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INFLUENCE OF DETERGENT CONTAMINATION ON THE ENGINEERING PROPERTIES AND HYDRAULIC CONDUCTIVITY OF EXPANSIVE

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Abstract: In this study, the influence of varying concentration of mymy detergent at 2%, 4%, 6%, 8% and 10% by mass of the expansive soil on the Engineering properties and Hydraulic conductivity of expansive soil was studied. Compaction characteristics (MDD and OMC), California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), and Hydraulic Conductivity (k), of the expansive soil are the determinant parameters used to evaluate the influence of the detergent on the geotechnical properties of the soil. Compaction characteristics indicate an initial increase in the MDD value from 1.73 kg/m^3 at 0% to 1.83 kg/m^3 at 2% detergent, further increase in the detergent contamination decreases the MDD values; whereas, the OMC decreases with increase in the detergent concentration. Similarly, increase in the detergent concentration causes an increase in the CBR values from 3.2% at 0% detergent contamination to 13.8% at 10% detergent contamination respectively. The maximum value of the UCS shows a 7.58% increase at 7 days curing compared to when the samples were not cured. Detergent contamination of the expansive soil reduces the k value to 9.8 x10^{-6} (cm/sec) at 6% detergent content with no significant differences with curing time
Keywords: Expansive soil, Detergent, UCS, CBR, Hydraulic conductivity

1. INTRODUCTION

Expansive soil is a problematic soil that is usually encountered by engineers alongside with collapsible soil, quick clay and other problematic materials in any civil engineering works (Zumrawi, 2015). Expansive soil is a kind of high–plasticity clay with strong hydrophilic mineral components, such as Montmorillonite (Mt), Kaollinite (K) and Illite (Ill) (Qin–Yong et al; 2018). They are termed problematic due to their repeated swelling and shrinkage behaviour when absorbing and losing water. Raja and Thyagaraj, (2019); Ahmed et al., (2013) has also attributed their shrinkage and swelling behavior to the expansion of the diffused double layers that is caused by changes in the moisture content of the expansive soil that emanates from rain, flood or leakage of sewer lines.

Typical examples of the expansive soil are Black Cotton soil (BCS), Peat soil and Clay. These soil types are unsuitable for construction due to their high compressibility, high moisture content, low shear strength and low bearing capacity. Although, Girdhar and Kumar (2018) stated that their nature and behavior can be controlled through the application of chemical agents which may either occurred naturally, manufactured or waste products of manufacturing process and that the main advantage by the use of the chemical agents is setting time and curing time can be controlled.

According to Oriola and Moses (2010), BCS in Nigeria covers an estimated area of 104 * 10^3 km^2 of northeastern Nigeria, resulting in significant construction costs when using the normal methods of dealing with unsuitable subgrade (excavation and carting away). Also, the work of Ikeagwuani et al., (2018) reported BCS as the major cause of building failures in Adamawa state, Nigeria due to the differential settlement rising from the shrink–swell behaviour of the soil on the building foundation and thus causing cracking on the walls. Adeniji (1991) reported a crack measuring 70mm in width and up to 3m in length on building as a result of BCS.

Detergent have gained popularity for their ability to automatically dispense into washing machine, providing softness, reducing static, enhancing fabric resilience, and being gentle on skin and eyes (Tripathy and Tyagi, 2007). A detergent typically contains surfactants and other ingredients to clean fabrics effectively. The consumption of cleaning products, such as detergents, has increased significantly in recent years due to urbanization (McCall et al., 2020), family size growth (Han et al., 2020), and increased awareness of health issues during the spread of infectious diseases, such as the coronavirus (COVID–19) (Vayisoglu and Oncu, 2021). In many developing nations where sewage networks or waste–water treatment plants are not available, these untreated domestic surfactant–rich wastewater is

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released into the environment directly (Ghasemzadeh et al., 2023). Surfactants alter soil properties, such as pH (Pinto et al., 2010), salinity, electrical conductivity (Lado et al., 2012, and Rodda et al., 2011), hydraulic conductivity (Misra and Sivongxay, 2009), water repellency (Leuther et al., 2018), and capillary and surface tension (Wiel–Shafran et al., 2006), depending on the level of concentration and sorption. Additionally, contamination of soil with surfactants causes the particles to separate, disperse, and change in stability (Piccolo and Mbagwu, 1989); the structure to deteriorate (Leuther et al., 2019); and the aggregates' tensile strength to vary (Lehrsch et al., 2012).

While the effects of various contaminants on the engineering properties and hydraulic conductivity as been studied when contaminated with different kinds of hydrocarbon–based pollutants Ghasemzadeh and Tabaiyan, (2017); Khosravi et al., (2013); Ostovar et al., (2020); and Safehian et al., (2018) examined the impact of diesel fuel on the shear strength and compaction characteristics on contaminated soil. Similarly, Kererat, (2019); and Khamehchiyan et al., (2007) also investigated the influence of oil on the shear strength and compaction characteristics of impacted soil. In addition, Park et al., (2006) found that the optimum water content of the surfactant–contaminated kaolinite and sand mixture decreases while the MDD and undrained shear strength increases. Additionally, sandy soils contaminated with surfactant–rich bath greywater were found to have decreased porosity and water content, while increasing dry density and unconsolidated undrained shear strength (Ganiyu et al., 2020). However, there exist a gap in knowledge on the impacts of surfactant–rich detergent contaminants on the engineering properties and hydraulic conductivity of expansive soil. Therefore, this study aims to address this gap by investigating the effects of different concentration of detergent contaminated soil on the engineering properties and hydraulic conductivity.

2. MATERIALS AND METHODS

This section described the materials that were used for the research as well as how they were sourced. The processing and sample preparation was also discussed in details in this section. The materials used include the expansive soil, detergent and water.

Experimental Materials and Source

- Expansive soil: The expansive soil sample used for this experimental studies was collected at 1.5m depth below the ground surface after the excavation of the top soil along Lusada–Agbara road, Ogun State, Nigeria and then transported to Geotechnical Engineering Laboratory of the Covenant University, Ota, Ogun State where it was air–dried for 48 hours before conducting any test on it. The expansive soil was brownish in colour and forms a hard lump when air–dried and as a natural moisture content of 16.7%. On the arrival and air–dying of the collected soil samples at the laboratory, the soil samples was grounded and sieved to obtain soil with particle sizes passing through a 2 mm sieve sizes, this is to obtain the particle size range for an expansive soil. This is done in accordance with study of (Lokmane et al., 2019; and Wang et al., 2023). On the expansive soil samples, index properties such as the specific gravity, Atterberg limit, and Particle size distribution was conducted. Engineering properties including, compaction characteristics, unconfined compressive strength and California bearing ratio was conducted on the natural soil sample. Also, the ease of flow of water through the natural expansive was carried out using the falling head method. The natural soil as a liquid limit of 52% and plasticity index of 27%, the expansive soil was classified as CL (lean clay) or CH according to USCS classification system and as A–7 based on AASHTO soil classification respectively.
- Detergent: 'Mymy' detergent powder was used as the contaminant for this research. It was purchased from a shopping store at Covenant University, Nigeria. Mymy detergent is surfactant–rich detergent and common used as a household detergent in Nigeria for cleaning and laundry due to its affordability and accessibility to many household.
- Water: A quality, odourless, tasteless and portable drinkable tap water was taken from the Geotechnical Engineering Laboratory of the department of Civil Engineering. The portable water was free of organic matter of any kind. The water was used to prepare the mixture of the expansive soil and detergent in this study.

Specimens Preparation

In this study, the soil specimen mixed with the various concentration of the 'mymy' detergent was tested to determine their engineering properties and Hydraulic conductivity. Two group of mixture was design for the experiment. The first group is the uncontaminated expansive soil, named UE. In this group, the natural expansive soil was not mixed with any percentage of detergent concentration. In the second group, named DT, the expansive soil was contaminated with varying percentage of detergent concentration by mass of the soil sample as shown in Table 1. The detergent was added into the soil samples in different percentages on dry weight of the expansive soil. After mixing the detergent in its powder form in dry weight of mass of the expansive soil in 2%, 4%, 6%, 8% and 10%, it was thoroughly mixed together until a homogenous blend of soil–detergent was achieved and thereafter the required water ratio was added to mix the materials into a paste. In total, 6 specimens were prepared for this study. The specimens for the UCS were thereafter cured for 7 days at room temperature.

Table 1: Table showing the materials mix proportion

Group	Expansive soil Wt.%	Detergent Wt.%	w/s
Uncontaminated Expansive soil, UE	100	-	0.2
Detergent contaminated Expansive soil, (DT)	98	2	0.2
	96	4	0.2
	94	6	0.2
	92	8	0.2
	90	10	0.2

Table 2 shows the results of the physical properties of the expansive soil; with the soil having a plasticity index greater than 20 (i.e. P.I .≥ 20) and silt/clay content of 80%, the soil was classified as CL or CH soil in accordance with the Unified Soil Classification System (USCS) soil classification based on ASTM D2487 (2017) standard and A–7 from AASHTO soil classification system. This type of soil has been reported to be highly expansive in nature due to the presence of the expansive clay minerals. The physical properties of the expansive soil specimens were determined in accordance with (Qin–yong et al., 2018). Table 3 also shows engineering properties of the natural soil samples for the prepared at the natural moisture content of 16.7% and dry density of 1.73 kg/m^3. The loading rate of UCS test was fixed at 1 mm/min in accordance with the work of (Qin–yong et al., 2018).

Table2: Physical Properties of the Natural Expansive Soil

Property	Value
Natural Moisture Content (%)	16.7
Specific Gravity	2.47
% Passing No. 200 Sieve	33
Liquid Limit (LL)	52 %
Plastic Limit (PL)	25 %
Plasticity Index (PI)	27 %
Linear Shrinkage	37.5 %
USCS Classification	CL (Lean Clay) or CH
AASHTO Classification	A–7
Silt or Clay	80%
Cu	3.2
Cc	1.1

Table 3: Mechanical Properties of the Expansive soil

MDD (kN/m^3)	OMC (%)	UCS (kN/m^3)	CBR (%)
1.732	15.1	103.6	3.2

Experimental Method

In this research work, the influence of detergent contamination on engineering properties of expansive soil was measure using standard proctor compaction test method under a 2.5*kg* rammer and 447*mm* falling height to determine the MDD and OMC of the UE and DT in accordance to ASTM 2000, D698a, and two mechanical test was also conducted to determine the California Bearing Ratio (CBR) and the unconfined compressive strength (UCS). The UCS is a method that quickly measures the compressive strength of soil. This test determines an increase or decrease in the compressive strength at different surfactant–rich detergent concentration by unconfined compressive strength. In accordance to ASTM 2000, D2166 the test was performed on air–dried soil passing through sieve No. 200 and prepared in a cylindrical mould of 76mm in length and 38mm in diameter. Varying concentrations of detergent was added in dry weight of the expansive soil. All samples were prepared at their natural OMC and MDD respectively. For the Hydraulic conductivity test, falling head permeability tests was used to determine the coefficient of permeability at varying detergent concentration in accordance with BIS 2720, (1986).

3. RESULTS AND DISCUSSION

Influence of detergent contamination on the index properties of expansive soil

Figure 1 shows the influence of detergent contamination on the LL, PL, and PI of expansive soil. Measure values of LL and PL are 52% and 25% respectively at 0% DT contamination, while the obtained value of the plasticity index for the natural expansive soil at 0% DT contamination was 27%. Since the plasticity index of the non–contaminated soil is greater than 20 (i.e. P.I. ≥ 20) and its silt/clay content is 80%, the soil was classified as CL or CH soil in accordance with the Unified Soil Classification System (USCS) soil classification based on ASTM D2487 (2017) standard and A–7 based on AASHTO soil classification system. This type of soil has been reported to be highly expansive in nature due to the presence of the expansive clay minerals.

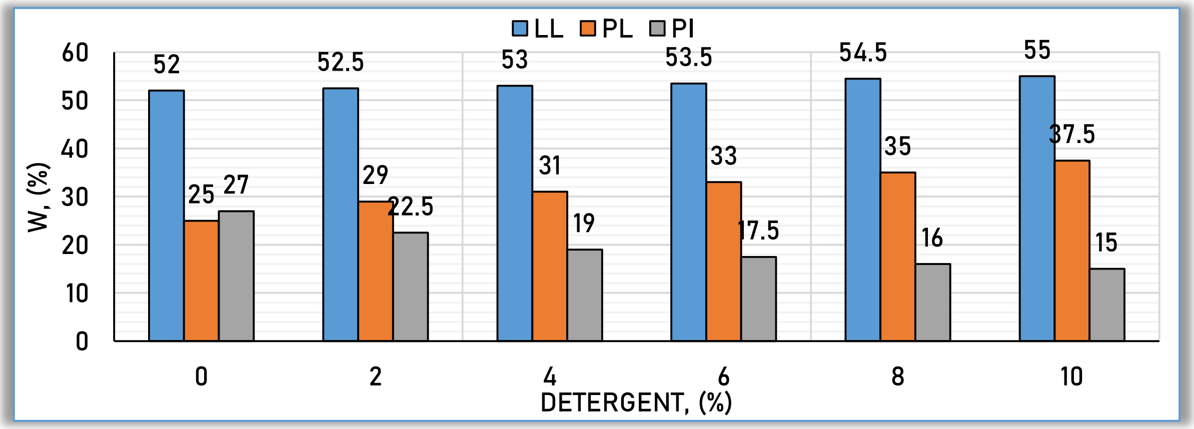

Figure 1: Influence of detergent contamination on index properties of expansive soil

The addition of detergent to the soil shows an increase in both LL and PL values, as LL values increases from 52% to 55% and the PL increases from 25% to 37.5% respectively, when the detergent concentration was increased from 0% to 10%. However, the result of the plasticity index gives varying values, such that the PI decreases from 27% to 15% as the detergent concentration increases from 0% to 10%.

Similar result was observed by Hamza et al., (2022) when quicklime was used as soil stabilizers, it was reported that the PI decreases from 45% to 13% in the high plasticity clay as the quicklime content increases. When combined with the expansive soil, the detergent contaminant causes the clay particles to flocculate, resulting in the development of flocs in the mixture. The amount of water needed for the blend to flow and behave like liquid also decreases becauses the flocs are much larger than tee thin, filmy montmorillonite flakes of soil particles and are small enough to have a specific surface ranging from 700 to 840 m^2/g (Mitchell and Soga, 2005). This results in the decrease in the PI. In contrast, the results obtained by Phanikumar and Raju, (2020) when lime sludge was used as an expansive soil stabilizer shows that the LL and PL obtained decreases while the PI increases from 27% to 30% as the lime sludge content increases from 0% to 12%. Also, the occurrence of ion exchange interaction between the detergent and the expansive soil particles, causes the flocculation of the clay particles (Feng et al., 2007), therefore causing a significant reduction in the PI as the amount of clay particles and hydrophilic minerals decreases (Qin–yong et al., 2018). Goswami and Singh (2005) also mentioned that the arrangement of particle and the presence of divalent cation promote flocculation and increase the LL of kaolinitic soils. Therefore, the LL behaviour of the soil reflects the various complexes cation exchange in the soil.

Influence of detergent contamination on the compaction characteristics

Figure 2a and 2b shows the influence of varying detergent content on the compaction characteristics of the expansive soil. The result shows that at 0% DT contamination, dry density recorded was 1.73 kg/m^3. However, when the DT concentration increases to 2% the dry density reaches its maximum dry density (MDD) of 1.83kg/m^3 and further increase in DT concentration; the dry density decreases and reaches the minimum of 1.65 kg/m^3 at 10%DT contamination. When the detergent comes in contact with water, its lubricating and viscous qualities reduce the resistance between soil particles, which makes it easier for the grains to slip over one another during the compaction process and, ultimately, lowers the MDD. The initial increase in the dry density may have been caused by the detergent's pore filling effects, which filled the pore spaces of the expansive soil up to 2% DT contamination. Also, as the soil discrete is lighter in weight, this result in the reduction of blend dry density (Joga and Varaprasad, 2019). Also, since the relative volumetric mass of detergent is smaller than the expansive soil, this can also be attributed to the reason for the decrease in the dry density as the concentration of the detergent increases beyond 2%DT concentration. Additionally, the contaminated solution's higher viscosity and lubricating properties caused more compaction energy to be dissipated, which prevented soil particles from rearranging into a denser packing and, thus lowered the maximum density (Ghasemzadeh et al., 2023).

The moisture content results shows that, in contrast to the dry density, an increase in the detergent concentration leads to a proportional increase in the soil–DT blends moisture content, with maximum moisture content of 18.2% obtained at 10% DT content. This can be attributed to the water absorption characteristics of the detergent, due to the detergent's ability to absorb water, leading to the compacted blends of higher OMC.

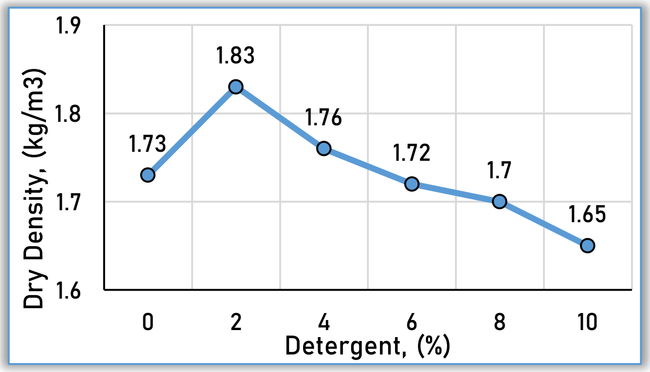

Figure 2a: Influence of detergent contamination on the dry density

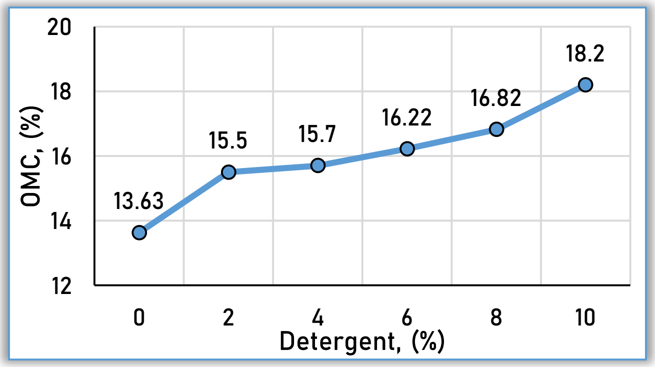

Figure 2b: Influence of detergent contamination on the moisture content

Although the value of the MDD of the detergent contaminated expansive soil fall below the specified standard of MDD >2000kg/m^3 for sub–base and base course materials (FMWH, 2013), detergent contaminated expansive soil can still be used as a subgrade materials when the concentration is between 2%DT and 4%DT, since the obtained MDD value at this concentrations meets the standards for maximum dry density for subgrade of MDD > 1.76kg/m^3 (Amusan et al., 2024).

Influence of detergent contamination on CBR

In Figure 3 the variations of the CBRs is presented for different detergent concentration in the detergent–expansive soil blends. As the detergent concentration increases from 0%DT to 8%DT in the mix blend, the CBR value also increases from 3.2% to 14.9%, respectively. Increase in the DT concentration beyond 8%, the CBR decreases to 13.8% which is equivalent to about 6.7% below maximum CBR value at 8% DT. Similar result was obtained by Durotoye and Akinmusuru (2016) when the effect of NaCl was studied on the engineering properties of expansive soil. Such that, as the NaCl concentration increases the CBR increases.

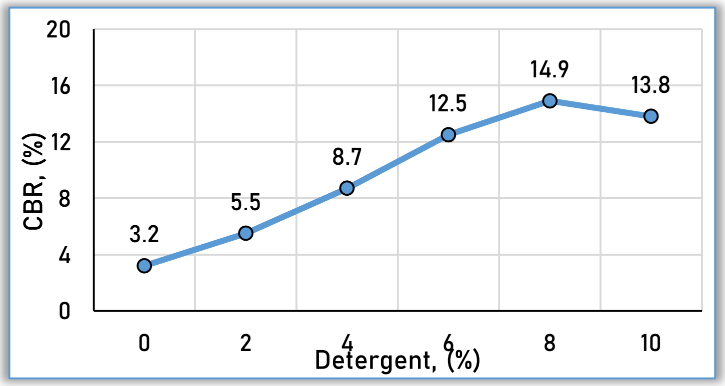

Figure 3: Influence of detergent contamination on CBR

Influence of detergent contamination on the UCS

One of the most significant metrics for evaluating the mechanical characteristics of stabilized soil, which is a vital component of foundation and road design, is UCS, which is based on the soil's ultimate strength in resisting axial pressure under lateral pressure. The result of the influence of detergent on the UCS of the expansive soil is shown in Figure 4. The UCS value at 0% DT is 103.6kN/m^3 and increases with increase in the detergent concentration to 247kN/m^3 at 6% DT with no curing, while at 7 days curing, the UCS value recorded was 96.2kN/m^3 at 0%DT and 265.8kN/m^3 at 6% DT. Increase in the DT concentration above 6% causes a corresponding decrease in the UCS for both curing time (0 day and 7 days) such that at 8% DT to the UCS value was 232.4*kN/m*^{3} at no curing time and at 10% DT to 215.9*kN/m*^{3} at 7 days curing time respectively. The increase in the UCS value above 103.6*kN/m*^{3} and 96.2*kN/m*^{3} at both curing time can be attributed to the strong microscopic between the soil grains and the detergent. Such that strong bonds between hydroxyl and carboxyl groups are formed as the clay concentration in the expanded soil samples experience cation interaction (Awad et al., 2013).

The maximum value of UCS at 8% DT at both curing period suggests that with increase in the detergent contaminant, flocculation between the detergent and the expansive soil occur until the detergent contents reaches its optimum value. With the addition of excess detergent content, the soil specimen strength decreases as a result of the surplus detergent above 8% DT that remains in the soil mixes which equal the rise of silt particles in the total soil particles. Additionally, the detergent contaminant's lack of cohesiveness causes the contaminated soils strength to decrease. Even though the curing period had little effect on the UCS value, mixing with detergent for 7 days curing period increases the UCS value for every DT contamination concentration.

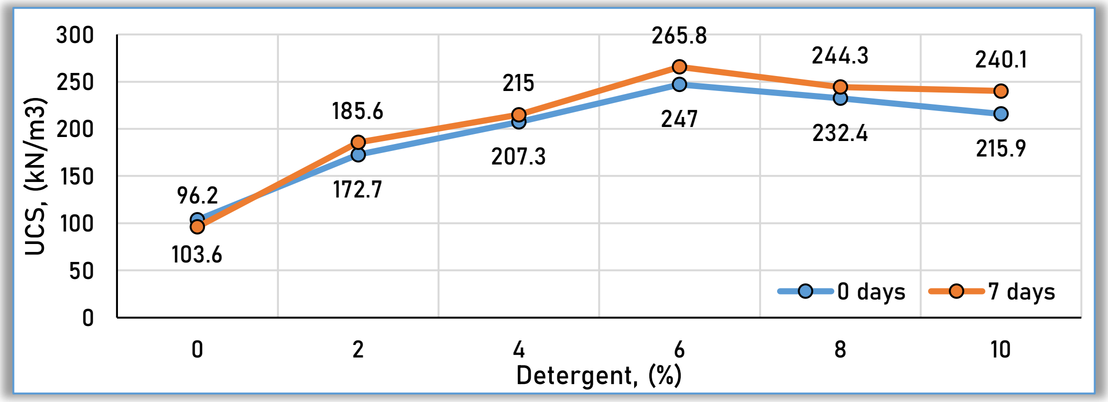

Figure 4: Influence of detergent contamination on UCS

Influence of detergent contamination on hydraulic conductivity

Figure 5 shows effect of detergent contamination on the coefficient of permeability of the expansive soil. When not cured, k decreases to 9.80E–06 *cm/sec* at 6% DT from 1.90E–05 cm/sec at 0% DT and thereafter increases with increase in the DT contamination. Furthermore, at 7 days curing period, the lowest k value was recorded at 4% DT to be 9.66E–06 *cm/sec*.

Based on the result obtained, the permeability at the same hydraulic heads reduces when detergent is added and the curing time extended to 7 days. The expansive soil's pore spaces cling to one another and stop the water from passing through the pores. Similar result was obtained when xanthan gum biopolymer effects was studied on the dispersive properties of soils by Joga and Varaprasad (2020).

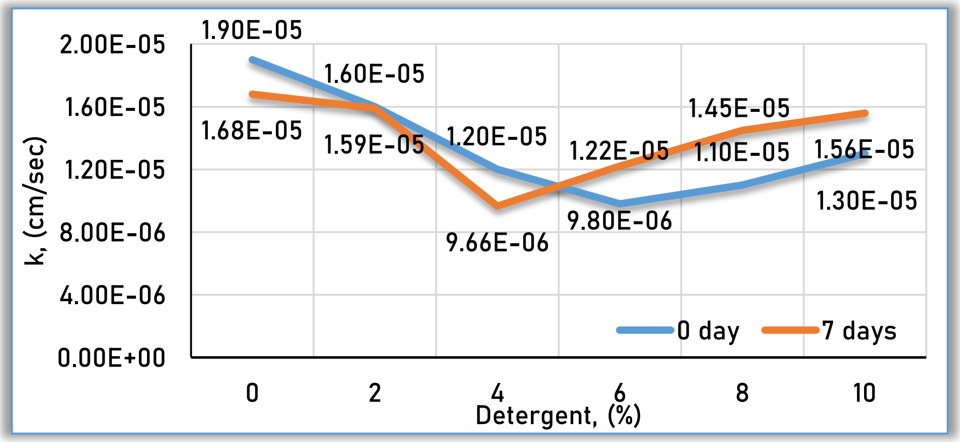

Figure 5: Influence of detergent contamination on Hydraulic conductivity

4. CONCLUSIONS

This paper studied the influence of detergent contamination on the engineering properties and hydraulic conductivity of expansive soil using a series of laboratory experiments. From the results obtained when varying concentration of detergent was use to contaminate the expansive soil; the following conclusions are drawn;

- The presence of detergent contamination in expansive soil increases the MDD value at 2% concentration, and thereafter decreases with increases in the detergent concentration, while the OMC increases with increase in the detergent concentration.
- Addition of detergent up to 8% concentration increases the CBR values of the expansive soil.
- UCS value increases with increase in the detergent concentration, with no significance influence at 7 days curing period.
- The detergent contamination reduces the value hydraulic conductivity of the expansive soil at 6% and 4% contamination for 0 and 7 days curing period respectively. While further increase in the concentration of the detergent increases the k values.

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