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AN OVERVIEW ON OIL CONTAMINATED SAND AND ITS ENGINEERING APPLICATIONS

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ABSTRACT: Oil leakage is considered as one of the significant environmental issue worldwide, which affects the physical and chemical properties of the surrounding sand. A range of remediation methods for oil-contaminated sand was recommended but none are considered to be cost effective especially in developing countries. In order to find an alternative and cost-effective remediation method, the use of oil contaminated sand in engineering and construction has been considered. This paper reviews the main sources of oil contamination, the existing remediation methods and critically analysed several factors that affecting the properties of oil contaminated sand. Emerging applications of oil contaminated sand in engineering and construction are also presented.

Keywords: *Contaminated sand, Remediation, Mechanical properties, crude oil, Engineering.*

1. INTRODUCTION

Oil and gas are considered to be the most significant sources of energy worldwide. However, the main drawback with this type of energy is the severe damage it has already inflicted on the environment [1] due wars, vandalism, terrorism, and theft [2]. This pollution can also be caused by leakage, oil spillage, corroding pipelines, transporting petroleum, human error during the separation process, and the produced water that is considered to be the largest by-product or waste stream (by volume) associated with the production of oil and gas [3-5]. Intentionally or unintentionally, oil spill contamination impacts on the properties of the surrounding sand and changes its physical and chemical properties [3]. To minimize its effect on the environment, a range of remediation methods for sand contaminated with oil ranging from sand washing, bio-remediation, electro-kinetic sand remediation, and thermal desorption, have been implemented but they are not all considered to be cost effective [6]. Some researchers have investigated the use of oil contaminated sand for engineering applications as an alternative remediation method and concluded that sand contaminated with oil can be used for road base materials or topping layers in parking areas [7-9]. Although its use in civil engineering construction is considered to be a clever and successful solution in terms of cost and reducing the environmental impact, a better understanding of the properties of sand contaminated with oil is needed because, a) very few studies in literature have dealt with its mechanical properties [10], b) it would provide useful information in designing the foundations of structures to ensure that the sand can bear the estimated load during its life time [3], c) crude oil pollution is not identical in terms of its effect because it is affected by a number of factors such as the permeability, adsorption properties, and the coefficient of partition [11], d) the extent of contamination on the chemical composition and properties of sand varies from place to place [12], and e) this information is critical to effectively utilize them in construction applications. This paper provide an overview of the main sources of oil contamination, the effect of oil contamination on the mechanical properties of sand, the existing remediation methods, and some emerging applications of oil contaminated sand in engineering and construction.

2. SOURCES OF CRUDE OIL CONTAMINATION IN SAND

2.1 Leakage of Crude oil

One of the most critical environmental impacts of exploration, production, operation, and transportation of crude oil is the spillage that causes severe contamination of the surrounding environment [13]. Despite the fact that most spillages are accidental, there are some cases where crude oil was spilled intentionally, such as in the Gulf in 1991, where it was reported that about 1.1 billion litres of crude oil were spilled into the Arabian Gulf, the Persian Gulf, and in the Kuwait desert between August 1990 and February 1991. These are considered to be the largest oil spills in history [14, 15]. As a consequence of this intentional leakage, 700 km of coastline between Kuwait and Saudi Arabia were polluted, and approximately 49 square kilometers of the Kuwait desert was affected. Furthermore, the British petroleum BP deep water horizon drilling rig that exploded in the Gulf of Mexico in 2010 caused a spill of around 91 million litres of oil that affected about 110 km of the Louisiana coastline [16, 17]. Moreover, around 71 million litres of crude oil was intentionally discharged from oil storage tanks at the Harouge Oil Operation petrochemical and refining complex at the Ras Lanuf Terminal in Libya in August 2008 [16, 17] to circumvent an explosion in the tank from the fire caused by a human error during annual maintenance [16]. This is an example of a crude oil spill caused by negligence associated with the operating companies. In fact, most crude oil spills were caused unintentionally due to ageing facilities, lack of maintenance, and human error.

In most oil producing but developing countries, the oil contaminated sand is left in the field without any treatment because the available remediation methods are too costly. Figure 1 illustrates the final stage of oily wastewater, including the contaminated sand around the discharge disposal point.

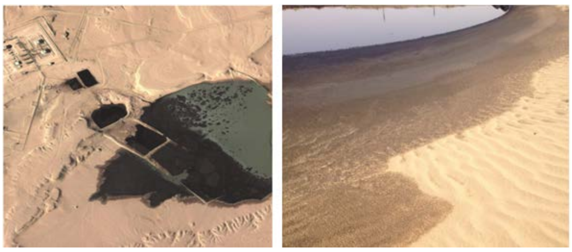

Figure 1: Oil contaminated sand caused by produced water

2.2 Produced Water

The second source of contaminated sand is the produced water considered to be the major volume of waste stream in the oil production industry—roughly three barrels of water for every barrel of oil [18]. It exists as a consequence of the production of oil and gas from underground reservoirs that contain formation water [19]. The globally estimated average volume of produced water is 210 million barrels/day, and this results in an annual production of 77 billion barrels/year [20]. The estimated volume of produced water in offshore platforms worldwide is approximately 107 million barrels/day, while the estimated total production of offshore oil is 120 million barrels/day. Figure 2 shows a comparison between onshore and offshore produced water over a 25 year period (from 1990-2014). According to Teodor [21] more than 44 million barrels/day of produced water is discharged into the sea.

The quantity of produced water from the oil industry has increased dramatically, and it does not remain constant during the operational life of an oil well, indeed the amount of produced water actually increases as the production of oil deceases [22]. In some older oil fields, the water cut exceeds 95% [20, 23]. This quantity of produced water is expected to increase in the future, which means this continuing discharge of oily waste water into the environment is now a major concern [24].

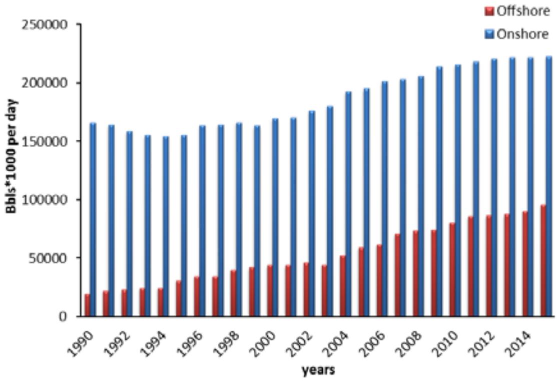

Figure 2: Global onshore and offshore water production [25].

The problem with produced water is that it contains a high percentage of crude oil, whereas dispersed oil consists of small droplets suspended in oily produced water. This concentration of dispersed oil can be affected by its density, the efficiency of the separation stages, the chemical treatment, the shear history of the droplet, and interfacial tension between the water and oil [26]. Chemical treatment and soluble organics help to reduce the interfacial tension between oil and water in produced water, but the methods used to remove oil and grease (OG) depend on the end use of the produced water and the internal composition of the oil. Table 1 shows the typical treatment and performance of oil removal expressed by the minimum size of particles removed.

Table 1: Oil and grease removal technologies based on the size of the particles removed [27].

Oil Removal Technology	*Minimum size of particles removed (μm)*
API gravity separation	150
Corrugated plate separator	40
Induced gas flotation (no flocculants)	25
Induced gas flotation (with flocculants)	3-5
Hydroclone	10-15
Mesh coalesce	5
Media filter	5
Centrifuge	2
Membrane filter	0.01

Produced water from the separators (an item of production equipment used to separate liquid components of the well stream from gaseous elements), typically contains 40-1200 mg/L oil droplets of less than 20 μm and 1-50 mg/L solid particles of less than 10 μm [28]. Because the current systems cannot remove particles (oil droplets) less than 10 µm, small droplets of oil can interfere with oily produced water. Based on Environmental Protection Agency (EPA) regulations, the daily maximum limit for OG is 42 mg/L and the monthly average limit is 29 mg/L [22]. Despite the fact that many countries have implemented more stringent regulations for discharging produced water to reduce the effect of these components on the environment, huge amounts of produced water are still discharged onshore or offshore. The main issue with crude oil contamination caused by oil spillage and oily wastewater is the resultant changes in the physical and chemical properties of the surrounding soil [3]. Hence, to eliminate or minimize the adverse effect of oil contaminated sand on the environment, a suitable remediation method should be implemented, but this requires a better understanding of the composition and properties of oil contaminated sand.

3. OIL CONTAMINATED SAND

3.1 Sand composition

Sand is a naturally occurring material (NOM) that is considered to be an important engineering material. In most cases its physical characteristics are determined by experiments and these properties are then used to predict its expected behavior under working conditions, including its beneficial uses [29].

Sand is considered to be a three phased material (liquid, solid, and gas), whose geotechnical use is mainly based on its mechanical behavior. When sand is contaminated with oil, the composition of these phases is altered because the chemicals change its mechanical properties [30, 31], and cases of geotechnical failure due to changes in the mechanical properties of sand [32] have been reported. These failures occur because sand contains different materials (organic and inorganic), and the nature of each single particle is derived from the minerals which are in turn affected by the original rock from which the particle has eroded. Unlike rock, sand is not a solid or cemented material because the individual particles have not bonded together, instead it is considered to be a skeleton of sand grains in frictional contact with each other [33]. A further explanation was given by Murthy [34] who stated that sand is a natural aggregate of mineral grains with or without organic constituents that can be separated by gentle mechanical means. Its mechanical properties such as permeability, compressibility, shrinkage, swelling, and shear strength are based on an interaction of the three phases of sand [30]. The solid phase is the framework surrounded by a pore space that is shared by the liquid and gaseous phases. The flow of pore water can be affected by the size of the pores and the degree of saturation and hence the permeability (k) might be decreased [33].

3.2 Sand contaminated with crude oil

Understanding the properties of oil contaminated sand is very important [35] in order to determine the extent of its adverse effects to the environment and to decide the most suitable remediation method. Similarly, the physical and chemical properties of sand change as soon as they come into contact with crude oil [36]. The degree of change depends on many factors such as the type of sand, and the specific composition and quantity of the spilled hydrocarbon. When crude oil is spilled, the liquid hydrocarbon travels down to the groundwater causing partial saturation of the sand and the pathway of the hydrocarbons. Once a hydrocarbon reaches the ground water table, it spreads horizontally within the capillary zone and further saturates the sand [36]. These spreads are much greater with light crude oil than medium and heavy crude oil because light crude oil contains high percentage of light hydrocarbons that can easily penetrate and migrate through the particles of sand. This is why sand contaminated with light crude oil is considered to be one of the most adverse environmental issues.

Hydrocarbon contamination has a direct effect on the erosion of sand and water infiltration, and may also cause fire on the ground. Whereas fire-induced or fire-enhanced sand water repellence has often been cited as the major cause of post-fire enhanced runoff and erosion [37], hydrocarbon contamination can also affect the physio-chemical characteristic of a sand [38]. Sharma and Reddy [30] concluded that the intrinsic permeability (k) of contaminated sand increases when there is an increase in density and decrease in the viscosity of the fluid filling the voids. This clearly indicates the significant effect that the density and viscosity of oil contamination have on the permeability of sand. Furthermore, the aggregation of fine particles and fusion of minerals may reduce the stability of the sand-organic matter aggregate.

Oil contamination can adversely affect the plant and contaminate ground water resources used for drinking or agricultural purposes [1]. Rahman et al. [39] also showed that not only is the ecosystem affected by the spillage of crude oil, so too is the safety of civil engineering structures. Thus, it is not safe to construct buildings on contaminated sand because any changes in the engineering properties and behavior of the layers of sand may affect the bearing capacity and differential settlement of the foundations [40]. This demonstrates the need for a detailed understating on the effect of oil contamination on the physical and mechanical properties of oil contaminated sand.

3.3 Properties of oil contaminated sand

Several studies have been carried out to gain a better knowledge of the mechanical properties of oil contaminated sand. In 1992, Evgin and Das [41] used a triaxial test to investigate clean and contaminated quartz sand, and concluded that full saturation with motor oil significantly reduced its frictional angle. A similar investigation was conducted by Al-sanad and Ismael [42] using direct shear, and tri-axial and consolidation tests to determine how age affected the mechanical properties of sand contaminated by up to a maximum percentage of 6% by weight. They found that the strength and stiffness of oil contaminated sand increased due to ageing, while the amount of oil actually decreased due to evaporation. The same authors also investigated the strength, compressibility, and compaction of soil contaminated with 3 to 6% of crude oil and concluded that the compaction and California Bearing Ratio (CBR) values improved when the amount of oil was up to 4% by weight. However, there was no significant reduction in permeability and strength and the friction angle had only decreased by 2^{o} whereas the compressibility increased and the strength parameters were affected more by heavy crude oil than light crude oil [14]. The effect of temperature on the strength, permeability, and compressibility of sand contaminated with heavy and medium crude oil was also investigated by Aiban [43]. He concluded that the compressibility increased as the temperature increased, and the shear strength parameters were not sensitive to the testing temperature.

The mechanical properties of clayey and sandy soils were investigated by Khamehchiyan et al. [10] and they concluded that their strength, permeability, density, optimum water content, and Atterberg limits decreased. In contrast, an increment in these properties was observed in a fine grained sand contaminated with oil in a consolidation settlement test conducted by Singh et al. [44]. One of the most recent observations from a similar investigation showed that the friction angle, dry density, compression index, and Atterberg limits increased while the optimum water cohesion had decreased [45], while Khosravi et al. [3] concluded that the cohesion increased while the frictional angle and compressibility decreased.

The above studies clearly indicated that the threats posed to humans and the environment by oil contaminated sand is very high. Also, oil contamination also adversely affects the physical and mechanical properties of sand. These issues have made the assessment and remediation of contaminated sites very significant. In the next section, the existing remediation methods are presented and their advantages and disadvantages are carefully evaluated.

4. REMEDIATION METHODS

There are many limitations on the disposal of oil contaminated sand. Equally, the remediation of sand contaminated with oil is complicated, takes a long time, very expensive process and needs to comply with stringent environmental legislations. Over the past decade, the awareness of contaminated sites has increased, especially where public water supplies rely on ground water, while contaminated sand has also become a societal issue because it causes adverse health and environmental problems.

The extensive seepage and contamination caused by crude oil spills is based on the properties of the sand [12] because contaminated sand would need major remediation and/or reclamation to make it suitable for any future use. Research studies have resulted in several technical methods which could remediate these problems, but they do have advantages and disadvantages [46, 47].

The cost of alternative remediation methods as described by US EPA-(1997) varies from 50 - 1000 (US $ per ton). Figure (3) indicates that the cost depends on the remediation technique and the concentration of contaminants. The most expensive methods are Incineration and Vitrification and they vary between ($280-1000) and ($100-1000) respectively, while the cheapest methods were soil washing and solvent extraction at ($60-230) per ton.

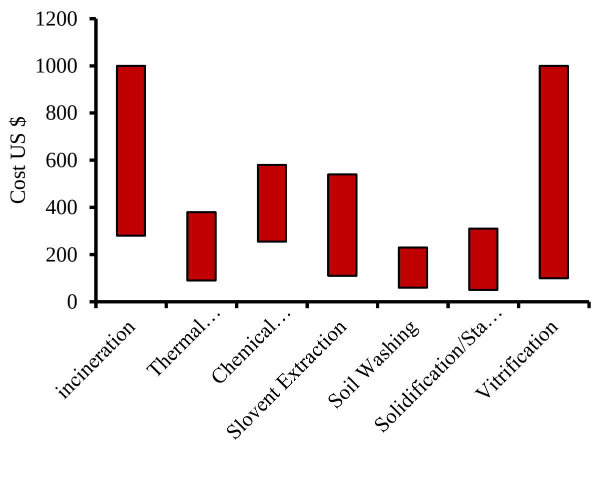

Figure 3: Cost of hydrocarbon remediation methods [48].

In every instance a clean -up requires knowledge of the mechanical properties of the contaminated sand in order to select the best remediation method in terms of cost and efficiency. Several methods were addressed, as mentioned above, but they not considered to be cost effective [6], especially in developing countries where none of these methods are available, which means the cost would be prohibitive. Eagle et al. [49] presented the capital cost of the cheapest remediation method, i.e. soil washing, where the soil washing plant used attrition, screening, and wet classification and where remediation took 23 months. This cost would be magnified in developing countries where none of the above mentioned remediation methods are available. On this basis, there is a definite need to find a better and more cost-effective way of utilizing oil contaminated sand. One possible approach is to mix it with cement and then use it in the construction industry. This method however requires an understanding on how the mechanical property of concrete is affected by the oil contamination to assist the engineer in evaluating the suitability of this material in engineering and construction.

5. ENGINEERING APPLICATIONS OF OIL CONTAMINATED SAND

5.1 Stabilization with cement

Several researchers [4, 50-53] mixed the oil contaminated sand with cement and investigated the properties of the produce mortar and concrete. Wasiu et al [4] investigated the effects of crude oil on the compressive strength of concrete, and they concluded that 18 to 90% of the compressive strength was lost due to 2.5 to 25% contamination with crude oil. Abdul-Ahad and Muhamed [52] made a similar observation and indicated there was a significant reduction in the compressive strength and about an 11% reduction in the splitting-tensile strength of concrete soaked in crude oil. Moreover, the effect of used engine oil on the structural behavior of reinforcement concrete [54], and the effect of used engine oil on the properties of fresh and hardened concrete were investigated. It was concluded that the oil acted as a chemical plasticizer that improves its fluidity and doubles the slump of the concrete mix while maintaining its compressive strength [53]. A similar study was conducted by Mindess and Young [55] and they concluded that adding engine oil to a fresh concrete mix could be similar to adding an air-entraining chemical admixture, which enhances some of the durability properties of the concrete.

5.2 Construction application

Some studies have been carried out to determine the beneficial use of contaminated sand in construction. Mindess and Young [55] indicated that the potential of sand contaminated with petroleum for use in road and highway construction was good. Similarly, the possibility of an end-use scenario of contaminated sand based on their retained compressive strength is high. For instance, lesser strength is required for landfill but a higher compressive strength is required to make bricks or some other structural objectives. Based on the United States Environmental Protection Agency (USEPA) guidelines, the recommended compressive strength at 28 days for landfill disposal material is 0.35 MPa and 1.0 MPa in France and the Netherlands [56] respectively, whereas a higher compressive strength of 3.5 MPa in a sanitary landfill is required according to Wastewater Technology Centre (WTC), Canada [57]. Nevertheless, based on the British standard for precast concrete masonry units (BSI, 1981) a higher compressive strength of 2.8 and 7 MPa, respectively is required for blocks and bricks, and a minimum of 7 days cube compressive strength between 4.5 and 15 MPa are required for sub base and base materials, by the Department of Transport in UK. This shows there is a high potential for using oil-contaminated sand in construction, but an understanding of the details of its physical and mechanical properties is important, in order determine the end-use application of oil contaminated sand.

6. CONCLUSION

The main source of, and the advantages and disadvantages of the existing remediation methods for oil contaminated sand are presented in this paper. Similarly, the effect of crude oil on the mechanical properties of sand and its concrete were reviewed. Emerging engineering applications of oil contaminated sand are also presented. From this review the following conclusions can be drawn:

- Oil leakage and oily wastewater are the main sources of oil-contaminated sand, which severely impacts the environment and the mechanical properties of the surrounding sand.
- Oil contamination have an adverse effects on the physical and mechanical properties of oil contaminated sand and its concrete. However, at a certain level of contamination, some important properties were enhanced.
- The existing remediation methods are into expensive for producing but developing countries. Thus, an alternative but cost effective method is to mix oil contaminated sand with cement and use it in construction.
- The properties of oil contaminated sand and its concrete were found to be suitable for some engineering applications including road and

highway construction, landfill disposal material and precast masonry units.

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