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Treatment of Contaminated Synthetic Based Muds (SBM) Drilling Waste in Block 47 Oman

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Abstract

The development and use of Non Aqueous Fluids (NAF) like Oil Based Muds (OBM) and Synthetic Based Muds (SBM) for drilling operations during exploration and production of Oil & Gas has made the process more efficient and has helped develop new techniques in high depth drilling, offshore drilling and directional and horizontal drilling. The use of OBM's and SBM's carries an additional environmental liability for the operator, as the generated drilling waste ("cuttings") is contaminated with traces of the hydrocarbon base material used to prepare the drilling muds as well as crude oil, that posse an environmental hazard for on-site disposal.

Typically 0.25 bbl of SBM are retained on cuttings per meter of hole drilled, the use of separation equipment and dryers can reduce the final percentage to < 5 % retention on the cuttings. However, this concentration is still high for a safe environmental disposal of the cuttings in most countries thus requiring treatment for further disposal of these solids.

There are 3 main processes currently being used in the industry to deal with these wastes:

The first option is Thermal Desorption (TD) where the cuttings are heated up to 800 C and the cuttings reduced to minerals and ash. The vapors are processed through a condenser and scrubbing system to avoid air emissions. This is an expensive process and requires regular PMS (preventive maintenance)

Second option encapsulation where the cuttings are mixed with lime or silica and cement in varying ratios a concrete block is formed that can be buried in a land fill. Depending on the size of the block and percentage of cement, lime or silica the blocks can end up leaching and releasing the base fluid.

The third and industry accepted application is bioremediation where active enzymes are mixed with water and the oils are digested into cell material, CO₂ and H₂O, the process is usually applied using land farming techniques.

In this paper, we discuss the use of a technique that uses chemical, physical and biological processes to treat the solids under a land farming protocol that is more effective than straight bio-remediation.

Introduction

During the second half of 2010 and most of 2011, a deep exploration well (> 5,000m) was drilled in Block # 47 near Adam in the Sultanate of Oman. Project Location Coordinates: 22°31'47" N 57°27'50" E, Elevation: 1044 ft.

During the drilling process, WBM and SBM were used and as a result, there approximately 2,800 cubic meters of SBM drilling waste was generated. The waste remained in a sand pit that was originally lined using a HDPE liner and the pit was fenced to avoid any trespassing by the local fauna. The



Fig. 1



Fig. 2

cuttings tested using the retort method, showed an average concentration of synthetic fluids and hydrocarbons of 22%.

The Ministry of Environment and Climate Affairs (MECA) of the Sultanate of Oman, establishes that all the solid waste streams generated in the Sultanate should be treated prior to disposal to a maximum Total Petroleum Hydrocarbons (TPH) of less than 1.0%. The Block operator is liable for these wastes.

The contractor was contracted to perform an on-site remediation of these wastes applying the technology known as FreeRAD; the final objective, was to bring the TPH to below the 1.0% W/W threshold. Free-RAD© is an economical alternative process to deal with these wastes. The process uses highly reactive free radical compounds that can decompose complex hydrocarbons and organic molecules into

simpler and shorter ones or into CO₂ and water. UV active compounds are also used in order to employ UV radiation in the decomposition process.

Surfactants are added to release the hydrophobic condition of the materials and allow for hydration and exposure of a much larger surface area. Finally, using bio-augmentation techniques, oleo-phagic bacteria are released into the substrate to finalize the hydrocarbon decomposition.

The operators of Block 47- Adam in

Contaminated soil transfer.



Fig. 3

Oman carried out several deep well drilling operations. In one location, 2,800 m³ of SBM cuttings were generated, these cuttings had an average TPH concentration of 22%. FreeRAD technology was implemented and in 22 weeks brought down the mean TPH concentration to less than 1.0%. The material was treated using two treatment cells adjacent to the waste pit and under an extensive land farming protocol.

This was the first application of this technology in the Middle East under extreme weather conditions. The results show that the technology can offer a feasible and economic option to the operators in the field that carry the environmental liability over long periods of time after the drilling phase is completed. The proposed treatment scheme was designed to avoid waste transportation especially in public roads. Based on this premise, two treatment cells were implemented on site, both being 60m L x 40 m W and with a full depth of 1m, the cells were lined with a 3mm HDPE liner. The material was dig out using a long reach excavator that deposited the material directly into the bucket of a front loader to avoid any spillage. The cells were filled up to 0.6m to begin the process.

Treatment cells full of contaminated soil.



Fig. 4

Statement of Theory and Definitions

Technology description.-

Aliphatic and Aromatic hydrocarbons are non-polar, hydrophobic compounds, which do not ionize. As a result, they are only slightly soluble in water. The solubility directly depends on the molecular weight of the hydrocarbon species. These molecules also present surface properties that allow them to wet a whole range of substrates including clays and soils. Organic liquids commonly referred to as Non-Aqueous Phase Liquids (NAPLS) or Non Aqueous Fluids (NAF) are used to reduce the torque and drag while drilling. An invert emulsion of water (in most cases brine) and oil is produced to control well stabilization and solids removal.

In order to remove the contaminants from the solids wastes a series of physical, chemical and biological processes are applied to enhance the degradation of these compounds into no-hazardous inorganic compounds like CO₂ and water. The most important processes that take place throughout the treatment are as follows:

1. Hydration and surfactant addition - In order to “open” the material and expose a larger surface area to the chemicals, UV rays from the sun and oxygen from the air ionic and non-ionic surfactants are used to remove the hydrophobic capacity of the muds. Large quantities of water are used to flood the treatment cells and the surfactants are mixed using earth moving equipment and tractors.
2. Chemical oxidation - It is used to decompose the organic molecules; reagents are added that trigger a series of transition, propagation and chain terminating reactions that deliver strong free radical species that partially or completely oxidize all the organic compounds present in the waste material.
The stoichiometry of the reactants, the reaction kinetics and the thermodynamics of the processes will determine the rate and oxidation efficiency of any particular organic compound. Kinetics or reaction rates are perhaps the most important. In fact, reactions that would be considered thermodynamically favorable based on E₀ values may be impractical under field conditions. The rates of oxidation reactions are dependent on many variables that must be considered simultaneously, including temperature, pH, concentration of the reactants, catalysts, reaction by-products, and system impurities (e.g., natural organic matter [NOM], oxidant scavengers, etc.)¹. Laboratory tests allow to determine the best chemical combination to treat specific soils.
The dynamics of the process is complex starting with a catalytic decomposition that creates Hydroxyl (OH⁺) radicals which are very strong oxidizing agents. A chain-propagating sequence usually takes place, which can also generate superoxide ions (O₂⁻), hydroperoxide ions (HO₂⁻), and organic radicals (R•) all these compounds act in the oxidation process of the organic molecules. The main objective here is to partially or completely oxidize the organic compounds, in most cases like the SBM, chain partition or ring breakdown can be accomplished with this technique to allow the following steps to completely decompose the organic contaminants.
3. Photo degradation - UV, in conjunction with oxygen, degrades some hydrocarbons into fatty acids and alcohols that are then more biodegradable and more soluble. Photochemical oxidation is usually slow in stable middle size chain hydrocarbons. The use of photo active additives to the treated material enhances the decomposition of the organic contaminants.
4. Biodegradation / Bio-augmentation - Hydrocarbons are subject to biodegradation by microorganisms present in soil, sewage, and water. Microbial metabolism of hydrocarbons may result in either complete or incomplete hydrocarbon degradation, depending upon several environmental (e.g., pH, temperature, dissolved oxygen and redox state) and molecular factors (e.g., HCs type including the length of chain, number and position of fusion of aromatic rings in the molecule). Lower molecular weight HCs tend to oxidize completely to form CO₂ and H₂O while the heavier HCs will degrade partially to yield various oxygenated metabolites (e.g., various phenolic and acid metabolites, cis-dihydrodiol, etc.). Anaerobic and facultative bacteria present in the soils and sediments are also capable of metabolizing these substances although at a much slower rate than their aerobic counterparts. The residence time of a HCs in soil or sediment may thus be longer in anaerobic conditions, but bio-transformation will still be occurring. Should the compounds be located deep within the soil layer, however, degradation may or may not occur depending upon the soil structure and bioavailability of the HCs.

By controlling the environmental conditions (moisture content, temperature, pH, O₂ conc., small chain HCs availability, organic matter availability, phosphates, nitrates, etc.) a particular population of hydrophilic microorganisms can be reproduced exponentially in only a few days this process is known as bio-augmentation and has been in use for more than 30 years².

5. Combined processes - It has been proved³ that UV radiated hydrocarbon contaminated materials will biologically decompose in less than half the time non radiated material will take to reach the same levels of concentration using *Sphingomonas* sp. strain EPA 505 and *Sphingomonas yanoikuyae* bacteria under laboratory conditions. It is also true that hydrocarbons are degraded through the process of photo oxidation. The photo-induced oxidation of hydrocarbons in the aqueous phase is brought about by singlet oxygen, ozone, HO- radical, and other oxidants. Photo oxidation by singlet oxygen appears to be the most dominant process for the breakdown of hydrocarbons and other organics. Under ozone and light, the "half-lives" of several hydrocarbons vary between a few hours to a few days. The most common products of photolysis are endoperoxides that undergo secondary reactions to yield a variety of products including diones.

Basic Work Methodology.-

The first step was to promote hydrocarbon decomposition into smaller chains or a complete oxidation into CO₂ and H₂O by the introduction compounds rich in free radicals ready to attach and break the hydrocarbon chains. Then, the next step was the addition of mineral amendments; these introduce highly UV receptive compounds that promote a fast photodecomposition of the hydrocarbons. Finally, previously produced enhanced organic compost was added to promote bio augmentation of highly oleophagic organisms. Particle size reduction, aeration and sun exposure are achieved via intense tiling.

In summary, the work was executed based on the below process:

- Site Preparation works – Construction of Treatment Cells whereby the surface of the identified treatment area was properly compacted and then lined with at least 3mm liner. This method was to ensure the liner will not be damaged during the mechanical homogenizing process. A bund was constructed around the treatment cell.
- Mobilize Equipment, Material & Personnel to site - The intended contaminated soil was transferred to and spread in the treatment cell to be treated evenly to cover the treatment cell area; maximum depth of 30cm.
- Hydrate the contaminated soil with water just enough to cover the soil and homogenize the treatment area with agricultural tractors fitted with disc plows.
- Dosing of ionic surfactants with strong oxidizing to create larger surface area and exposure of the hydrocarbons to the sunlight (UV), oxygen from air.
- Addition of proprietary free radical agent which generates ionic reactions that not only promotes hydrocarbon breakdown, but it also enhances the native microorganisms to degrade the contaminants more effectively than conventional bioremediation process. This process was to promote photo oxidation and bio augmentation. The dosage was determined and administered using water as dissolution medium; with the use of pumps and spraying systems the material was applied every other day. The photo-induced oxidation of hydrocarbons in the aqueous phase was brought about by singlet oxygen, ozone, HO-radical and other oxidants. Mechanical means using Agricultural tractors are used to plow the material to promote exposure to air (O₂) and sunlight (UV) to enable the aerobic digestion of the hydrocarbons. This process will enhance and increase the natural biota and do not contemplate the introduction of foreign microorganisms to the ecosystem.
- Daily samples were taken and tested for values of several parameters including pH, moisture content and TPH to determine the effectiveness of the system and for further requirements. Moisture was always maintained at 60% and pH can vary from 6.5 to 8.5 and may need adjustment. Weekly samples was used to determine nitrates and phosphates. This process will continue until the decontamination levels drop to below 10,000ppm TPH. Once this stage is achieved, the addition of mineral soil amendment agent was stopped.
- Grab and composite samples are used in conjunction with a statistical methodology to determine that the whole site was cleaned and the environmental agencies can provide the clearance for the material to be removed and disposed. However, this final material was very good and fertile topsoil; agriculture test can be performed to determine fertility and nutrient content if desired.

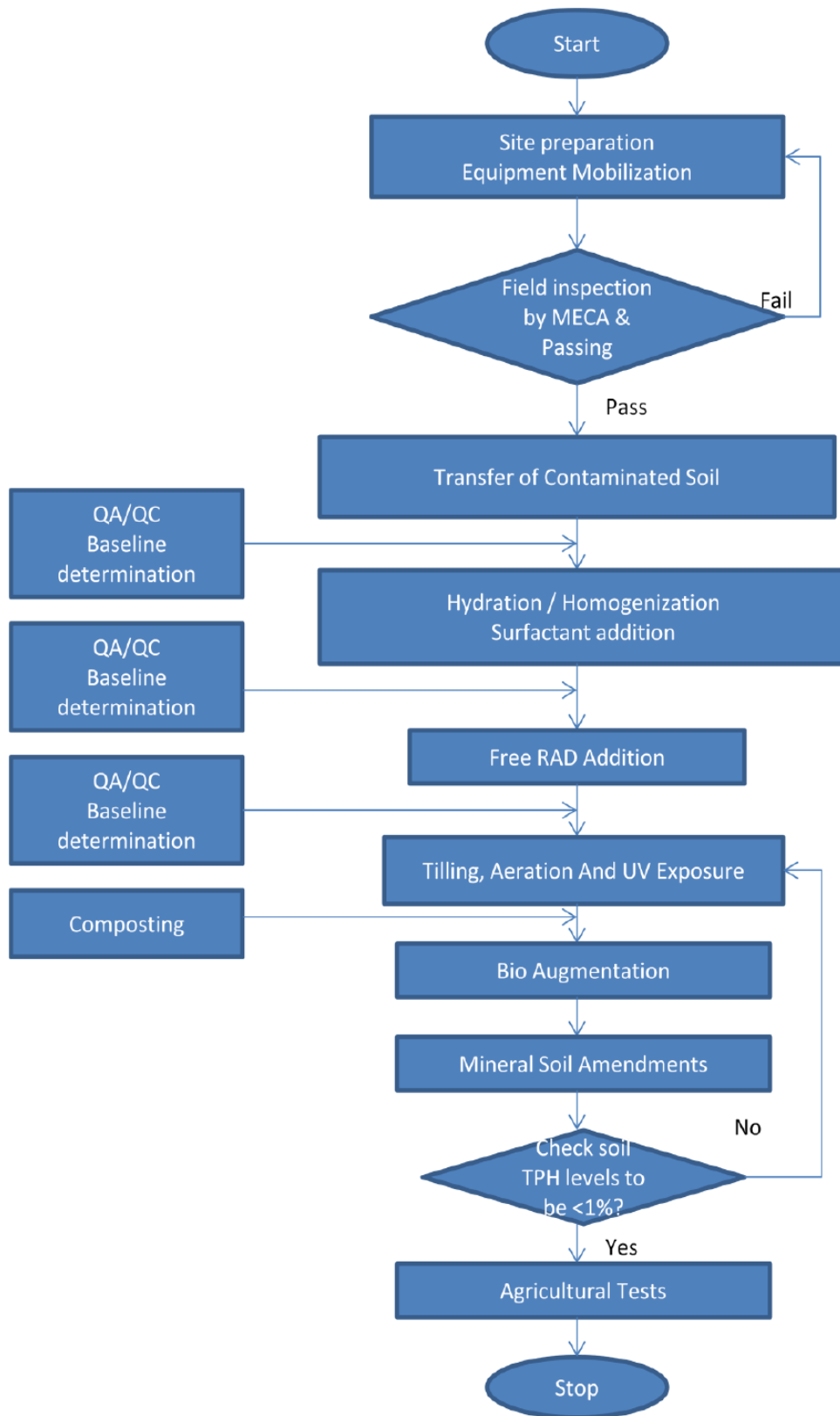


Fig. 5

Description and Application of Equipment and Processes

Process details.-

The project was carried out following a series of steps that were continuously monitored for QA/QC protocols to determine the efficiency of each of these steps. The main activities carried out throughout the project were:

Process 1: Treatment cell and Site Preparation.-

The construction of the treatment cell has to take place in a compacted and stable area, the area is fenced to avoid animals coming in contact with the treated material. The cell is lined using a 3mm HDPE liner to avoid contamination of the soil below. The site requires a field laboratory, equipment and materials storage and a composting area as well as parking for the crew's vehicles and heavy equipment. Before any work can proceed inspection and approval by the Omani environmental authorities has to take place.



Fig. 6

Process 2: Material Transferring.-

The material is then transferred using a long reach excavator and a front loader. The material is homogeneously spread throughout the cells surface at the same level.



Fig. 7

Process 3: Hydration / Homogenization / Surfactant addition.-

Water is added to cover the level of the material by at least 6". The material is homogenized and the step is considered complete when all the material is "water wet". Surfactants are added and physical mixing is implemented using tilling equipment and earth moving equipment. The step is considered complete when the hydrophobic nature of the cuttings is lost.



Fig. 8

Fig. 9

Process 4: Chemical Oxidation.-

Chemicals are added using centrifugal pumps and they are completely mixed using the agricultural tractor tiling utensils. The reaction can take place within 1 to 24 hrs. The process is repeatedly based on laboratory testing results.



Fig. 10

Process 5: Drying and UV active compounds addition.-

The material is then added under strict monitoring of the pH levels, caustic soda or citric acid are used to maintain optimum level of pH for the secondary reactions to take place. Tilling, aeration and UV exposure continue throughout.



Fig. 11

Process 6: Composting.-

Using local organic waste (food and animal waste) combined with hay and straw are composted and the indigenous oleophilic bacteria is bio-augmented. The process is monitored following the temperature of the pile. Nitrogen, Phosphorous and potassium are added to the pile to enrich the nutrient level of the pile.

Process 7: Bio-degradation.-

The compost rich in microorganisms is added and the bio-degradation process is started in both cells maintaining humidity and pH levels at all time. Mineral soil amendments are added as urea and NPK. The material is tilled daily to promote UV exposure and aeration.



Fig. 12

Process 8: Quality Assurance / Quality Control.-

The whole process is monitored by continuous sampling and testing of different parameters to ensure that the physical, chemical and biological processes take course on a timely manner and efficient enough to set the basis for the next process. Triplicates of about 20 gm of each dried soil sample were placed in bottles. Twenty ml of analytical grade dichloromethane were used as an extracting solvent. To improve extraction, each sample was treated in an ultrasonic bath (Decon Model # FS100B) for 30 minutes. Extraction and sonication were repeated twice for each sample. The filtered solvent was passed over anhydrous sodium sulphate to remove possible water residue. The collected solvent was completely evaporated using a rotary evaporator (Buchi Model# R-215). The flask that contains the oil was then desiccated using silica gel. The oil containing flask was weighed to the nearest 0.0001 gram. The results were subtracted from the weight of the empty flask. Average oil content was calculated from 3 triplicates.



Fig. 13

Process 9: Agricultural Tests.-

Agricultural tests were carried out at the end of the project to determine the grade of soil achieved after the remediation process. Once the process was completed and validated with the final analytical report for the treatment cells, we decided to see if the treated soil was a good soil for agricultural processes.

Starting in June 1, 2013 a series of agricultural tests were carried out during two months to raise a crop in the treatment cells. Composite cells were taken at the crop-root level" (20-40 cm) with the results shown on the attached soil reports from GLT Oman. The results show:

pH - The pH value found is a typical value for an alkaline soil which is common in the region. We compared the result with a soil from a farmland not far from the site (~10km) and the results were identical with the treated soil.

Salinity - Initially we had a very high salinity in the soil when the treatment started; this was due to the fact that the muds are being prepared with concentrated brines. However, the salinity before starting the agricultural tests was close to that of the adjacent farmlands in the area. This is because they use brackish water from deep wells in their irrigation practices which was the same water used throughout the process.

Phosphorous P - The orthophosphates, $H_2PO_4^-$ and HPO_4^- , are the primary forms of phosphorus taken up by plants. Plant roots absorb phosphorus from the soil solution. In comparison to other macronutrients, the phosphorus concentration in the soil solution is much lower and ranges from 0.001 mg/L to 1 mg/L. Our soil had a healthy 18 mg/Kg, but P-sorption is not a guarantee. In general, roots absorb phosphorus in the form of orthophosphate, but can also absorb certain forms of organic phosphorus. Phosphorus moves to the root surface through diffusion. However, the presence of mycorrhizal fungi, which develop a symbiotic relationship with plant roots and extend threadlike hyphae into the soil, can enhance the uptake of phosphorus, as well especially in acidic soils that are low in phosphorus.



Fig. 14

Nitrogen (N) - N is hard to evaluate, diagnostic testing for nitrogen soil fertility can provide a very effective guide to nitrogen fertilizer management. Diagnostic N testing requires sampling of the subsoil, at least to the third foot depth. The soil test N index is the total of nitrate-nitrogen from the surface layer to the depth sampled. If properly sampled, this soil test N index can minimize the risk of nitrate movement to ground water and also optimizing the nitrogen fertilizer investment. Also, the diagnostic N test does not function if there are large amounts of organic N that will be mineralized during the growing season. This includes (a) alfalfa as the preceding crop, and (b) manure applied the previous fall or the current spring. Diagnostic soil test N is based only on nitrate-N in the root zone. Our reading indicates a very low level but all the counter indication factors are present for the reading, extensive use of organic material and soil amendments before the sampling took place.

Carbon (C) - Soil carbon, or soil organic carbon (SOC) as it is more accurately known, is the carbon stored within soil. It is part of the soil organic matter (SOM), which includes other important elements such as calcium, hydrogen, oxygen, and nitrogen. Soil organic matter is made up of plant and animal materials in various stages of decay. Undecomposed materials on the surface of the soil, such as leaf litter, are not part of the organic matter until they start to decompose. Our soil was extremely rich in carbon due to the high content of organic matter added during the treatment process.

Based on discussions with PhD Ahmed Al Busaidi of the Sultan Qaboos University – College of Agricultural Agricultural and Marine Sciences - it was decided to raise typical grass type crops, though the planting season did not coincide with the standard planting seasons (being this time the middle of the summer). The following crops were tried to be grown on the remediated soil and their growth pattern was studied.



Fig. 15

1. White Milky Jowar - *Sorghum bicolor*
2. Alfalfa (*Medicago Sativa*).
3. Barley (*Hordeum vulgare*).
4. Local cane (*Arundo donax*).

Two techniques were used to apply the seeds: a) Direct throw and b) Throw and rotavator. The seeds were mixed in batches of 30kg/each sp. And a hand method for throwing them was used after an extensive watering of the field. The direct throw left the seed in the surface and the rotovator insured the covering of the seed up to 4" deep in the soil. The seed sprouting was compared with control seeds planted in wet cotton in the lab at the same time. The first problem encountered was the wild birds eating the seeds that were in the surface.

The sprouting was normal against the controls in the lab, once the leaves started to come out a sudden slow down on the growth was realized the plants would reach about 2" off the ground and then started to dry out. The recorded ambient temperatures in the field at this time were 45-52 C with the soil reaching temperatures of up to 65 C. According to PhD Al Busaidi, these extreme temperatures caused thermal shock to the plants and kill them.

We can also see that the nutrients were in the soil by the rapid growth of algae where water stayed stagnant for a few days. Domestic grasses were transplanted into the shaded areas also with the same faith as all the other species transplanted, initial growth followed by decay.

Two sets of trials were ran for planting these grasses, however, in both cases we were not successful and this was because of the harsh conditions and thermal shock induced in the young plants. During the last part of the month of June and for the remainder of July test were carried out transplanting other species into the cells. One of the species tested was *Arundo donax* which is a cane very popular in the area. *Arundo donax* is native to eastern and southern Asia, and probably also parts of Africa and southern Arabian Peninsula. It has been widely planted and naturalized in the mild temperate, subtropical and tropical regions of both hemispheres, especially in the Mediterranean, California, the western Pacific and the Caribbean. It forms dense stands on disturbed sites, sand dunes, in wetlands and riparian habitats. The transplanted canes were covered using a synthetic material to reduce the heat of the summer both on the plants and the soil, however they had the same faith as the sprouts tried before, and they would grow new leaves only to lose them after they grew about 2".

Presentation of Data and Results

Sample preparation for gravimetric determination:

Triplicates of about 10 grams of each wet soil sample were placed in bottles and mixed with anhydrous sodium sulfate. Ten ml of analytical grade dichloromethane were used as an extracting solvent. To improve extraction, each sample was treated in an ultrasonic bath (Decon Model# FS100B) for 30 minutes. Extraction and sonication were repeated twice for each sample. The filtered solvent was passed over anhydrous sodium sulfate to remove possible extra water residue. The collected solvent was completely evaporated using a rotary evaporator (Buchi Model# R-215). The flask that contains the oil was then desiccated using silica gel. The oil-containing flask was weighed to the nearest 0.0001 gram. The results were subtracted from the weight of the empty flask. Average oil content was calculated from 3 triplicates.

GC/MS instrumental conditions:

GC-MS analysis was performed on a Perkin Elmer Clarus 600 GC System, fitted with a Rtx@-5MS capillary column (30m × 0.25mm i.d. × 0.25µm film thickness; maximum temperature, 350°C), coupled to a Perkin Elmer Clarus 600C MS. Ultra-high purity helium (99.9999%) was used as carrier gas at a constant flow of 1.0 ml/min. The injection, transfer line and ion source temperatures were 280, 290 and 290 °C, respectively. The ionizing energy was 70 eV. Electron multiplier (EM) voltage was obtained from autotune. All data were obtained by collecting the full-scan mass spectra within the scan range 40-550 amu. The injected sample volume was 1 µl with a split ratio of 40:1. The oven temperature program was 80° C (holds for 5 minutes) and accelerated at a rate of 10o C / min–280 o C hold for 30 minutes. The unknown compounds were identified by comparing the spectra obtained with mass spectrum libraries. The standard mix solution (C7-C40) was used for confirmation purpose.

Final sampling and analysis.-

Initially, samples of the pit were analyzed to determine the composition of the oil present in the contaminated material. Gas Chromatograms were used and the results are shown on figure 16. It is clear that the material is composed of long chains of aliphatic hydrocarbons in the range of C-12 to C-22.

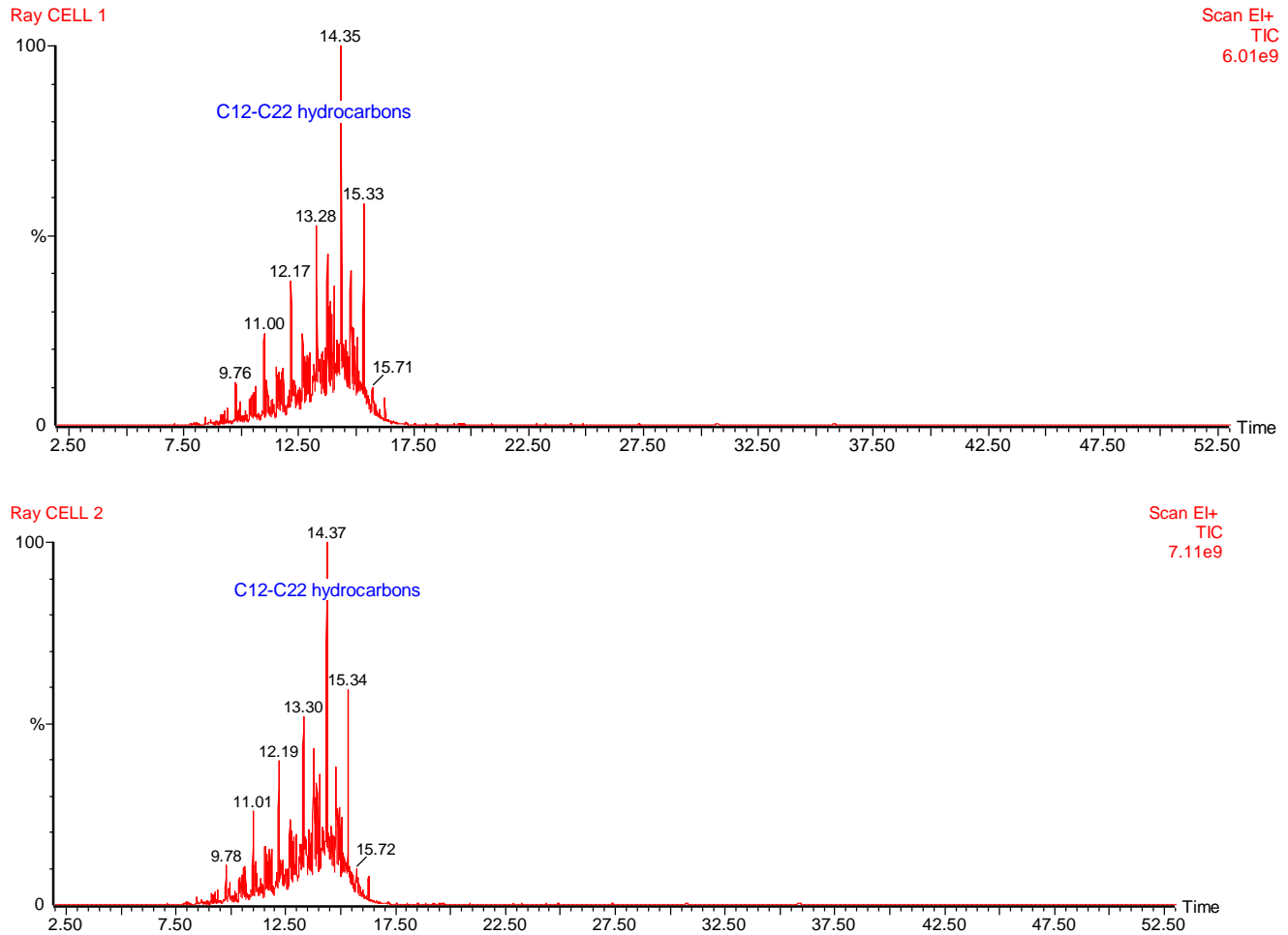


Fig. 16

TPH concentrations of the material inside the pit were determined by the retort method using an evaluation by weight. The average initial concentration was around 22.0% W/W.

The protocol continued with retort testing for the first 12 weeks and with a continuous daily sampling and testing that allow for process adjustments and to determine the de-contamination curve. Once we have reached values of TPH below the threshold limit (1.00 %) with our field testing equipment and following MECA recommendations. A comprehensive sampling protocol and statistical method was devised in order to ensure that the whole volume of the materials in the cells complied with the decontamination levels required.

Each cell was sampled according to the cell sampling diagram attached as Figure 17 to this report. The sampling was carried out as per the following chart: Date of Sampling: 22 June 2013.

Cell - A

Table 1

Sample ID	Type	Mass	Depth
1A	Grab Sample	500g	0.20 cm
2A	Grab Sample	500g	0.25 cm
3A	Grab Sample	500g	0.30 cm
4A	Grab Sample	500g	0.35 cm
5A	Grab Sample	500g	0.40 cm
6A	Grab Sample	500g	0.45 cm
7A	Grab Sample	500g	0.50 cm
8A	Grab Sample	500g	0.55 cm
CompA*	Composite Sample	800g	N/A

* Composite sample is prepared by taking 100g from each of the grab samples.

Table 2

No.	Samples	Triplicate	Sample Weight (g)	Oil content (%)	Average (%)	Standard Deviation (%)
CELL - A						
1	6A	1	20.0261	0.534		
		2	20.0268	0.478	0.554	0.088
		3	20.0232	0.651		
2	7A	1	20.0275	0.645		
		2	20.0181	0.725	0.691	0.041
		3	20.0232	0.704		
3	8A	1	20.0168	0.6		
		2	20.038	0.585	0.556	0.063
		3	20.0312	0.484		
4	1A	1	20.0151	0.556		
		2	20.0127	0.691	0.613	0.07
		3	20.0169	0.594		
5	2A	1	20.0194	0.611		
		2	20.0157	0.664	0.627	0.032
		3	20.0103	0.606		
6	3A	1	20.0303	0.553		
		2	20.03	0.557	0.55	0.008
		3	20.03	0.541		
7	4A	1	20.014	0.584		
		2	20.0175	0.513	0.554	0.037
		3	20.0146	0.565		
8	5A	1	20.0144	0.573		
		2	20.0121	0.608	0.618	0.0513
		3	20.0127	0.674		
9	COMP A	1	20.0127	0.622		
		2	20.0379	0.642	0.59	0.074
		3	20.035	0.505		

CELL - B

Table 3

Sample ID	Type	Mass	Depth
1B	Grab Sample	500g	0.20 cm
2B	Grab Sample	500g	0.25 cm
3B	Grab Sample	500g	0.30 cm
4B	Grab Sample	500g	0.35 cm
5B	Grab Sample	500g	0.40 cm
6B	Grab Sample	500g	0.45 cm
7B	Grab Sample	500g	0.50 cm
8B	Grab Sample	500g	0.55 cm
CompB*	Composite Sample	800g	N/A

*Composite sample is prepared by taking 100g from each of the grab samples

No.	Samples	Triplicate	Sample Weight (g)	Oil content (%)	Average (%)	Standard Deviation (%)
CELL - B						
1	1B	1	20.0576	0.559		
		2	20.0053	0.587	0.575	0.014
		3	20.016	0.579		
2	2B	1	20.0185	0.672		
		2	20.001	0.552	0.603	0.062
		3	20.0051	0.586		
3	3B	1	20.0229	0.55		
		2	20.017	0.57	0.532	0.049
		3	20.0127	0.477		
4	4B	1	20.0335	0.59		
		2	20.0453	0.58	0.575	0.018
		3	20.0598	0.554		
5	5B	1	20.0111	0.549		
		2	20.0071	0.651	0.56	0.086
		3	20.0231	0.48		
6	6B	1	20.0182	0.526		
		2	20.0396	0.58	0.56	0.03
		3	20.0205	0.574		
7	7B	1	20.0231	0.537		
		2	20.0206	0.441	0.519	0.071
		3	20.02	0.579		
8	8B	1	20.0334	0.481		
		2	20.0578	0.57	0.541	0.045
		3	20.0137	0.513		
9	COMP B	1	20.0134	0.614		
		2	20.0314	0.493	0.553	0.06
		3	20.0304	0.553		

Table 4

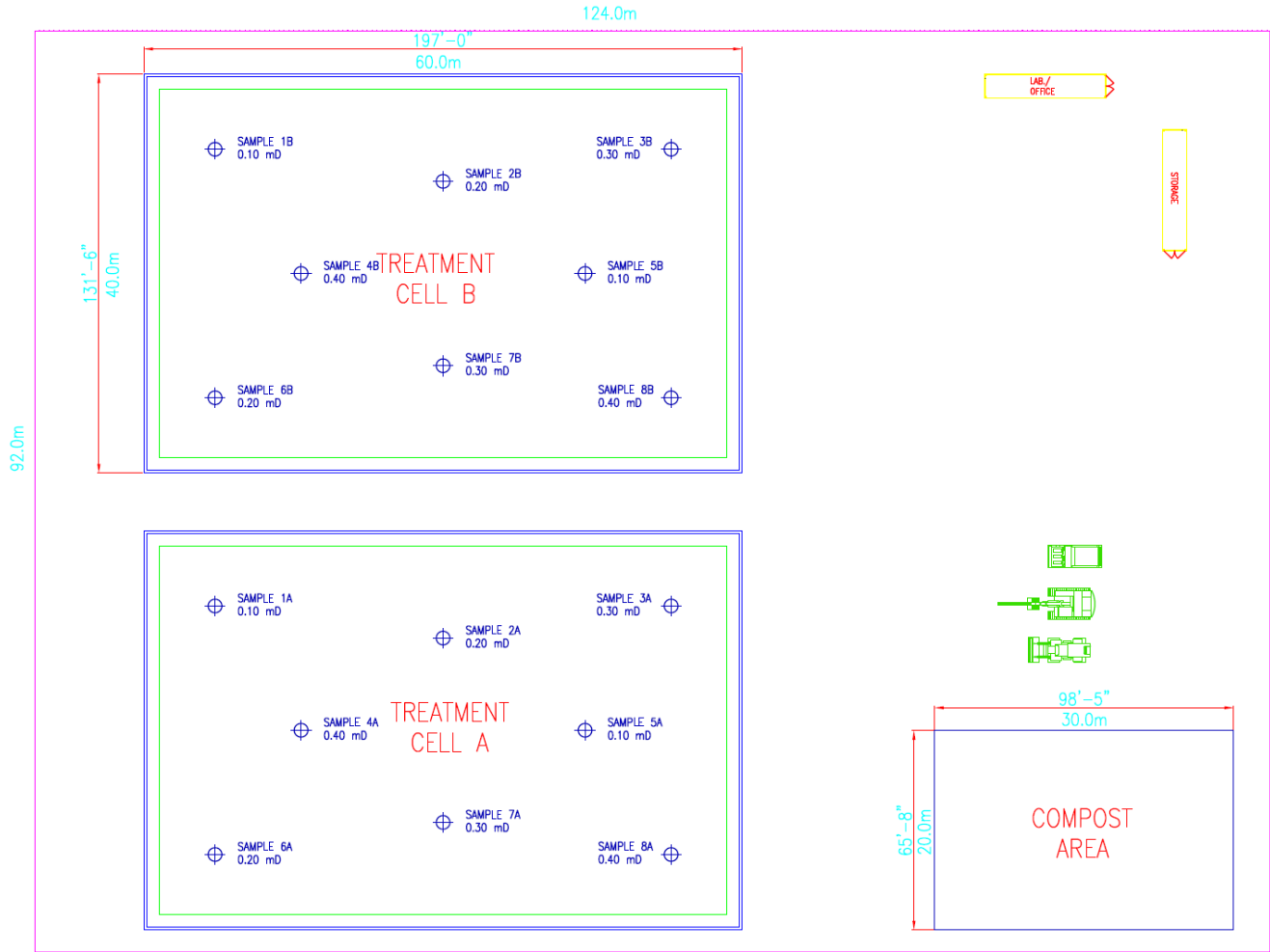


Fig. 17

Process results.-

The whole process, starting from the hydration of the waste until reaching the desired level of de-contamination was 22 weeks long. This unexpected long time was due to the highly paraffinic nature of the synthetic oil used to make the invert emulsion in the SBM formula.

Decontamination Curve.-

The de-contamination curve for the materials on each cell is shown below. The graph shows that the percentage of TPH in the samples was reduced from 22% to less than 0.5 % TPH. It took around 4-5 weeks to reach half the level of TPH concentrations in the soil samples. But after reaching that, the rate of decrease of the TPH levels became slower due to the presence of the long chain hydrocarbons that were harder to be broken down.

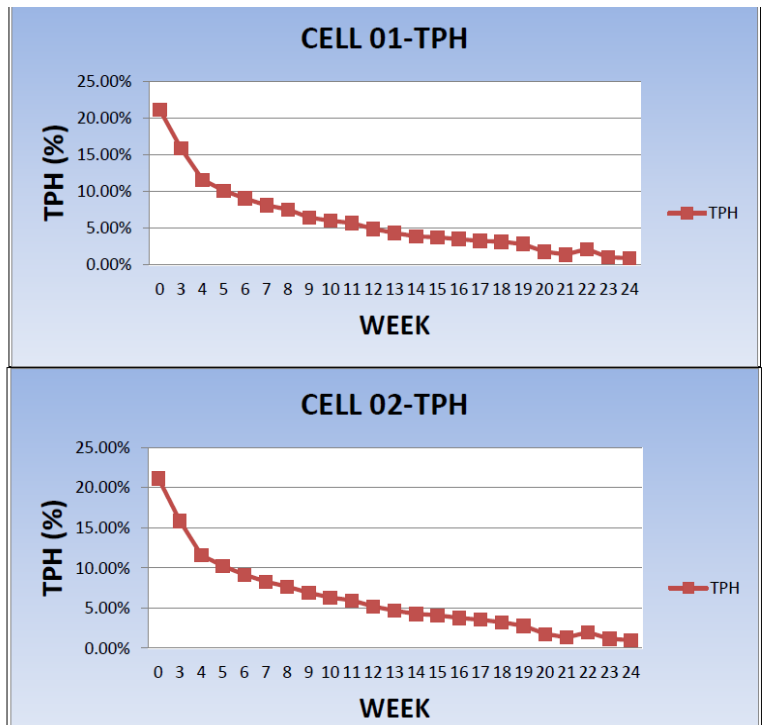


Fig. 18

Conclusions

This was the first application of this technology in the Middle East under extreme weather and highly contaminated waste materials. The results show that the technology can offer a feasible and economic option to the operators in the field that carry the environmental liability over long periods of time after the drilling phase is completed especially in exploration wells. The final threshold of decontamination was reached over a period of 22 weeks where in tropical regions and with crude oil, as the main contaminant, the periods can be shorten in less than half the time with the same initial concentrations. For the particular case of Oman where bio-remediation techniques had proven not effective in treating drilling wastes specially SBMs, this can be a way to process such wastes specially with the huge areas available for land farming and the high intensity of UV solar light. The final tests that was added to the remediation process was to see if this soil will be good for bearing crops after treatment. In this case we failed to prove the point and this might be due to the harsh environmental conditions (peak summer) but it would be worth trying the same tests in the cooler months of autumn and winter.

Oman Green Awards is a platform to honour and appreciate outstanding environmental vision, endeavours, initiatives and achievements. As the country's first Environmental Awards, the Oman Green Awards have been created to awaken the eco-consciousness in every Omani citizen and resident. The ultimate aim is to motivate behavioural change and increase awareness in relation to the protection and preservation of our environment. It gives us immense pride to say that we received the Green Research Award (awarded for the best research in the field of environment conservation) for the successful implementation of this technology for the first time in Oman.

Before the treatment -



Fig. 19

After the completion of Enhanced Soil Remediation works using Free-RAD© Technology



Fig. 20

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