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Bioremediation Process: Application of Gravel Generated in Oil Well Drilling in Native Soil Quality

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Abstract

Oil well drilling, according to the different phases of the operation, utilizes different types of fluids. This has been causing environmental problems and drawing the environmentalists' attention lately. Such fluids can be usually water (WBM – Water Base Mud) as in continuous phase, or a synthetic fluid (SOBM – Synthetic Oil Base Mud) used in highly deviated and/or maritime wells. The main components of these synthetic fluids are principally: alkanes (as n-paraffin), alkenes (olefins in general), ethers and esters (vegetable oils). One of the application functions of these fluids is to carry to the surface gravel impregnated with fluid; consequently, the disposal of gravels, without any treatment, can cause major environmental problems with regard to soil contamination. The bioremediation process is an alternative biotechnology technique of management of this low-cost waste which is effective in soil restoration. Therefore, the objective of the work was to develop and design the process of bioremediation of gravels generated during oil well drilling, these gravels being contaminated with a biodegradable drilling fluid of low toxicity and rich in potassium, so that this nutrient balanced with nitrogen and phosphorus contribute as inorganic fertilizer. This research is being developed in partnership with Carboflex Company and the Capixaba Research Institute, Rural Extension (Incaper) in Brazil, aiming at the quality of native soil with the use of gravel and hence contributing to minimize any environmental impact.

Introduction

Gravel and drilling fluid are the residues that characterize the drilling of oil and gas wells. The use and disposal of these wastes have attracted a national and international concern about environmental protection regarding oil and gas onshore and offshore exploitation, which has required specific legislation to regulate this process in Brazil, especially after the opening of the petroleum sector in the country [1].

In the well drilling process, as the sediment formation is cut by the drilling process and removed, great amounts of cuttings are generated and, at the end of the process, these cuttings are mixed with clay, sand and waste drilling fluid, most common separating solids in order to remove cuttings, sludge and sand fluid. There may also be residual traces of fluid; typically 10 to 15% by weight of drilling fluid is adhering to the cuttings [2].

Most drilling fluids used in the world are water-based. Water-based fluid (WBM) is a mixture of solids, liquids and chemical additives with water (brine, freshwater or saltwater) as solvent part [4]. This type of drilling fluid has a low cost compared to others (SOBM or oil, aerated), is biodegradable and easily disperses in the water [5].

The biological treatment, bioremediation, is considered one of the most effective ways to make the cuttings[6] environmentally acceptable; thus, it is the method adopted by the ABNT NBR 14283 [7]. Bioremediation strategies include the use of indigenous microorganisms (site) without any interference from active remediation technologies (intrinsic bioremediation, *in situ* or natural), the addition of stimulating agents such as nutrients, oxygen and biosurfactants (biostimulation), and the inoculation of enriched microbial consortia (bio addition) [8].

One major advantage of the bioremediation techniques is the possibility of their being applied on the contaminated site itself. When compared to conventional techniques (incineration, landfill, etc.), they are usually more economical, permanently eliminating the risk of contamination; they have good public acceptance and are encouraged by the environment regulatory agencies. Besides, they may be associated with other chemical or physical treatment methods[10].

In this environment-friendly respect, this work objective is to develop and carry out intelligent soil recovery (ISR) applying the *in situ* bioremediation method in cuttings generated by the drilling process, these cuttings being contaminated with low toxicity biodegradable drilling fluid rich in potassium. This research is being developed in partnership with the Rural Extension of Capixaba Research Institute (Incaper) in Brazil aiming at the quality of the native soil as inorganic fertilizer, thus minimizing environmental impact.

1. Drilling Mud – WBM

The aqueous drilling fluid was developed by Carboflex company R & D laboratory, named as CarboEco (Figure 1).

Figure 1: Appearance of CarboEco Mud

This fluid is composed of viscosifiers, weighing agents, filtrate loss agents and special additives (lubricants, antibacterial, clay anti-hydration), as shown in Table 1. The water-based fluid development aimed to select an additive that could increase drilling performance and minimize concerns about the harmful effects of drilling fluids additives in oil production areas, as well as consider the cost, performance, quality, environmental effects, compatibility assessment of production and exploration, drilling and use of logistics [11,12].

Table 1: WBM Formulation

Additive	Units	Concentration
Water	Bbl	0.908
Bioflex XG	Lbs/Bbl	1.0
Magnesium Oxide	Lbs/Bbl	0.5
Potassium Chloride	Lbs/Bbl	7.0
Carbobgel	Lbs/Bbl	6.0
Celuflex BV	Lbs/Bbl	2.0
Carboquat	Lbs/Bbl	6.0
Flexcide G	Lbs/Bbl	0.3
Lubdrill	Lbs/Bbl	3.5
Calcium Carbonate	Lbs/Bbl	10.0
Barite	Lbs/Bbl	10.0

For environmental effects, the fluid was characterized in ecotoxicity tests in freshwater environment (onshore) and marine environment (offshore), as shown in Table 2.

Table 2: Chronic and Acute Toxicity of WBM – Onshore e Offshore

Onshore Environment			
Chronic Toxicity, FPS, *Ceriodaphnia dubia*	CENO: 7,812 ppm	CEO: 15,625 ppm	VC: 11,048 ppm
Offshore Environment			
Chronic Toxicity, FPS, *Lytechinus variegatus*	CENO: 15,625 ppm	CEO: 31,250 ppm	VC: 22,097 ppm
Acute Toxicity, FPS, *Mysidopsis juniae*	CL50, 96h: 125,000 ppm		

Source: LABTOX, Laboratory of Environmental Analysis, Rio de Janeiro, Brazil.

The low toxicity of the drilling fluid is mainly related to the acute toxicity bioassays presented in the crustacean *Mysidopsis misidáceo juniae*, which offers similarity and belongs to the same family as the American organism, *Mysidopsis bahia*, common in the eastern U.S. The FPS limit of 30,000 ppm for the crustacean species due to a lack of toxicity thresholds established in the Brazilian legislation and a lack of published studies on drilling fluids for the Brazilian species.

With these results of toxicological evaluation, the drilling water-based fluid was tested on a large scale in well-MGD-01-ES, drilled in São Mateus, Espirito Santo, Brazil in 2011.

2. Gravel and Mud

As shown in Figure 2, the generated gravels contaminated with drilling fluid from the drilling of well 1-MGD-01-ES were collected and sent to the Incaper Capixaba Institute in order to validate the bioremediation technique,.

Figure 2: Gravels generated from the well drilling.

This institute is responsible for evaluating the incorporation of gravel contaminated with drilling fluid to the soil intended to be applied as a fertilizer. For this application, tests will be needed in order to research the essential nutrients present in the drilling gravel and the subsequent correction of the main necessary chemical elements such as nitrogen, phosphorus and potassium.

3. Bioremediation *in situ*

For the bioremediation method application, Incaper laboratory performed the preliminary nutrient evaluation tests, such as P, K, Na, Ca, Mg, Cu, Mn, Fe, Zn e S by the agriculture ministry method and Cd, Cr, Pb e Ni by the Embrapa 1999 for conventional cuttings without fluid, and cuttings contaminated with our fluid as shown in Table 3.

Table 3: Chemical characteristics of the gravel drilling oil wells (Carboflex)

	Nutrients						
Gravel	P	K	Ca	Mg	S	Na	Cu
No Mud	148	23,600	22,850	3,000	1,031	400	0.0
Mud	224	79,000	173,250	22,000	2,159	8,600	4.0
	Nutrients						
Gravel	Mn	Fe	Zn	Cr	Ni	Cd	Pb
No Mud	62	8,000	8.0	153	16	0.6	0.0
Mud	112	1,296	4.0	174	33	5.0	92

Method: Extration with HCl 2 mol/L – Hot plate (Emprapa, 1999)
Units: $mg.L^{-1}$ ou % = $mg.L^{-1}$ ÷ 10,000

The results in Table 3 show nutrient increase with the fluid (mud), something that was predicted due to an additive incorporation.

However, there was a significant increase in the content of potassium and phosphorus, validating the fertilizing technique, consequently decreasing the costs with these nutrients, potassium being the most expensive chemical element, according to Lobo (2008) [9].

For the evaluation of the results, gravel with and without fluid contamination was analyzed. The test known as greenhouse test consists in fertilizing corn plants, with a mixture of (one to one) organic material and drilling fluid contaminated gravel. This mixture was added to the local soil, which contains native bacteria (in situ bioremediation) in an oven at a temperature of 20 to 40º Celsius.

With these pretests, the Incaper Institute will perform the field test where corn will be planted and cultivated in a larger area located in the Bananal do Norte experimental farm in Cachoeira de Itapemirim, Espirito Santo State, Brazil. Since this is a larger area, this technique will validate the bioremediation technique in a real scale. The field test scheme, as shown in Figure 3, concerns a 384-m^2 (16x24) surface divided in 3 rows of 16-m^2 blocks (4x4) spaced by 1.5 to 2.0 m. However each block will receive different gravel treatment dosages (already contaminated with our fluid).

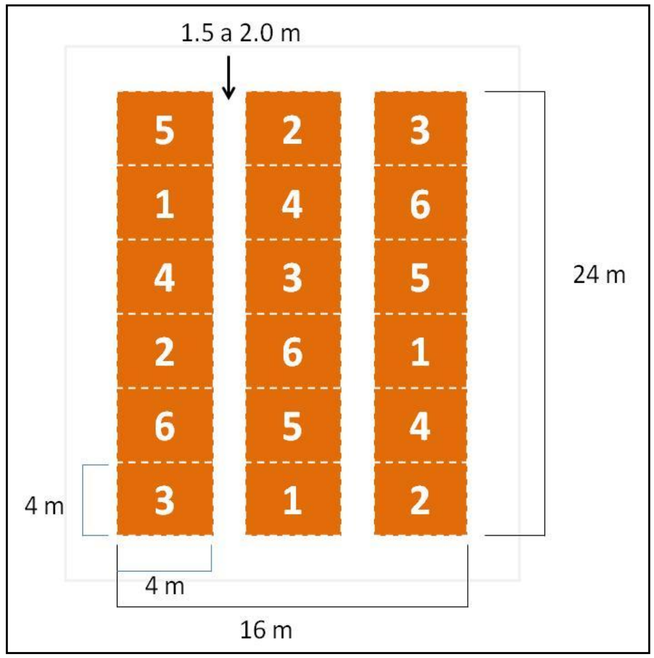

Figure 3: Field test design – Cornfield

The soil treatment dosages for fertilization will depend on the gravel quantity and the study of the plantation, shown on Table 4.

Table 4: Fertilization treatment dosages in soil with gravel for the corn crop culture.

Treatment	Ton/ha	Kg/parc
1	2	3.2
2	5	8.0
3	10	16.0
4	20	32.0
5	30	48.0
6	40	64.0

In the above table, there are 06 (six) different treatments where the only variation is the amount of gravel (in Ton/ha or Kg/parc equivalent). These six treatments are drawn up as outlined in Figure 3 in order to monitor the entire test field and to assess the limits of the use of gravel.

Fertilization will also depend on the addition of the gravel in two stages: furrow and cover. The grooves are opened in the soil (which contains the gravel) and fertilized with 150g/mL super simple 20g/mL ammonium sulphate, lime and 100g/mL 20g/mL FTE (silicate compound fertilizer micronutrients such as Zn, B, Cu, Fe and Mn, elements essential to plant growth). After this fertilization, the grooves are filled with the soil (gravel) and the corn seeds. Then, the grooves are covered with soil that will contain 50g/mL ammonium sulphate and irrigated until the corn seeds start germinating.

Conclusions

The main objective of the present study is the implementation of the bioremediation method intending to improve the quality of the native soil by using the cuttings generated in well drilling and already contaminated with drilling fluid, helping to reduce costs and minimize environmental impact.

The CarboEco aqueous drilling fluid presented toxicity results in freshwater (onshore) and marine (offshore) environments within acceptable environmental limits. And with that, its use in larger scale in the drilling of well 1-MGD-01-ES in Espirito Santo was a challenge to a pilot project to address this issue.

In partnership with Incaper, satisfactory initial results were presented in the laboratory as seen from the results of analyzed nutrients from cuttings contaminated with fluid, especially high levels of potassium, an expensive fertilizer on the market, and therefore an alternative for cost minimization with the use of gravel.

Other tests in greenhouse (greenhouse test) and in field are being evaluated by Incaper. This project also aims at modeling such tests with drilling cuttings in other regions of Brazil such as Bahia, Sergipe and Rio Grande do Norte as well as assessing non-aqueous fluids (oil based), providing partnerships with relevant institutes across the country (CONAMA, IBAMA and other state agencies) and of interest to Petrobras and other drilling fluid and service companies, thereby allowing confidence in planning and operational purposes.

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Nomenclature

WBM = *Water Base Mud*
SOBM = *Synthetic Oil Base Mud*
ABNT = *Brazilian Association of Technical Standards*
NBR = *Brazilian Standard*
P&D = *Research & Development*
Bbl = *Barrel*
Lbs/Bbl = *Pound (s) per barrel*
FPS = *Suspended Particulate Fraction*
CENO =*Higher Nominal Concentration of the Sample does not cause significant effect*
CEO =*Lower Nominal Concentration of the Sample causing significant effect*

VC =*Value Chronic initial geometric mean CENO and CEO*
CL_{50} =*Concentration Lethal 50% for the test population*
P = *Phosphorus*
K =*Potassium*
Na = *Sodium*
Ca =*Calcium*
Mg = *Magnesium*
Cu =*Copper*
Mn =*Manganese*
Fe =*Iron*
Zn =*Zinc*
S =*Sulfur*
Cd =*Cadmium*
Cr = *Chrome*
Pb =*Lead*
Ni =*Nickel*
B =*Boron*
Ton/ha =*Ton per hectare*
Kg/par = *Kilogram per parcel*
FTE = *Frited Trace Elements*

References

1. Schaffel, S. B.: "A Questão Ambiental na Etapa da Perfuração de Poços Marítimos de Óleo e Gás no Brasil." Rio de Janeiro, Brasil, Mestrado, 147p., 2002.
2. Mairs, H., Smith, J., Melton, R., Pasmore, J., and Maruca, S.: "Efeitos Ambientais dos Cascalhos Associados a Fluidos Não-aquosos: Fundamentos Teóricos." IBP, Anexo IX, Brasil, 2000.
3. MMS.: "Offshore Stats, Year end 2000." In: U.S. Department of the Interior, Minerals Management Service, Engineering & Operations Division, Operations Analysis Branch, Washington, D.C., 2001.
4. Economides, M. J., Watters, L.T., and Dunn-Norman, S.: "Petroleum Well Construction." 1 ed., John Wiley & Sons, New York, 1998.
5. Durrieu, J., Zurdo, C., Benaissa, S., and Clark, D.: "Environmentally Friendly Invert Fluid Systems with Enhanced Rate of Biodegradation." SPE 61212, SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, Stavanger, Norway, June 26-28, 2000.
6. Perie, F. H., Seris, J. L., Martignon, A. P.: "Biological Treatment of Drilling Waste." SPE 29695, In: SPE/EPA Exploration & Production Enviromental Conference, Houston, Texas, USA, 1995.
7. Cassini, S. T., Chernicharo, C. A. L., Andreoli, C. V., França, M., Borges, E. S. M., and Gonçalves, R. F.: "Hidrólise e Atividade Anaeróbica em Lodos." In: Digestão de Resíduos Sólidos Orgânicos e Aproveitamento do Biogás, Rima Editora, v. 1, p. 11-52, São Carlos, São Paulo, Brasil, 2003.
8. Bento, F. M., Camargo, F. A. O., and Okeke, B. "Bioremediation of Soil Contaminated by Diesel Oil." Brazilian Journal of Microbiology, v. 34 (Suppl. 1), p. 65-68, 2003.
9. Lobo, V. "O Mercado e o Desafio da Indústria de Fertilizantes do Brasil."Bunge Fertilizantes, Brasil, 2008.
10. Seabra, P. N. C. "Aplicação de Biopilha na Biorremediação de Solos Argilosos Contaminados com Petróleo."Tese de Doutorado, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brasil, 2005.
11. England, A. A. "The Characterization of a Drilling Fluid Additive."Chevron Services Co., SPE/IADC Drilling Conference, Dallas, Texas, EUA, 1988.
12. Amorim, L. V., Farias, K. V., Silva, A. R. O. S., Pereira, M. S.

P., Lira, H. L., Ferreira, H. C. "Desenvolvimento de Formulações de Fluidos Base Água para Perfurações de Poços de Petróleo – Estudo Preliminar". 4º PDPETRO, Campinas, São Paulo, Brasil, 2007.