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Research paper

Predicting variations in the permeability and strength parameters of a sand-bentonite mixture (SBM) contaminated simultaneously with lead (II) and diesel

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ABSTRACT

This study dealt with a sand-bentonite mixture that was exposed to different concentrations of diesel and lead (II) simultaneously in order to address the effects of these contaminants on some of the physical and mechanical variations in the sand-bentonite mixture. To accomplish the stated objectives, an extensive series of tests including compaction, direct shear, and permeability, were performed. Furthermore, the characterization experiments focused on in this study included the determination of changes in the pH, EC and microstructure characteristics of the samples with regard to different concentrations of the aforementioned contaminants. The results indicated that in the samples with different concentrations of lead (II), the presence of diesel caused an approximately 6% increase and 45–50% decrease in the maximum dry density and optimum moisture content, respectively. Although the effects of the lead and diesel were in the same direction in the compaction test, they had an adverse effect on the direct shear and permeability tests. The thickness of the diffused double layer was seen as a contributing factor in the performance of the clay part. Also, the pH decreased while the EC increased due to the lead contaminant. These parameters did not change significantly with the addition of diesel to the samples. Moreover, the scanning electron microscope (SEM) images showed an aggregate structure with more macropores due to lead contamination. Diesel enlarged the size of the particles by flocculation as well. As a result, by adding diesel to the lead-contaminated samples, the number of voids decreased as they became filled with diesel.

1. Introduction

Population growth and urbanization are creating a demand for industrial and agricultural activities more than at any other time. Subsequently, various sites have been extensively polluted by organic and inorganic contaminants (Wang et al., 2015). Groundwater is one of the main sources of drinking water supply in most parts of the world that may get contaminated due to the leakage of leachate from landfills (Resmi et al., 2011). Groundwater pollution can be prevented by the construction of engineered landfills. Compacted clay can easily generate some fissures in a desiccated environment (Wang et al., 2018); therefore, in industrialized countries, the use of a compacted sand-bentonite mixture (SBM) is as an alternative to clay liners due to its low permeability and lack of vulnerability to shrinkage cracks (Alston et al., 1997). The results of previous experimental studies on different SBM ratios indicated that a bentonite content of 20–30% is an optimal combination for sand-bentonite mixtures (Sobha and Jose, 2008; Akgun et al., 2015).

Remediation methods for the co-existence of heavy metals and oil contaminants in soils, such as chemical washing, bio-remediation, solidification/stabilization, immobilization, separation by centrifuge and other technologies, have attracted considerable attention in recent years (Riser-Roberts, 1998; Mulligan et al., 2001; Yao et al., 2012; Du et al., 2014). However, for large contaminated areas the cost-effectiveness of these methods has not been proven.

Also, these contaminants change the physical and mechanical properties of soils. So, in order to ensure that the landfill will be good enough to serve its purpose during its lifetime, knowledge of the geotechnical characteristics of contaminated soils is required. Many studies have already been done on the geotechnical properties of oil-contaminated soils. Evgin and Das (1992) conducted a number of triaxial tests on clean and oil-contaminated sand. They reported that the friction angle was significantly reduced for oil-saturated loose and dense samples, and the volumetric strain increased. Al-Sanad et al. (1995)

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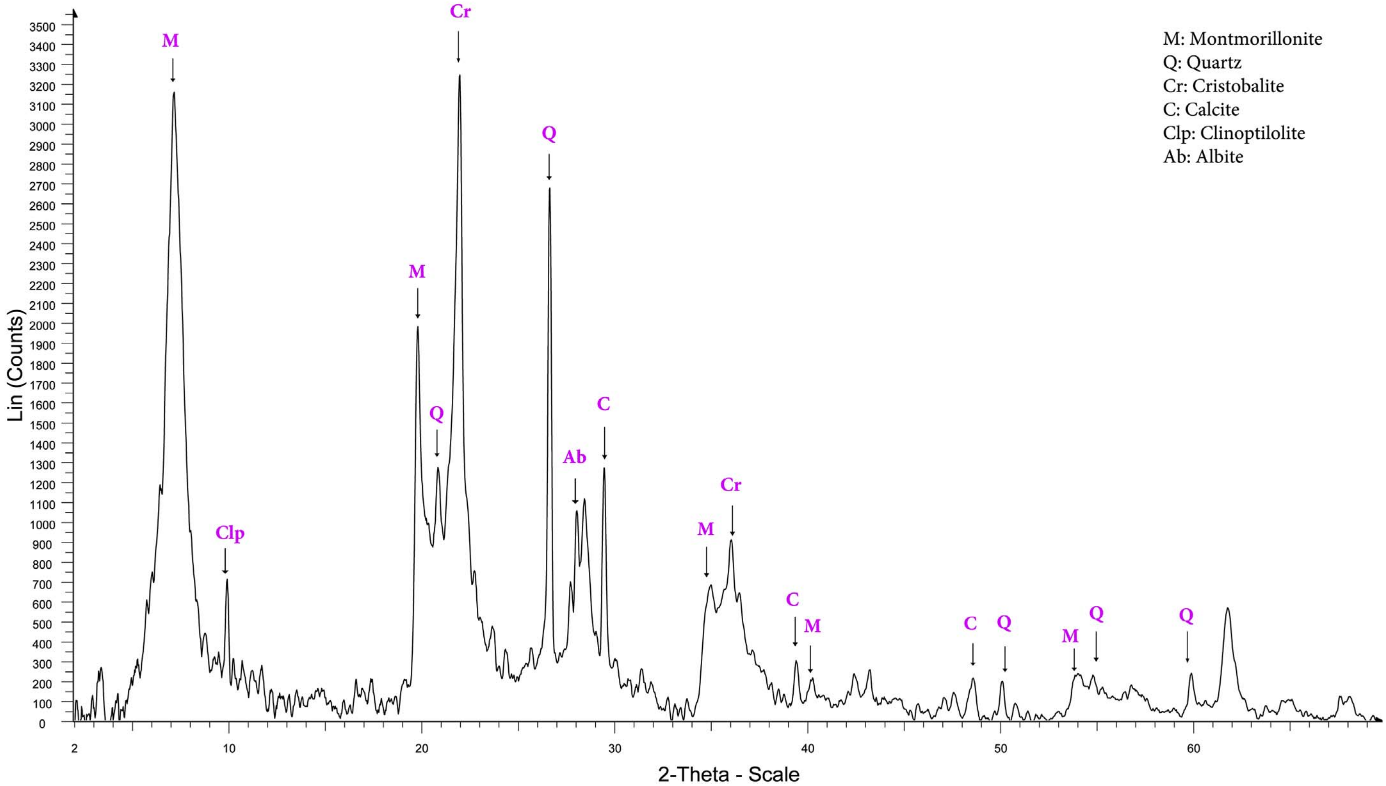

Fig. 1. XRD analysis of bentonite.

performed a laboratory test on oil-contaminated Kuwaiti sand. The results obtained show a reduction in strength and permeability and an increase in compressibility. In addition, a study by Al-Sanad and Ismael (1997) indicated that there was an increase in the strength and stiffness of Kuwaiti sand contaminated with oil due to aging and a decrease in the oil content as a result of evaporation. Shin and Das (2001) investigated the load capacity for unsaturated sand at different ranges of oil content. It was observed that the load capacity dropped drastically upon contamination with oil. Khamehchiyan et al. (2007) presented the effect of oil contamination on sandy and clayey soils, and reported a reduction in the strength, permeability, maximum dry density, optimum water content, and Atterberg limits of these soils. The results obtained by Singh et al. (2008) indicated that petroleum hydrocarbons increased the consolidation settlement of fine-grained soil. Kermani and Ebadi (2012) observed an increase in the friction angle, maximum dry density, compression index, and Atterberg limits for fine-grained soils. In addition, the optimum water content and cohesion decreased with an increase in the oil content. Khosravi et al. (2013) studied the mechanical properties of kaolinite contaminated with different concentrations of diesel. They stated that there was an increase in the cohesion, while the frictional angle and compressibility decreased. Abousnina et al. (2015) investigated the effect of petroleum derivatives on the geotechnical properties of fine sand. They found that the cohesion increased with up to 1% of oil contamination, and then decreased. This was accompanied by a reduction in the permeability and friction angle.

Bowders Jr and Daniel (1987) studied the effect of the chemistry of pore fluids on two types of soils. They reported that organic chemicals have a tendency to shrink the diffused double layer (DDL); therefore, there will be a decrease in the repulsive forces, and the flocculation of the clay particles will be promoted. Stern and Shackelford (1998) showed that the permeability coefficient of a sand-bentonite mixture increased about 20 times when a solution of 0.5 M $CaCl_2$ was used. Shariatmadari et al. (2011) performed many laboratory tests to investigate the effects of three inorganic salts, namely, NaCl, $CaCl_2$ and $MgCl_2$, on typical clay in Tehran. Their results indicated that the maximum dry density and hydraulic conductivity increased, while the optimum water content, swelling volume, compression index and liquid limit decreased. The main reason for such effects was the changes that occurred in the diffused double layer of the clay particles. Oztoprak and Pisirici (2011) presented the corresponding effects of landfill leachate on the microstructure and macro behaviour of Istanbul clay. They commented that there was an increase in the permeability coefficient and a reduction in the strength due to structural changes brought about by mineral disintegration and particle re-alignment. Li et al. (2015) studied the effect of lead (II) on the mechanical properties and microstructure of Chinese clay. They stated that as the concentration of the solution increased, the maximum dry density and hydraulic conductivity increased, while the Atterberg limits and optimum water content decreased. They explained these effects using the diffused double layer theory. Dutta and Mishra (2016) compared the behaviour of bentonite in the presence of Zn^{2+}, Pb^{2+} and Cu^{2+}. The results showed that an increase in the heavy metal concentration led to a decrease in the liquid limit, free swelling, swelling pressure, and swelling potential of the bentonite, and an increase in the hydraulic conductivity.

Previous studies were confined to detecting the effects of just one type of contaminant (organic or inorganic compound) on the soil. Since soils in oil-rich areas may be subjected to contamination by both heavy metals and oil simultaneously, the aim of this study was to investigate the changes in the microstructure and mechanical behaviour of contaminated soils when both contaminants are co-existing. The laboratory program included compaction, permeability and direct shear tests. Also, changes in the pH & EC were reported.

2. Materials and methods

2.1. Sand-bentonite mixture

In this research, the SBM was artificially prepared by mixing 80%