kg dry weight.

The disposal alternatives includes grinding (slurrification) and injection into geologic formation, shipment ashore for treatment and disposal or use of any other treatment technology so approved by the Director of Petroleum Resources.

Several treatment process / methods are approved by the Department of Petroleum Resources for the treatment of drill cuttings. The treated material should meet the following criteria:

Toxicity Characteristics Leaching Procedure [(3)]

Oil and Grease	=	100mg/l
Chlorides	=	5000mg/l
Arsenic	=	5mg/l
Barium	=	100mg/l
Cadmium	=	1mg/l
Chromium (total)	=	5mg/l
Lead	=	5mg/l
Mercury	=	0.2mg/l
Selenium	=	1mg/l
Silver	=	5mg/l
Zinc	=	50mg/l

When solidification process is employed in the treatment, the solidified material shall meet the following criteria:

1. Unconfined comprehensive strength (QU): >20Lbs/in ^{2} (psi)
2. Permeability: $\leq$ 1x 10^{-6} cm / sec
3. Wet / Dry durability: $\geq$ 10 cycles to failure
4. Moisture content $\leq$ 50% by weight or zero free moisture.
5. pH = 6.5 to 9.0
6. Electricity conductivity (EC) = 8 mmhos / cm
7. Sodium Absorption ration (SAR) = 12

REVIEW OF TREATMENT METHODS

Several waste treatment methods are approved by the Department of Petroleum Resources (DPR) for the treatment of E & P wastes, in this case, drill cuttings. Amongst these, the treatment methods that often been employed include; slurry injection, cement fixation, incineration and thermal desorption. These methods are reviewed in the succeeding texts.

Slurry Injection

Permanent disposal of drilling wastes can be achieved using different methods of injecting drilling wastes into underground formations. Slurry injection technology involves grinding or solids processing into small particles, mixing them with water or some other liquids to make a slurry (slurrification) which is then injected into an underground formation at high pressure enough to fracture geological formations (rock) [(4)]. Different names are given to this technique: slurry fracture injection, fracture slurry injection, drilled cuttings injection, cuttings re-injection and grind and inject.

Two common types of slurry injection are known; annular injection, and injection into disposal well.

Annular injection involves introducing the waste slurry through the space between tow casing strings. For the disposal wells, injection is done to either a section of the drilled hole that is below all casing strings, or to a section of the casing that has been perforated with a series of holes at the depth of an injection formation. It is important to know that there also exists a process called sub fracture injection which involves injection into formation at pressure lower than the formation's fracture pressure.

Geological considerations to be determined before slurry injection include;

1 Permeability characteristics of the rock

2 Rock fracture rate, size and configuration of fracture

3 Drinking water aquifers

The common problems encountered are often mechanical and are related to operations.

1 Plugging of the casing or piping because solids have settled out during or following injection.

2 Excessive erosion of casing, tubing and other system components caused by pumping solids – laden slurry at high temperature.

Environmental problems are of deep concern. Unanticipated leakage to the environment creates liability to the operator and also stoppage of injection on site.

Cement Fixation

Solidification / stabilization is a practice to encapsulate waste in a monolithic solid of high structural integrity. This technique restricts contaminant migration by greatly reducing the surface area exposed to leaching and also isolate the waste within a hard capsule. [(5)]

Solidification / stabilization of wastes frequently employs cement as the principal agent. For cement fixation, waste materials are mixed with cement followed by the addition of water for hydration, if necessary because the waste does not have enough water. The hydration of the cement forms a crystalline structure, consisting of calcium alumino-silicate. This results in a rock-like, monolithic, hardened mass.

Cement fixation is best suited for inorganic waste. Organic contaminants are known to interfere with the hydration process, reduce the final strength, and are not easily stabilized. They may also reduced the crystalline structure formation resulting in a more amorphous material.

Limitations of cement fixation become prominent when;

1 Organic content is above 45% by weight

2 Wastes have less than 15% solids

3 Excessive quantity of fine soil particles are present

4 Too many large solid particles are present

Thermal Treatment

The use of high temperatures to reclaim or destroy hydrocarbon contaminated materials is typical of thermal technologies. Thermal treatment is mostly used in treating organics; it also reduces the volume and mobility of inorganic such as metals and salts.[7]

Additional treatment may be necessary for metals and salts depending on the final fate of the wastes.

Thermal treatment technology are designed for a fixed land-based installation, however, a few mobile units exist. Thermal treatment technologies can be grouped into two categories:

1 Incineration

2 Thermal Desorption

INCINERATION

Incineration is a process by which wastes are oxidized or combusted at high temperatures (1,200^{oC}–1,500^{oC}) converting them to non-hazardous materials. Incineration of drilling wastes occurs in rotary kilns, which incinerate any waste regardless of size and composition.

Incineration systems are designed to destroy only organic components of waste; however, most hazardous wastes are non-exclusive in their content and therefore will contain both combustible organics and non-combustible inorganics. By destroying the organic fraction and converting it to carbon dioxide and water vapor, incineration reduces the waste volume, and to the extent that the organic components include toxic compounds, into threat to the environment. [6].

Inorganic components of wastes fed to an incinerator cannot be destroyed, only oxidized. Most of the inorganic materials are chemically classified as metals, and enter the combustion process as a component of a waste. Generally, these metals will exit the combustion process as oxides of the metal that enters.[6]

Most metal compounds will remain in the incinerator ash, however, the volatility of certain metals which may have a boiling point lower than the incinerator temperature (e.g. arsenc, autonomy, cadmium and mercury) may create problems in the flue gas.

High metal content wastes are not good candidates for incineration, although appropriate air pollution control equipment can usually remove metals to acceptable flue gas levels for discharge to the atmosphere.

Thermal Desorption

Thermal desorption is a non-oxidizing process to vaporize volatiles and semi volatiles through the application of heat. Treatment efficiency is related to the volatility of the contaminants. Thus light hydrocarbons, aromatics and other volatile organics are removed at low temperatures between 250^{0}C and 350^{0}C. Heavier compounds such as polycyclic aromatic hydrocarbons are less easily removed except for high temperature systems up to 520^{0}C Secondary waste streams are produced, solids, water condensates and oil condensates, each of which may require analysis to determine the best recycle / disposal option.

In most cases, the liquids are separated and reused in drilling mud to improve the economics of this method. In other cases where high salts and metal content are present in the original waste, additional treatment may be required to reduce the potential impacts on the environment.

THE DCR TECHNOLOGY

There are several chemical reactions in which solid reaction products are formed from solid and / or fluid as starting materials with the aid of a reaction partner. The resultant solid reaction product thereby forms a significantly larger specific surface area in comparison with the reacting components. Chemical reactions of this kind can be applied to homogeneously disperse other substances or substances mixes by chemical means. In order to achieve this, the components of dispersing chemical reaction is firstly charged with the substance to be dispersed (pre-distribution step) and then, in a second step, the actual chemical reaction is allowed to take place (dispersing step). In this way, fluid phases, for instances oily phases, as well as aqueous and non-aqueous solutions are converted into extremely finely dispersed, pulverulent solid preparations.

Among the numerous dispersing chemical agents that produce finely dispersed sold reaction products with a large specific surface, and which thus fulfills the requirements for dispersing by chemical means, calcium oxide (CaO) is by far the most important, especially in the form of a commercially available highly reactive pulverized quicklime

Lime (CaO) is one of the oldest chemicals used on Earth[8]. Lime and its by-products used in the waste treatment industry are summarized in table 3.

Table 3: Characteristics of major lime, limestone products and by-products used in waste treatment [9]

Regent	Formula or Composition	Bulk Density	pH
High Calcium quicklime	CaO	769 – 1121	10.5 – 12.4
Dolomitic quicklime	CaO –MgO	790- 1400	9.0
High Calcium hydrate	$Ca(OH)_2$	400 – 641	10.5 – 12.4
Normal dolomitic hydrate	$Ca(OH)_2$. $Mg(OH)_2$	400 – 560	9.0
Dolomitic pressure hydrate	$Ca(OH).Mg(OH)_2$	480 – 640	9.0
High Calcium limestone	$CaCo_3$	-	6.5
Dolomitic limestone	$CaCO_3$. $MgCo_3$	-	-*
Lime Kiln dust	10 – 15% lime	-	~12.4
Cement kiln dust	Lime varies	-	~12.4
Fly ash +	Lime varies	-	~12.4
Waste lime	Lime varies	-	~12.4

** Non-reactive*

+ High calcium fly ash may have up to 2.4% uncombined CaO

Chemically these by-products are poorly defined and their use in place of lime requires extensive analysis to determine the equivalent quantity of lime. Most common forms of lime used in waste treatment are quicklime or unslaked lime (CaO) and hydrated or slaked lime ($Ca(OH)_2$)[10]. Lime is available almost everywhere in unlimited quantities as a raw material that is used on a large scale in many technical fields like several other stabilization technologies. The patented DCR process utilizes calcium oxide as a reagent[1]. On reaction with water, the calcium hydroxide formed as the corresponding reaction product provides a carrier material that is completely problem-free from an ecological point of view. This calcium hydroxide is continuously neutralized by carbon dioxide from the surrounding medium, for instance, from the atmosphere or from a biologically active soil surrounding with the formation of – a water – insoluble product, which in the form of limestone, is a natural and harmless basic component of our environment.[1]

The formation of a low soluble calcium carbonate occurs on all exposed calcium hydroxide surfaces, which are covered by a coherent carbonate crust. The crust acts as a protective and isolating inert layer, which in the course of lime increases in thickness due to the continuing influence of the carbon dioxide. Thus, the very last fate of any compacted body of $Ca(OH)_2$ will be to become fully carbonated and to form an inert water insoluble body of limestone. This in situ carbonate formation is essential to the long-term behaviour of compacts consisting of DCR-treated toxic waste.[1]

The reaction process can be summarized in a schematic as shown below in Figure 1.

Thus, the DCR technologies are a group of patented waste treatment processes using CaO (quicklime) for the immobilization of heavily oiled sludges, oil-contaminated soils, acid tars, and heavy metals in $Ca(OH)_2$ and $CaCo_3$ matrices[1],[10].

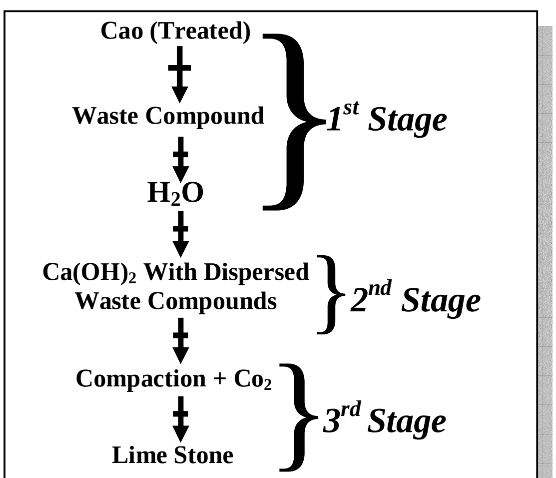

FIGURE 1: THE DCR REACTION PROCESS

Source: Dr. F. Bolsing:
DCR Technology Immobilization and Detoxification of Hazardous Compounds [1], [10]

This technology was originally developed in Germany by Professor Friedrich Boelsing of the University of Hannover, and has been successfully used in the treatment of various waste materials from the petroleum industry[1], viz:

1 Treatment of drill cuttings

2 Treatment of waste drillings mud or fluid

3 Treatment of tank farm sludges

4 Remediation of waste pit or sites

5 Treatment of residues from other treatment processes, e.g. ash fro incineration and treated drill cuttings from thermal desorption.

6 Treatment of oil-contaminated soil

In Europe, DCR technology has been widely utilized in the treatment of over one million cubic metres of both organic and inorganic wastes for over 18 years. Recently, about 26,100 tons of sludges from petroleum barge – cleaning operations and 233,000 tons of acid tar residues remaining from lubricating – oil refining activities in the United States have been sterilized using this technology. [11].

The DCR technology is widely recommended for the field remediation of liquid organics and heavy metal contaminated materials [10]. Since in actual practical and field applications of the DCR process it is possible that wastes of different compositions and mixtures can be obtained, the treatment of the calcium oxide with other materials gives a reagent that preferentially absorbs any organics in a waste liquid or soil / sludge matrix upon initial mixing.

THE DCR TREATMENT / REMEDIATION CONCEPT

DCR technology significantly improves the applicability of known chemical methods in waste treatment and environmental remediation, hence its connotation as an advanced stabilization / solidification process which aims to overcome the limitations of other waste treatment processes when treating stable and recalcitrant waste materials.

The DCR treatment concept comprises the utilization of Dispersing Chemical Reactions [1] *for:*

1. The conversion of oily waste materials into finely dispersed solid preparations in-order to annul the mobility of a liquid phase (DCR immobilization of oily phase).

2. The conversion of hazardous compounds into water-insoluble chemical derivatives in-order to eliminate the water solubility of said hazardous compounds (DCR immobilization through precipitation, condensation, addition etc.).

3. The physical or chemical bonding of water-soluble hazardous compounds to functionalized inorganic or organic macromolecules in-order to form water-insoluble derivatives of said hazardous compounds (DCR Fixation through precipitation, condensation, addition etc.).

4. The formation of large surface areas of coherent organic phases in order to increase the rate of biological degradation of degradable organic harmful materials (DCR supported biological degradation).
5. The conversion of coherent organic phases into highly reacting finely dispersed solid preparations in-order to increase the chemical reactivity of chemical detoxification processes (DCR supported chemical detoxification).

The application of DCR Technology Offers the Following Advantages:

1. CaO is available cheaply in almost unlimited quantities.
2. $Ca(OH)^2$ is well known as a soil conditioning material for road construction and can be condensed with treated soil to create a load-bearing soil material, which cannot be penetrated easily by water.
3. The resultant reaction products are ecologically harmless and occur naturally.
4. DCR-treated soil can normally be reused for years afterwards by the usual construction machines.
5. An extensive array of application possibilities with a comparably small insensitivity towards fluctuations in pollutant concentrations and variety.
6. Possibility of combing immobilization by means of integration or adsorption of pollutants, with chemical or biological decomposition, precipitation or reforming reactions.
7. Possibility of treating waste oil and all the waste materials simultaneously.

DCR TECHNOLOGY COMPARED WITH OTHER TREATMENT METHODS.

Presented in Table 2, is a summary of the comparism of the DCR treatment technology with other treatment methods. From the table, it is clear that the DCR Technology can be a preferred method for the following reason:

1. The process has a value-added product, with an end-product, which can successfully be used in construction and other uses, which may help to provide lower treatment cost.
2. Most of the raw materials used in the treatment are available locally.
3. The re-useable end-product is non-polluting, and therefore, environmentally safe to be put into other uses.

The materials stabilized with cement are less stable and hence has potential for releasing organic materials and heavy metals into the environment over a period of time than the materials stabilized by DCR technology as the organic materials and heavy metals are fixed, immobilized and hence non-bio available. The heavy metals in the slag and ash by product from either the thermal Desorption or Incineration process, when disposed has potential for leaching into the environment, even when the disposal site is lined. Above all, the DCR technology can produce a useful secondary raw material that can be re-used in an environmentally friendly manner.

Table 2: DCR Technology Compared With Other Treatment Methods

ITEMS	DCR	INCINER-ATION	THERMAL DESORPTI ON	CEMENT FIXATION
Structure / Materials	Simple (In-Situ)	Complex construction, logistics and material handling	Complex construction, logistics and material handling	Simple (in-situ)
Effect On Inorganic Materials	Encapsulate Inorganic Materials Effectively	Ineffective For Inorganic Treatment	Ineffective For Inorganic Treatment	Partially effective for inorganic treatment
Re-Usable Materials	Re-Usable	Not Re-Useable	Not Re-Useable	Re-useable but low integrity
Cost	Relatively Lower cost. Value added by product re-use	Relatively high cost	Relatively high cost	Relatively Medium cost
End-Product Effect On Environ-ment	Environment-ally Friendly Micro & Macro Encapsulation	Not Environment ally Friendly	Not Environmenta -lly Friendly	Low Environme-ntal Friendliness, Macro Encapsulat-ion only

IMPLEMENTATION OF DCR TECHNOLOGY

The DCR Treatment Technology can be achieved using the schematic shown in Figure 2.

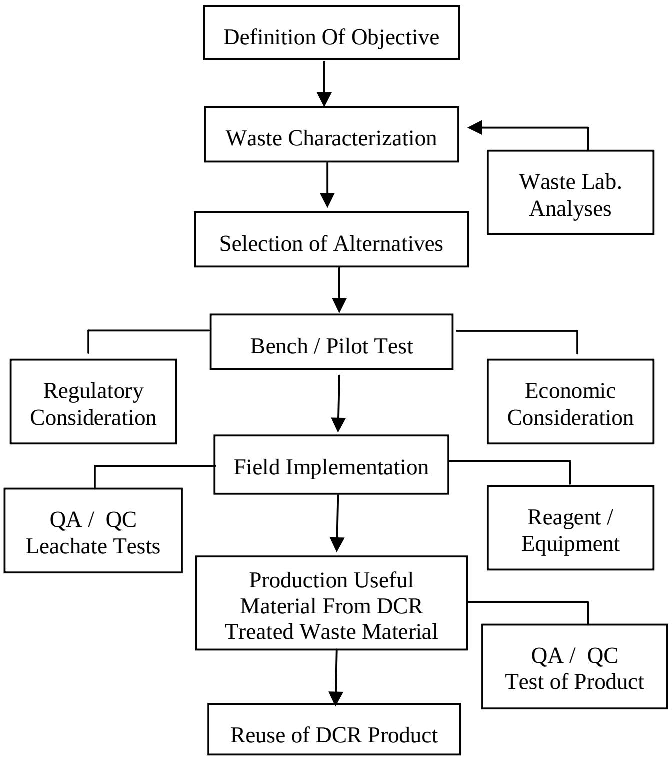

FIGURE 2: A SCHEMATIC SHOWING DCR IMPLEMENTATION

Source: Abridged from M.D. LaCrega. et. Al. "Hazardous Waste Management", McGrawHill [6]

1. **Definition Of Objective:** A clear definition of the objective for the DCR application to treat a waste material is very important. Since the DCR-treated material could be used as an input for producing other products, as construction material, etc, such uses must be considered in establishing the DCR treatment objective. It is pertinent to note that a proper use of the DCR-treated material will greatly improve the economics or the cost-effectiveness of treating the waste materials by the DCR technology process. The economics of the DCR-treatment process will be dependent on the chemical reagents, other materials, the labour and equipment to be used in the treatment.

2. **Waste Characterization:** DCR process requires the characterization of the waste material to be stabilized, as the characteristic of the waste will affect the selection of treatment alternatives, the types and quantities of chemicals to be used. The drill cuttings treatment, for example, requires the laboratory analysis of parameters, like, Total Hydrocarbon (THC), and the heavy metals content. This characterization must be carried out for the raw drill cuttings and DCR treated drill cuttings. These analyses will give information on the level or efficiency of treatment of the raw drill cuttings by the DCR process.

3. **Selection Of Treatment Alternative**: In the design of DCR process for field implementation, the selection of a treatment process must be carried out carefully. The factors that will affect the selection are the waste characteristics, the site configuration for material handling and processing, the DCR treatment objective for the material re-use, the regulatory requirements, and economics.

Since mixing to achieve a homogeneous mass is important in a DCR process, a mixing alternative must be chosen properly. For example, in the treatment of drill cuttings, a mechanized mixer, using batch process, where fixed amounts of wastes and reagents are added and blended may be employed.

The drill cuttings as shown in Figure 3, can arrive in skips, and stored in a storage basin, from where fixed quantity of the drill cuttings and reagents are transferred into the mixer as shown in Figure 4.

The blended material as shown in Figure 5, can then be transported to where it can be put into secondary uses or further processed into specific building materials, such as Interlocking Bricks or stones for external flooring and road pavings.

FIGURE 3: WET CUTTINGS

FIGURE 4: DCR MIXER UNIT

FIGURE 5: DCR TREATED CUTTINGS

DCR BENCH TEST OF DRILL CUTTINGS

In order to demonstrate the DCR treatment process, a Bench test was successfully carried out at our TPI laboratory in Port Harcourt, Rivers State.

Parameters and Materials for the Bench Test

The Details of the Bench Test are as follows:

1. Type And Source Of Waste: Drill Cuttings from Koronama 3 Well
2. Period of Test: Feb. 11, 2004 – Feb 13, 2004
3. DCR Testing Objective:
   - i. Stabilization, encapsulation, detoxification and Solidification of the drill cuttings.
   - ii. Produce construction material from the DCR-treated drill cuttings. e.g. Interlocking Bricks for road flooring.
4. Characterization of the Waste

   The TPH and heavy metal contents were analyzed in the laboratory.
5. DCR Materials
   - i. Treated Calcium Oxide (CaO)
   - ii. Water
   - iii. Drill cuttings to be treated
6. Apparatus
   - i. Mixers
   - ii. Plastic and glass containers
   - iii. Measuring cylinders
   - iv. Weighing balances
7. Mould Preparation
   - *i. Apparatus*
   - i. Mixers
   - ii. Moulds
   - *ii. Reagents / Materials*
   - i. Cement
   - ii. DCR treated drill cuttings
   - iii. Additives – granites, sharp sand
   - iv. Water
8. Quality Control / Quality Assurance Testing
   - i. Extractions & Leachate Test of raw drill cuttings and DCR-treated drill cuttings.
   - ii. Compressive strength test of the interlocking brick prepared using the DCR-treated drill cuttings and the interlocking brick prepared using ordinary sand.

THE DCR BENCH TEST PROCEDURE

The DCR process Bench Test was carried out in accordance with the following procedure:

1. A pre-determined quantity of the characterized raw drill cuttings was weighted out and transferred into a mixer.
2. A pre-determined quantity of treated lime (CaO) was also weighted out and transferred into the mixer containing the raw drill cuttings.

3. Sufficient amount of water that will assure proper hydration was added.
4. The above material was mixed properly resulting in a dry, dusty, soil-like material.

Samples were then collected from the DCR product for the Toxicity Characteristics Leaching Procedure (TCLP) test.

MOULD PREPARATION

1. A quantitative amount of the DCR product, cement, sharp sand and granite were poured into a mixer.
2. An appropriate amount of water was added and the materials mixed to form slurry.
3. The slurry was poured into plastic moulds and placed on the bench to solidify.
4. Another mould consisting of the cement, sharp sand, gravel and water was also prepared to kept to solidify. This was used as a control and comparism with the DCR treated cuttings.

After about 48 hours, the curing was complete and the casts were removed from the moulds. Comprehensive strength test was carried out on both casts of blocks – one prepared with the DCR treated drill cuttings and the other prepared with sharp sand.

RESULTS

The drill cuttings used in the DCR Bench Test are shown in Figure 3, while the DCR-treated drill cuttings are shown in Figure 5.

The paste like materials which had been moulded to form interlocking bricks are shown in Figure 6. It is pertinent to note that the two form interlocking bricks – one formed with DCR-treated drill cuttings and the other with ordinary sharp sand are surprisingly similar in texture.

The characteristic of the raw drill cuttings and the DCR-treated drill cuttings are summarized in Table 3. The table shows that the DCR treatment was successful in the treatment. This was proved by the reduction achieved for all the constituent components to below the limits stipulated by the Environmental Guidelines and Standards for the Petroleum Industry in Nigeria, Revised 2002.

Also shown in Table 4, is the comprehensive strength test of both interlocking bricks produced with DCR-treated drill cuttings and that produced with the ordinary sharp sand. The results showed no significant difference between the two interlocking bricks in compressive strength. Therefore, the interlocking brick produced with the DCR-treated cuttings can meet the same construction needs as the others produced with ordinary sharp sand.

Table 3. Results Of The Quality Control Test

Type Of Test	Parameters (Mg/L)	Cutting Quality Before Treatment (Mg/L)	Cutting After Dcr Treatment (Mg/L)	Reduction %	DPR LIMITS
LEACHATE TEST	pH	7.0	6.5	NA	6.5 – 9.0
	Cl	4,508.50	738.40	83.6	5000
	Mg	1,555.97	< 0.001	100	NA
	Ca^H	1,834.03	< 0.001	100	NA
	Mi	< 0.02	< 0.02	100	< 0.2
	As	18.25	< 0.03	100	5.0
	Cd	15.35	< 0.03	100	1.0
	Cr	8.76	< 0.03	100	5.0
	Pb	15.86	< 0.03	100	5.0
	Hg	BDL	BDL	100	0.2
	Fe	4.89	BDL	100	1.0
	Ag	BDL	BDL	100	5.0
	Zn	128.96	0.75	99.4	50.0
	THC	324.4	2.0	99.4	100

Interlocking Bricks Produced with DCR Treated Cuttings

Interlocking Bricks Produced with Natural Sharp Sand

FIGURE 6: INTERLOCKING BRICKS

TABLE 4: UNCONFINED COMPREHENSIVE STRENGTH TEST

❖ Interlocking Bricks Produced With Natural Sand.	- 38 (PSI)
❖ Interlocking Bricks Produced With DCR Treated Cuttings.	- 37 (PSI)
❖ DPR Limit	> 20(PSI)

CONCLUSION AND RECOMMENDATIONS

Dispersion by Chemical Reaction (DCR) is an advanced solidification, stabilization and encapsulation method for waste treatment. The technology was successfully demonstrated in the TPI Laboratory with the treatment of drill cuttings. The incomplete separation of drilling fluids from the drilling cuttings, called for an appropriate drill cuttings treatment prior to disposal in order to meet the discharge limitations stipulated by the Environmental Guidelines and Standards for the Petroleum Industry in Nigeria, Revised Edition 2002. The recommended drill cuttings treatment methods include thermal desorption, re-injection, incineration and solidification. These treatments were reviewed and the DCR technology was found to have major advantages over all currently used treatment methods. The advantages of DCR technology include:

i. A value-added end-product that can be used as input to other uses e.g. construction materials.

ii. The process technology that does not require complex facilities, but rather simple facility involving mixers, materials and chemicals that can be sourced locally.

iii. The re-useable end-product is non-polluting and therefore its disposal does not provide any threat to environment.

iv. The value-added end product of DCR which can be put to other uses without environmental risks makes the economics of DCR technology relatively more cost effective than other treatment methods.

Based on the above advantages, it is therefore recommended that DCR technology should be favourably considered in the treatment of drill cuttings by regulators and operators in the oil industry.

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