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A Review of Some of The Treatments of Oil-Contaminated Soils

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Abstract

Soil characteristics are impacted by the nearness to the contamination sources. Accidental oozes and leaks of crude-oil are frequent occurrences that change the shear resistance and stress-strain behavior of soils by incompletely or totally replacing the soil pore liquid with oil. Soil contamination has become a main objective of the research in several conditions; this issue arises from the effect of previous and present industrial activities; taking the essential solutions scientifically towards these issues have become an urgent case that must be carefully studied. Numerous methods of remediation and stabilization of oil-contaminated soils have been applied during the preceding period due to their influence on the potential for collapse. Soil Stabilization is the modification of soils to improve their engineering properties. Chemical stabilization techniques have been one of the most adopted methods for enhancing the geotechnical properties of oil-contaminated soils. To realize the importance of using various additives that can improve the soil polluted with oil, like cement, lime, fly ash, and others, It is necessary to study the mechanical behavior of soils contaminated with oil and treated with different materials. This paper aims to review the investigations work on different types of soil contaminated with oil and to enhance it with various additions.

Keywords: Crude oil, Contamination, Permeability, Compressive Resistance, Compaction , Treatments.

1. Introduction

Oil is the major source of energy in the manufacturing world. Oil leaks may be regarded as an unavoidable result of the ever-increasing demand for exploration, production, transportation and use of oil, the environmental influences of oil spills are greatly diverse. Approximately some hundred billion gallons of oil are used as a motor fuel in every city in the world for each year. Closely every gallon of oil used as a fuel is stored underground storage tanks **[1]**. the sources of the pollutants could be:

(i) Oil-fields.
(ii) Oil-refineries.
(iii) Oil-spills because of transmission by pipelines or tankers.

Soil contaminations are described as an alteration in the materialistic and chemical characteristics of the soil as a result of human involvement which leads to degrades its productivity and quality **[2-4].** Recent increases in industrial pollutants such as petroleum hydrocarbon and heavy metals usage have caused difficulties with soil pollution **[5]** & **[6]**.

Oil spills on ground when transporting or during oil extraction techniques is the primary cause of ecological issues **[7]**. The shear and compressive resistances of the soil, among other soil characteristics, might be significantly impacted by these problems. Crude-oil pollution has negative effects on the geotechnical characteristics, incorporating a depression in the bearing capacity of the foundations with a lack of significant depth and the effects on the stability of constructions due to the settlements **[8-10]**.

Soil pollution has become a major objective of the study in various conditions; this issue emerges from the influence of previous and present industrial activities; taking the necessary solutions scientifically for these problems has become an urgent case that must be carefully studied.

2. Treatment of The Oil- Contaminated Soil:

Several forms of treatments and stabilization of oil-polluted soils have been implemented during the previous decade due to their impact on the potential for collapse. Chemical stabilization techniques have been one of the most adopted techniques for improving the geotechnical features of oil-polluted soils. This technique is carried out to link the hydrocarbons in a structure formative by the stiffing , accommodating action of pozzolan and soil substances to create new components stabled chemically and mechanically. These components, if have stability and durability, could be investigated for the evaluation of possible utilization in the building of large-scale geotechnical constructions like sub-base, embankment, barrier system, or as filling substance in another kinds of construction elements. The parameters that are included in such an evaluation are mechanical resistances, permeability, compressive resistance, durability, and plasticity of the new components **[11]**.

Solidifications/stabilizations are another famous processes which utilize in enhance oil-polluted soils. Each process is prepared to be appropriate with the particular purpose, they could be classified into the following categories **[12]**:

- Cement-based processes.
- Silicates-based processes.
- Thermoplastic processes.
- Sorbent processes.

- Polymer-based processes.
- Encapsulation processes.
- Vitrification processes.

Between the mentioned above processes, silicates and cement-based processes have a celebrated cementation or pozzolanic reactions create components work as natural cement. These processes might provide cost-saving when compare with the other ones, because they overwhelmingly use several waste substances like fly-ash (FA), cement kiln dusts (CKDs), or blast furnace slags (BFS), as pozzolan additives. Different techniques were utilized in the latest years to repair soils contaminated with crude-oil. Wang et al. (2019) reported that the solvent/surfactant-aided soil-washing process demonstrated that crude-oil pollution soil could elicit the components of crude-oil **[13]**. Russell (1992) and Balba et al. (1998) reported that oil-polluted soil must be treated effectively with techniques to improve the mechanical features of soils **[14]** & **[15]**. Moreover, many authors like Moon et al. (2009) and Estabragh et al. (2016) concluded that soil could be enhanced by adding cement **[16]** & **[17]**. Furthermore, Alpaslan et al (2002) and Dermatas et al (2003) concluded that the utilization of some additives like lime, cement, and fly ash could help to enhance the soil features polluted with crude-oil **[18]** & **[19]**.

3. Mechanical Behavior of Contaminated Soil Treated with various additives:

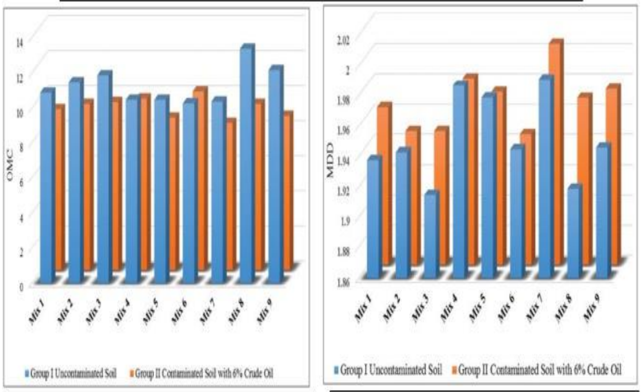
To realize the importance of using various additives that can improve the soil polluted with oil, it is necessary to study the mechanical behavior of the soil. In the four titles below, a summary of the relevant previous studies will be presented that focus on the properties of compaction, shear resistance, characteristics of the uniaxial compressive resistance test, and permeability of oil-contaminated soils that have been treated with some additives such as fly ash, cement, limestone, and other materials.

3.1 Compaction Characteristics of Treated soil:

Ghaffoori & Arbili (2019) **[20]** prepared an experimental program to investigate the impact of utilizing some additives, like fly-ash (FA) and Granulated Ground Blast Furnace Slags (GGBFSs), as a stabilizer for soil polluted with 6% of crude oil. Their program consisted of two groups, the first for clean soil (free of crude oil), and the second for soil contaminated with 6% of crude oil, and a comparison was made between the compaction results of the two groups. The percentages of materials that were used and the results they came out with are demonstrated in figure (1). They reported that the optimum moisture content was reduced when six percent of the crude oil was present in the soil specimens, and the reason may be attributed to the capillary impact. Moreover, they noted that the optimum moisture content was significantly affected when FA and GGFBFs were added to the polluted specimens, especially in the mixture which consist of (69% soil, 15% FA, 10% GGFBFs, and 6% crude oil). Furthermore, the maximum dry unit weight (MDD) dropped in both clean and polluted soil specimens by increasing the FA percent, while the utilization of GGBFSs gave a significant increment in the maximum dry unit weight, especially in the oil-free mixture which consists of (85% soil, 0% FA, 15% GGFBFs, and 0% crude oil) and in the polluted mixture which consists of (79% soil, 10% FA, 15% GGFBFs, and 6% crude oil). These behaviors of optimum moisture content and maximum dry unit weight have been confirmed by the results of many other previous authors like Okont and Govender (2011) **[21]**, Mahvash et al. (2017) **[22]**, and Sabbar et al. (2018) **[23]**.

Group I									
Mix. No.	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9
Crude oil%	0	0	0	0	0	0	0	0	0
Slag (GGBFS)	0	0	0	10	10	10	15	15	15
Fly ash (FA)	0	10	15	0	10	15	0	10	15
Soil	100	90	85	90	80	75	85	75	70
Group II									
Mix. No.	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9
Crude oil%	6	6	6	6	6	6	6	6	6
Slag (GGBFS)	0	0	0	10	10	10	15	15	15
Fly ash (FA)	0	10	15	0	10	15	0	10	15
Soil	94	84	79	84	74	69	79	69	64

Mix description for additional materials



Variation of OMC values with different materials content in soil

Variation of MDD values with different materials content in soil

Fig.1 Results of Compaction test.

Correia et al., (2020) **[24]** made an experimental study to evaluate the performance of diesel-polluted coarse-grained (DPCG) soils treated with four various percentages of lime (2%-8%). Their study was divided into two sections, the first for natural soil (free of diesel-oil), and the second for soil polluted with 8% of diesel-oil, and a comparison was made between the compaction results of the two sections. The behavior of compaction tests of natural soils and diesel-polluted soils treated with various percentages of lime are demonstrated in figure (2).

Their results demonstrated considerable drops in the dry unit weight and a raise in the optimum moisture content of the natural soils treated with lime. These results are anticipated and could be attributed to the density of fine lime particles. The peak dry unit weight of natural and diesel-polluted soil dropped by raising the percentages of lime. The decline in peak dry density, according to Nasehi et al., (2016) **[25],** is the result of the agglomerated and flowing clay particles filling greater areas, which causes a significant loss in dry unit weight. According to their conclusion, raising the ideal moisture level is necessary because lime (CaO) needs additional moisture for the pozzolanic reaction as well as additional moisture for its dissolution into (Ca^{2+}) & (OH^{-}ions), which provides additional (Ca^{+}ions) for the deionization process. Nevertheless, the existence of the diesel fuel proved that the lime did not absorb moisture, hence maintaining the ideal moisture levels in the soil.

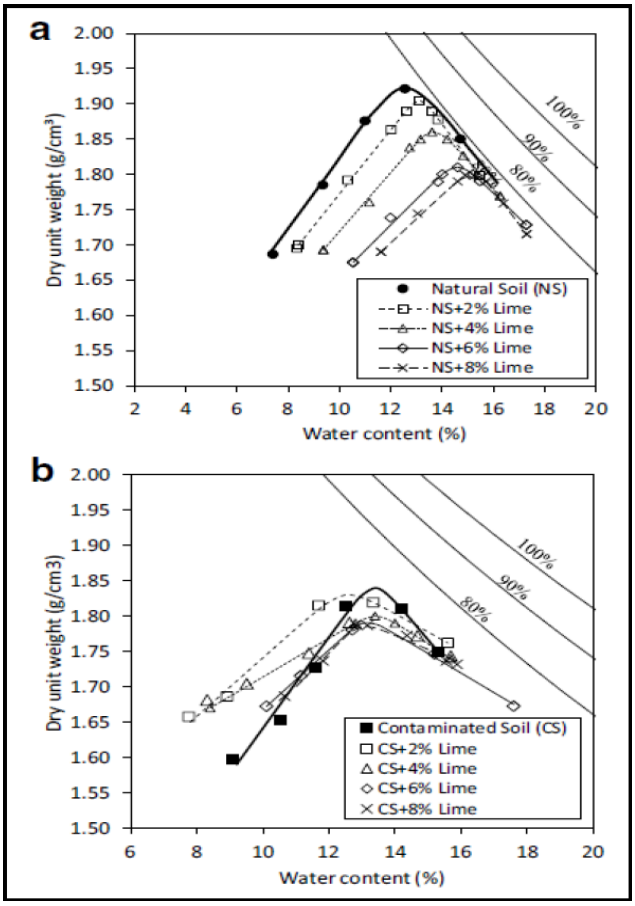


Fig.2 Compaction curves of lime treated soils: natural soil(NS); b diesel-contaminated soil (CS)

Abdulhamidv et al., (2021) **[26]** conducted a laboratory study aimed to minimize the contamination resulting from oil industries in the soils of Iraqi Region Kurdistan. In terms of compaction parameters, they studied four groups of soils including natural soil, soil treated with 8.7% of Portland-limestone cement (PLC), soil treated with 8.7% of ordinary Portland cement (OPC), and soil contaminated with 14% crude-oil. Their results are demonstrated in figure (3). In general, the curves of compunction of polluted soil and the two treated soils were located under the curve of natural soil. The peak dry unit weight of the polluted specimens considerably dropped to the lowest value of peak dry unit weight. The dry unit weight of the two treated soils was raised gradually. It could be noted a considerable increment in optimum moisture content contrasted to the optimum moisture content of natural soils, especially in relation to the samples treated with 8.7% PLC.

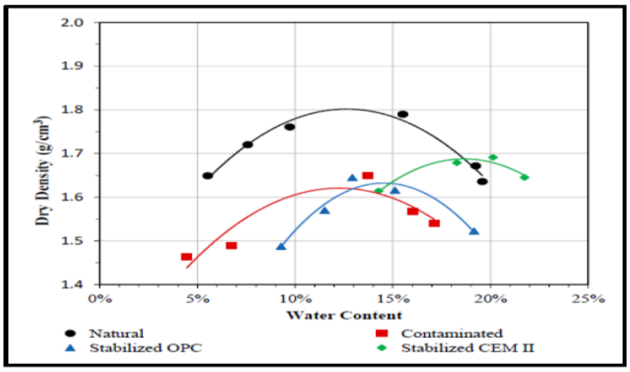


Fig.3 Results of Compaction test.

3.2 Shear Resistance of Treated Soil:

Nasehi et al., (2016) **[25]** studied the effects of utilizing nano hydrated-lime (NHL) on the shear resistance of soil contaminated with 9% by gas oil. Their study included comparing the shear resistance values of clean soil (CL0) specimens, specimens polluted with three different percentages of petroleum gas (CL3, CL6, CL9), and specimens treated with 5% of NHL. The shear stress/normal stress relations of their study are demonstrated in figure (4). Moreover, they observed an increment in cohesion values and a reduction in frictional angle of polluted soil specimens with raising of pollution content. The behavior was consistence with the results of Khosravi et al., (2013) **[27]** study, but contradicted those of Shah et al., (2003) **[28]** and Kermani and Ebadi (2012) **[29].**

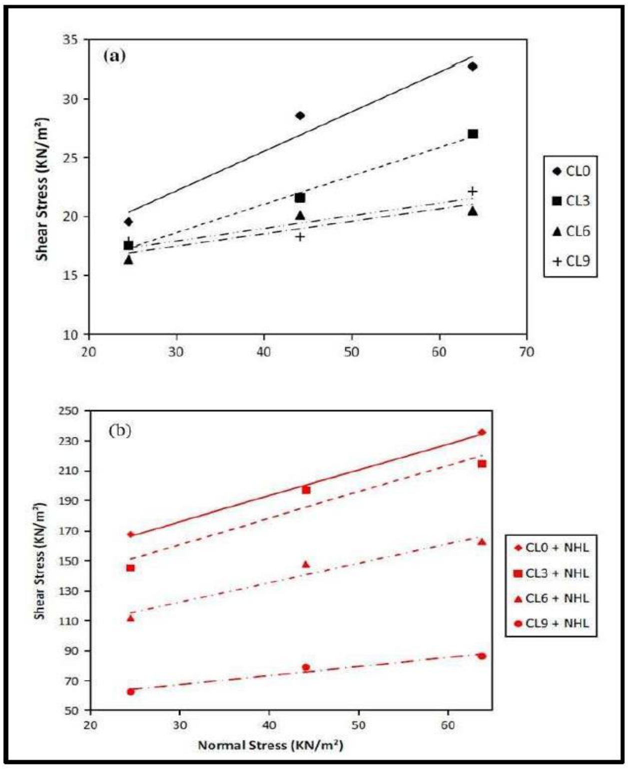


Fig.4 Shear/normal stress relations, (a) between CL0 and polluted soil specimens, (b) for treated specimens.

Oluwatuyi et al., (2020**) [30],** added 1:2 lime and cement as stabilizer-mixture, in four various percentages (5-20) %, in to clay specimens polluted with crude-oil and evaluated the shear behavior of treated specimens. Their experimental results (demonstrated in figure (5)) showed an increment in the values of cohesion if more percentages of stabilizer-mixture are utilized in the polluted clay specimens. Moreover, their experimental results recorded a reduction in the values of frictional angle if more percentages of stabilizer-mixture are utilized in the polluted clay specimens, and this behavior could be attributed to the impact of mixture which improve the resistance of the specimens via cementation and decreases the sensitivity of the shear resistance to the confining load.

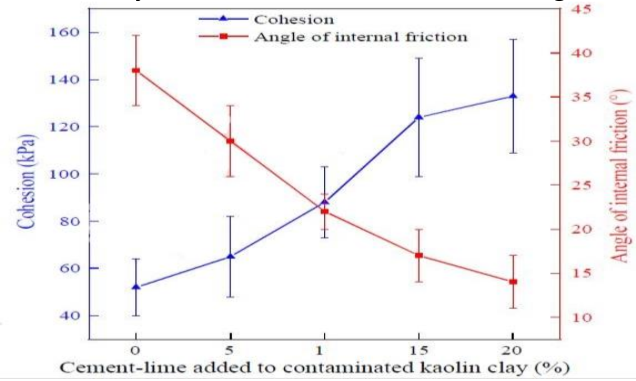


Fig.5 Direct-shear parameters behavior.

Abdulhamidv et al., (2021) **[26]** reported that shear resistance of oil polluted soil could be improved when treated with 8.7% of Portland-limestone cement (PLC) or 8.7% of ordinary Portland cement (OPC). From their results (which demonstrated in figure (6)), it could be noted that all soil specimens had nearly the same tendency, and a considerable increment in the treated soils has been noted contrasted with the polluted one.

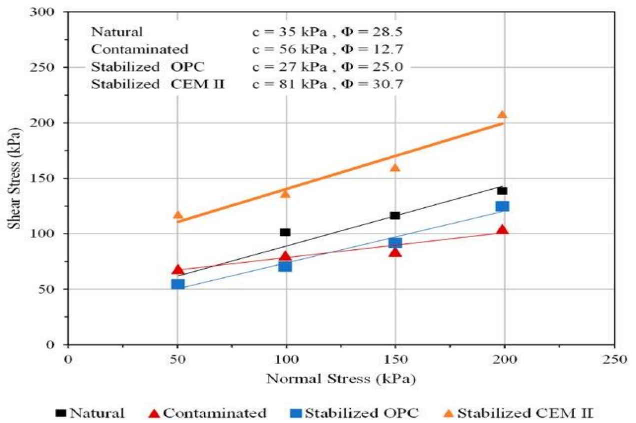


Fig. 6 Shear parameters behavior.

3.3 Compressive Resistance of Treated Soil:

Chen et al. (2017) **[31]** made an experimental study to evaluate the uniaxial compression resistance performance of diesel-polluted sandy soils treated with four various percentages of cement: three percent (C3), five percent (C5), eight percent (C8), and ten percent (C10). In their study, four percentages of diesel-content: four percent (D4), eight percent (D8), twelve percent (D12), and sixteen percent (D16) have been utilized to pollute the sandy soil specimens. The behavior of uniaxial compression resistance of natural sandy soils and diesel-polluted sandy soils treated with various percentages of cement and tested at various curing days are demonstrated in figures (7) & (8). Their results demonstrated that when the content of cement and the duration of curing are constant, the curve for the specimens with the largest pollution content lay under the curve for the specimens with the least pollution content, which means that with the rise of the pollution, the resistance tends to reduce, and this could indicate the uniaxial compression resistance performance of diesel-polluted sandy soils treated with cement. They recorded one exceptional case in the free of cement soil specimen (C0) tested after one week of curing, where the uniaxial compression resistance of the specimen with four percent of pollution content was greater than that of the unpolluted specimen (figure (2-10a)). They stated that the reason for this behavior was that without utilizing cement, only the reaction between soil grains and diesel in the soil occurred. They continued to explain the reason, saying: when the pollution quantity was small and the duration of curing was short, the decay in soil characteristics stayed incomplete and, on the contrary, the thin film of oil shared with adjoining soil grains worked as a sticky interface and allowed the soils to keep its structure, making a little increment in the uniaxial compression resistance.

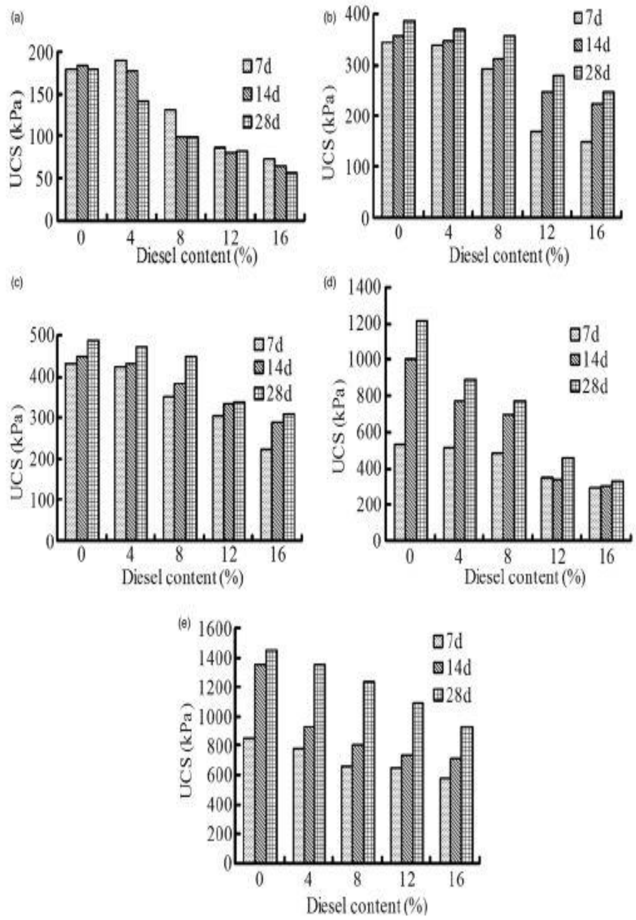


Fig.7 UCS vs pollution content at various curing days for various cement content: (a) free of cement, (b) 3% cement content, (c) 5% cement content, 8% cement content, (e)10% cement content**.**

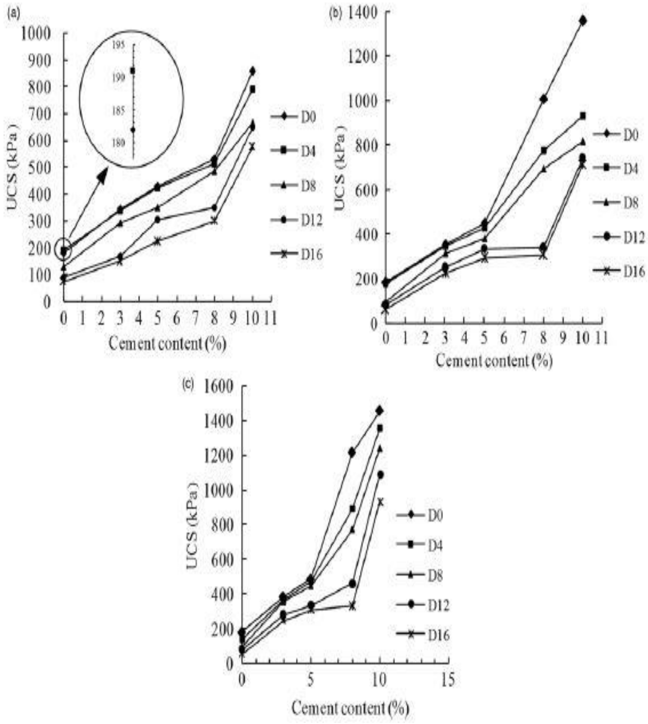


Fig.8 UCS vs quantities of cement as stabilizer agent for polluted soils at various curing days: (a) 7d, (b) 14d, and (c) 28d.

Through the study of Oluwatuyi et al., (2020) **[30],** which was mentioned previously, it was found that the uniaxial compressive resistance of clayey soils polluted with crude-oil can be improved by adding the stabilization-mixture. As demonstrated in Figure (9). It can be seen that the improvement depended mainly on the percentage of the added stabilization-mixture and the curing period of the soil specimens, where the uniaxial compressive resistance raised with the raise in the proportion of the stabilization-mixture and the increase in the curing period.

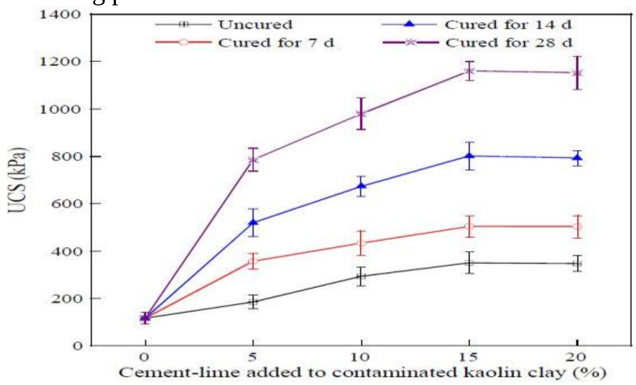


Fig. 9 Impact of cement-lime additives and curing periods on polluted clayey soil.

According to the experimental investigation of Correia et al., (2020) **[24]**, which was mentioned previously, it was found that the uniaxial compressive resistance dropped by 300% if 2% of lime was added to the polluted clayey soil comparing with the case in which 2% of lime was added to unpolluted clayey soil (figure (10a). Nevertheless, utilizing greater than 2% of lime had not gave a noticeable increase in the uniaxial compressive resistance of polluted clayey soil. Moreover, it was found that the initial unconfined modulus has the same behavior as the uniaxial compressive resistance (figure (10b). Figure (10c) compares their results of uniaxial compressive resistance for various curing periods (seven and twenty-eight days). Other authors reported similar increment in uniaxial compressive resistance values like George et al. (2015) **[32],** which reported that 20% of fly ash could gave the best resistance for polluted sandy soil.

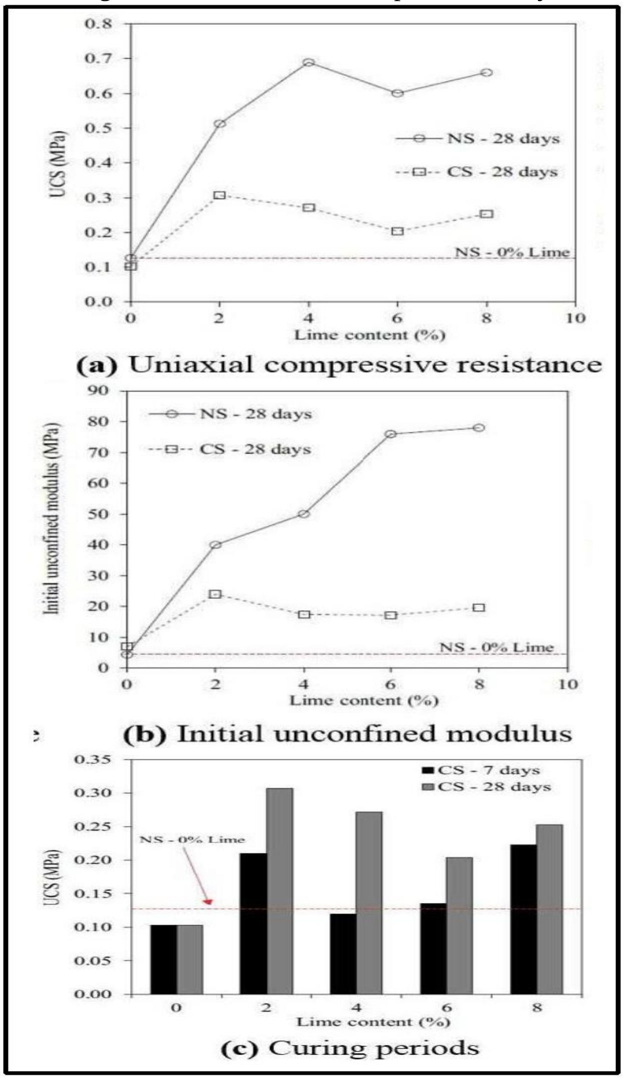


Fig.10 Impact of lime additives and curing periods on polluted clayey soil.

3.4 Permeability Characteristics of Treated Soil:

According to the experimental investigation of Abdulhamidv et al., (2021) **[26]**, which was mentioned previously, it was found that the permeability (K) has an adverse relation with the percentages of oil-pollution. They reported that oil-polluted soil has less permeability because the pore-spaces are occupied by the petroleum. This results in a decrease in the fluid velocity through the soil by reducing the porosity necessary to facilitate fluid motion inside the soil. Many authors like Khamehchiyan et al., (2007) **[33],** and Abousnina et al., (2015) **[34]** reported similar findings. Kogbara et al., (2011) **[35]** added 1:4 lime-GGBFSs and 1:9 cement-GGBFs as stabilizer-mixture, in three various percentages (5, 10, 20) %, in to sandy specimens polluted with diesel and evaluated the permeability of treated specimens. they reported that the lowest value of k was 5×10-9 m/s. Yu et al., (2018) **[36]** discovered that an enhancement in polluted-soil gated with a various percentages of Portland cement improved its resistance and decreased its permeability. Additionally, Saberian et al., (2018) **[37]** discovered that the samples' coefficient of permeability reduces as cement and fuel oil ratios were increased and decreased, respectively. As a result, the inclusion of cement significantly reduces the amount of fuel oil that reached the area around the contaminated soils. Therefore, from a geo - environmental perspective, adding cement can enhance and purify the soil. They also reported that after 28 days of curing, the K-value of the specimen with sixteen percent of cement and eight percent of fuel oil was 5.4 and 1.3 times greater than that of the sample with six percent of cement and fourteen percent of fuel oil, respectively. The above literature is summarized in table (1), which shows the impact of some additive materials utilized as stabilizer agents for soil polluted characteristics.

Table 1 Summery of mechanical behavior of contaminated soil treated with various additive

Authors	Soil types*	Polluted materials**	Additives	Results of treated soil
Ghaffoori & Arbili (2019) [20]	S	C-oil	FA	Reduction in MDD.
			GGBFs	Increment in MDD.
Correia et al., (2020) [24]	C	D-oil	Lime	Reduction in MDD. Increment in: UCS & initial unconfined modulus.
Nasehi et al., (2016) [25]	C	D-oil	NHL	Reduction in: MDD & frictional angle values. Increment in: cohesion values.
Abdulhamidv et al., (2021) [26]	S	C-oil	PLC OPC	Increment in: OMC% & shear resistance.
Oluwatuyi et al., (2020) [30]	C	C-oil	1lime:2ce-ment	Increment in: cohesion & UCR. Reduction in: frictional angle.
Chen et al. (2017) [31]	S	D-oil	Cement	Enhancement in UCS values.
George et al. (2015) [32]	S	D-oil	FA	Improvement UCS values.
Kogbara et al., (2011) [35]	S	D-oil	1lime: 4GGBFs 1cement: 9GGBFs	Reduction in permeability.
Yu et al., (2018) [36]	C	C-oil	OPC	Increment in UCS values. Reduction in permeability.
Saberian et al., (2018) [37]	S	F-oil	Cement	Reduction in permeability.

*S: sandy, C: clayey.
** C-oil: crude oil, D-oil: diesel-oil, F-oil: fuel oil

Conclusions:

This paper provides a review of the treatment of various oil-contaminated soils by different additives, amount, and their effects and findings. Cement, lime & fly-ash are the main used additives in the investigations. There are some conclusions based on this review:

- From the review of the literature, it could be cleanly noted that the oil-polluted soil could affect adversely some features of sandy and clayey soils.
- To solve problems of oil-contaminated soils, several authors focused to enhance the polluted soils by several methods. Most previous methods have dealt with the performance of polluted soil treated with some additives like cement, lime, fly ash, waste slags, etc.
- When using lime, NHL & cement with oil-polluted clay, there will be an increase in UCS and cohesion values.
- There is an improvement in shear resistance and reduction in permeability when the admixtures are used with oil-polluted sand.
- Cement improves the shear strength and reduces permeability.
- Lime increases the UCS & initial unconfined modulus of clay.
- Fly-ash reduces the MDD and Improvement UCS and cohesion
- GGBFs improve compaction parameters and decrease permeability.
- It is possible to do future studies to provide more data and information about improving soils with crude oil or derivatives or evaluating the engineering characteristics of soils contaminated with crude oil and treated with several additives.

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