International Journal of GEOMATE, Jan., 2017, Vol. 12, Issue 29, pp. 115-123
Geotec., Const. Mat. & Env., ISSN: 2186-2990, Japan; DOI: http://dx.doi.org/10.21660/2017.29.44861

PHYSICO-CHEMICAL AND GEO-ENVIRONMENTAL BEHAVIOR OF SEMI ARID SOILS

Waleed M Zahid[1], Arif Ali Baig Moghal[2], Ali Abdul Kareem Obaid[3], Mosleh Ali Al-Shamrani[4] and Syed Abu Sayeed Mohammed[5]

[1] Department of Civil Engineering, College of Engineering, King Saud University, Riyadh, Saudi Arabia.
[2,3, 4]Bugshan Research Chair in Expansive Soils, Department of Civil Engineering, College of Engineering, King Saud University, Riyadh, Saudi Arabia.
[5]HKBK College of Engineering, Bengaluru, India.

ABSTRACT: Soil is a basic building block for the most terrestric ecosystems and a complex heterogeneous medium consisting of both solid and fluid phases. Their physico-chemical characterization is of prime importance in understanding their prospective in various civil engineering applications. On the other hand, the ability of soils in absorbing and desorbing metal ions from the aqueous phase assumes importance since it governs both the environmental and agricultural issues. In this study, two different types of soils originating from diversified terrains of Saudi Arabia have been chosen and their potential application in various geotechnical and geo-environmental applications validated by carrying out typical characterization tests, including particle size distribution, density, shear and swelling characteristics. Further, in order to validate their potential applicability in typical landfill liners to retain toxic metal ions, their relative performance in retaining the heavy metal ions has been evaluated. Heavy metal ions such as copper and chromium were used to carry out sorption studies. Experimental data was used to plot adsorption isotherms. Langmuir isotherm was found to be more suitable than Freundlich isotherm for both the soils. It is observed both the soils, exhibited different physical and chemical characterization due to their difference in particle size gradations, as well as in mineralogy and surface morphology. Further, it is concluded that Al-Qatif soil can be used as a filter material and Al-Ghat soil as the main liner material to attenuate selected heavy metals, when they are used in the construction of a typical industrial landfill liner.

Keywords: Copper; Chromium; Sorption; Strength; Compressibility.

1. INTRODUCTION

Nowadays, due to the fast growing economy and urbanization in the Kingdom of Saudi Arabia there is an increasing demand in the construction sector to use locally available fill materials from adjacent cuts or nearby borrow sources. Their potential applicability depends on their successful understanding of various geotechnical properties, such as, unconfined compressive strength, compressibility and hydraulic conductivity. The safety of any geotechnical structure is dependent on the strength of the soil. Hence, the evaluation of the shear strength characteristics of geotechnical materials represents an important aspect in the design and analysis of foundations, embankments, retaining walls and earth slopes. Further, the compressibility characteristic of soils is one of the most important geotechnical properties in design considerations of embankments, backfill materials and highway subgrade. The compressibility of a soil mass is mostly dependent on the rigidity of the soil skeleton. This rigidity, in turn, is dependent on the structural arrangement of particles and in fine grained soils, on the degree to which adjacent particles are bonded together.

Compacted clayey soils are widely used as landfill liners to isolate hazardous and other waste materials from surrounding environments and to prevent the heavy metals commonly found in landfill leachates from migrating into groundwater. Arid soils have inherent advantages over other soils as the CEC of arid soils is much higher and they are alkaline in nature. Further, arid soils exhibit low water contents and are found at places with low water table and as a result they are unsaturated and possess relatively large pore water suctions. Further, they have a crust, which is rich in salts; due to upward moisture loss at the top of the profile by evaporation. It often results in arid soils which get cemented or bonded by the precipitation of salts. They are often cemented by calcium carbonate to form calcrete. These soils are usually sorted and deposited by wind resulting in the formation of poorly graded (single sized) soils having very loose soil structure [1]. These soils have a great potential to be used as landfill liner materials.

In this study, two types of soils are characterized based on physico-chemical and engineering properties for their suitability in various geotechnical and geo-environmental applications. A brief overview of experimental methodology adopted for characterizing the selected soils is also presented.

2. MATERIALS

Two clayey soils originating from diversified terrains of Al-Ghat and Al-Qatif regions have been selected for the present study. Al-Ghat is a populated town located 270 km to the northwest of Riyadh at latitude 26° 1' 36" N and longitude 44° 57' 39" E. On the other hand, Al-Qatif region is coastal oasis region lying on the western coast of the Arabian Gulf in the Eastern Province of Saudi Arabia. It is bound by latitudes 26° 33’ 54” N and longitudes 49° 59’ 46” E.

2.1 Sample Preparation Methodology

The soil sampling from both terrain sites was carried out from test pits at depths of 3 m and then transported to King Saud University laboratory. The soil was then air dried and pulverized using a Los Angles abrasion resistance machine, sieved through ASTM sieve 425 µm (No. 40) to obtain a homogenous mix, and stored in large plastic buckets (air tight) for the purpose of testing. The following sections deal with results pertaining to physical, chemical, geotechnical and environmental characterization of the selected soils.

2.2 Physical Characterization

2.2.1 Particle size distribution

Particle size analysis based on laser diffraction as per ASTM – B822 [2] was carried out to know the gradation. Particle size distribution curves obtained for Al-Ghat and Al-Qatif soils are shown in Fig. 1. It can be seen that major portion has a gradation ranging from 0.1 to 100 µm.

2.2.2 X-ray diffraction analysis

X-ray diffraction is carried out using Bruker D8 Discover system. The XRD analysis of soil samples was performed for 2θ (5° to 60°) as most of the predominant clay minerals fall within this range using 2.2kW Cu anode long fine focus ceramic X-ray tube at a scanning rate of 0.02 degree per second. About 10 grams for each representative sample was oven dried, and sieved through 425 µm sieve which was used in the test.

From Fig. 2, the X -ray diffraction analysis reveals that, for Al-Ghat soil the predominant clay minerals include kaolinite (known to induce moderate swelling), as well as quartz, calcium sulfate hydrate, sodium aluminium silicate, and dickite. In case of Al-Qatif soil, montmorillonite, palygorskite, illite, halloysite, and muscovite are detected, which are known to induce significant amount of swelling upon interaction with water [3-9].

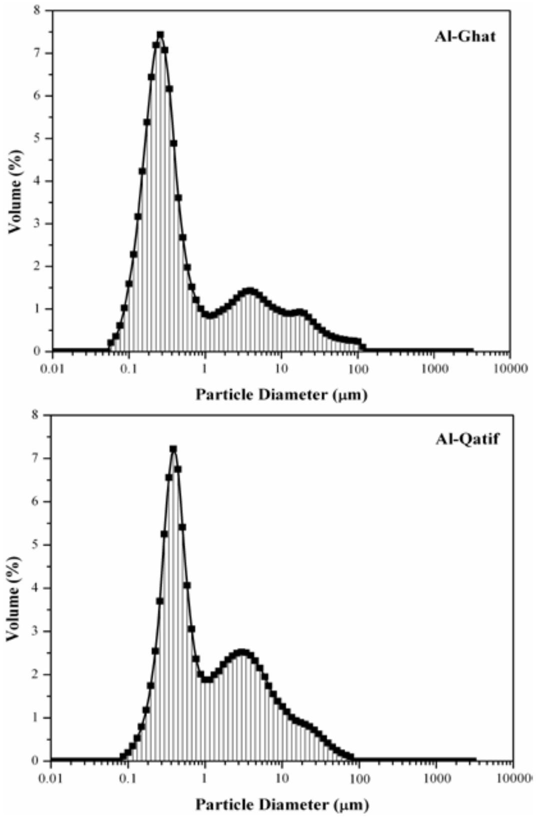


Fig.1 Particle size distribution curves

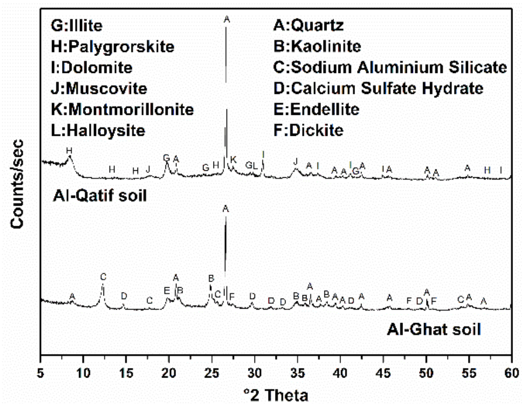
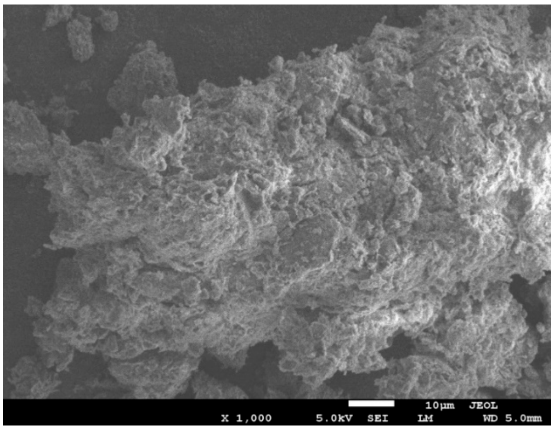


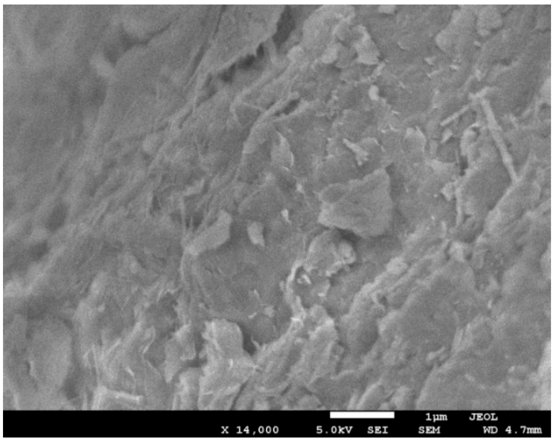
Fig.2 X-ray diffraction analysis

2.2.3 Scanning electron microscope studies

Scanning electron microscope (SEM) is used to study the qualitative changes occurring in the surface morphological characteristics of the soils. The JEOL JSM-7600F Scanning Electron Microscope (SEM) apparatus with a thermal field emission source with high voltage 40 kV is used to observe the surface morphological characteristics of selected soil samples. Powdered samples of the natural soils were prepared and dried in the oven at 60°C and subsequently subjected to vacuum. The tested specimens were glued on copper holders for scanning. Fig. 3 reveals "honeycomb" structured morphology for both soils (Al-Ghat and Al-Qatif) which is a characteristic of smectite containing straight and rigid bladed platelets. These types of soils are known to undergo significant changes in basal spacing when they come into contact with water.



a) Al-Ghat Soil (x 1,000 magnification)



b) Al-Qatif Soil (x 14,000 magnification)

Fig.3 Scanning electron micrographs

2.3 Chemical Composition

In order to analyze the chemical composition for the selected soils, Energy Dispersive X-ray analysis (EDAX) is carried along with scanning electron microscope (SEM) imaging using Oxford instruments INCAx-act apparatus. In this technique, each element has a specific and well-defined energy level, thus electrons are bombarded in the area of desired elemental composition, and the elements present will emit characteristic X-rays, which are then recorded on a detector. The energy differences between shells are used to identify the elements present in the sample.

The chemical compositions of the minerals present in Al-Ghat and Al-Qatif soils are shown in Table 1. Relatively higher values of silica (Si), alumina (Al) and iron (Fe), followed by lower values of calcium (Ca), magnesium (Mg), and potassium (K) are noticed in both soils. Further, this analysis indicates that both Al-Ghat and Al-Qatif soils have exchangeable potassium (K) ions. It is also noticed that, Al-Qatif soil has relatively higher (K) ions than Al-Ghat soil, which further explains the great ability of Al-Qatif soil in absorbing more water than Al-Ghat.

Table 1 Chemical Composition Values of Selected Soils

Chemical composition	Al – Ghat (%)	Al – Qatif (%)
Si as SiO_2	20.8	18.1
Al as Al_2O_3	12.8	6.6
Ca as CaO	2.3	1.1
Mg as MgO	0.64	3.96
K as K_2O	1.2	2.4
Fe as Fe_2O_3	17.47	10.38
Al/Si	61.54	36.46
Ca/ Si	11.06	6.08

2.4 Geotechnical Characterization

2.4.1 Atterberg's Limits

The liquid limit was conducted by using the cone penetration method according to British Standard [10]. The plastic limit of each soil was determined in accordance with ASTM – D4318 [11]. The plasticity index was then computed for each soil based on the obtained liquid and plastic limit values. The shrinkage limit test was conducted in accordance with ASTM –D427 [12]. The physical properties of Al-Ghat and Al-Qatif soils are reported in Table 2. Both the clays have been classified as 'highly plastic' clays. Al-Qatif soil reported a significantly higher liquid limit value of 158, which is typical for clays exhibiting relatively higher degree of swell.

The specific gravity (Gs) values were determined by using a water pycnometer in accordance with ASTM –D854 [13]. The specific surface area (SSA) was measured using the BET method in accordance with ASTM –D1993 [14], which is based on the work by Brunauer et al. [15]. This method works by measuring the quantity of the adsorption of nitrogen which is adsorbed on a solid surface by sensing the change in thermal conductivity of a flowing mixture of adsorbate and an inert carrier gas. The SSA values of Al-Ghat and Al-Qatif soils were found to be 27.08 and 124.25 m^2/g respectively as shown in Table 2. These soils differ substantially in specific surface area, and this difference is attributed to differences in mineralogical compositions (Fig. 2) as well as their particle size gradations (Fig. 1).

Table 2 Physical properties of selected soils

Physical Property	Al - Ghat	Al - Qatif
Liquid Limit (%)	66	158
Plastic Limit (%)	32	54
Plasticity Index (%)	34	104
Shrinkage Limit (%)	15	14
% Finer than 0.075 mm	87.3	99.1
USCS Classification*	CH	CH
Specific Gravity	2.85	2.77
Specific Surface Area (SSA) (BET Method) (m^2/g)	27.08	124.25

**'USCS' refers to unified soil classification system and 'CH' refers to clay with high plasticity.*

2.4.2 Density Characteristics

The proctor density values were determined by employing mini compaction test procedure developed by Sridharan and Sivapullaiah [16]. This method requires about 1/10 of material compared to that required in standard proctor test. The effort and time required to perform the compaction test using this apparatus are considerably less, as well as the compacted samples after trimming to required height can be used for various other tests directly. The developed apparatus consists of a mold 3.81 cm internal diameter, and height 10 cm, with falling hammer of weight 1.0 kg. The sample is compacted with 36 blows /layer in three layers for standard Proctor compaction curve. For each compaction test about 200 g of soil is used. After allowing sufficient time for moisture equilibrium, the sample is remixed thoroughly before compaction. The weight of the compacted soil together with the mold is measured and the weight of the compacted soil is determined. Knowing the water content, the resultant dry density is calculated.

The proctor compaction curves for both Al-Ghat and Al-Qatif soils are shown in Fig. 4. The maximum dry density of Al-Ghat soil is 1.64 g/cm^3 and the corresponding optimum moisture content is 25 %, while for Al-Qatif soil, they are 1.21 g/cm^3 and 42.5% respectively. It is noteworthy that, the proctor compaction curve of Al-Ghat soil follows typical parabolic path with a definite maximum peak while for Al-Qatif soil, the curve exhibits double hump pattern.

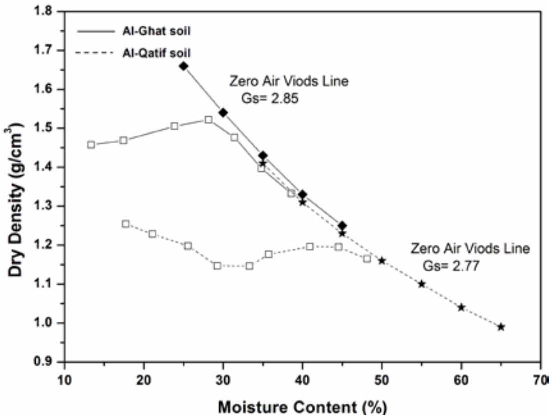


Fig. 4 Compaction curves of Al-Ghat and Al-Qatif soils

2.4.3 Consolidation Behavior

Standard test procedure in accordance with ASTM – D2435 [17] is employed to carry out one dimensional fixed ring oedometer consolidation tests. The wet mixed material was compacted using static compaction technique in a cylindrical consolidation metal ring of 75 mm diameter and 20 mm height. The inside of the ring was lubricated with silicon grease before molding the soils to minimize the friction between the ring and the soil specimen. The specimen was covered with filter paper to prevent clogging of pores by soil particles, then a set of porous stones were placed at the top and bottom of the specimens to provide double drainage condition for faster compression. The entire assembly was then mounted in the consolidation cell and positioned in the loading frame. At the start of the test, a seating load of 6.25 kPa was applied and the dial gauge reading was allowed to stabilize following which the sample was inundated with water. This stage would mark the beginning of the test. All the samples were loaded to 800 kPa starting from 6.25 kPa, at a standard load increment ratio of unity. For each pressure increment, void ratio – consolidation pressure curves were plotted and the coefficients of compressibility values (Cc) were calculated.

Fig.5 shows the void ratio – consolidation pressure curves for Al-Ghat and Al-Qatif soils. It is observed that, the swelling phenomenon at the initial seating load of 6.25 kPa is relatively more in Al-Qatif soil compared to Al-Ghat soil. The relatively higher swelling value in Al-Qatif soil is predominantly due to the presence of montmorillonite and playgorskite mineral (Fig. 2) resulting in abnormal swelling upon saturation with water, as well as higher specific surface area available in Al-Qatif soil 124.25 (m^2/g) (Table 2) allowing it to absorb more water. Whereas in case of Al-Ghat soil, the predominant mineral (Fig. 2) is kaolinite which is characterized by relatively lower water absorption values and has relatively lower susceptibility to swelling under variations in water content [7].

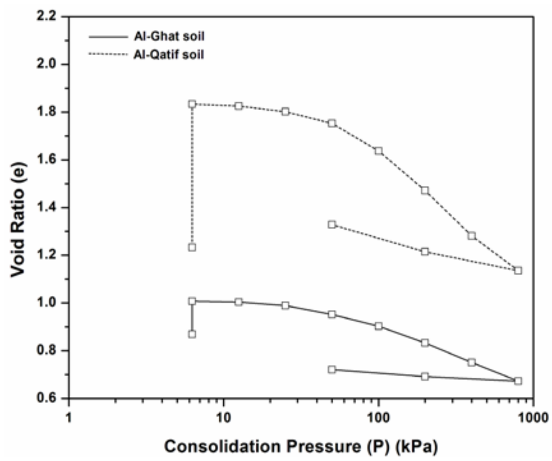


Fig. 5 Void ratio – pressure curves of Al-Ghat and Al-Qatif soils

2.4.4 Shear Strength Behavior

Standard test procedure in accordance with ASTM –D2166 [18] is employed to determine the unconfined compression strength values. The specimens used were mixed with the amounts of water corresponding to their respective Proctor maximum dry density values and kept in an air tight desiccators maintained for 24 hours at a relative humidity of more than 95% at 23°C (room temperature) in order to achieve uniform moisture content. The samples were then compacted using static compaction technique in a mold of 36 mm diameter and 72 mm height, and then loaded on the compression device and sheared at a strain rate of 0.5 mm/min as per ASTM –D2166 [18]. From the stress strain curves, the magnitudes of the peak stress and the strain values corresponding to peak stress were noted. Further, a minimum of three unconfined compression strength tests were carried out for each case to validate the results for repeatability and reproducibility.

Fig. 6 depicts the unconfined compression strength values evaluated from stress-strain curves of natural compacted specimens of Al-Ghat and Al-Qatif soils. It can be seen that the unconfined compressive strength of Al-Ghat and Al-Qatif soils are 340 kPa and 323 kPa respectively. Relatively higher strain values can be seen for Al-Ghat soil at breaking stress compared to Al-Qatif soil and is attributed to their respective differences in physical, chemical and mineralogical composition values.

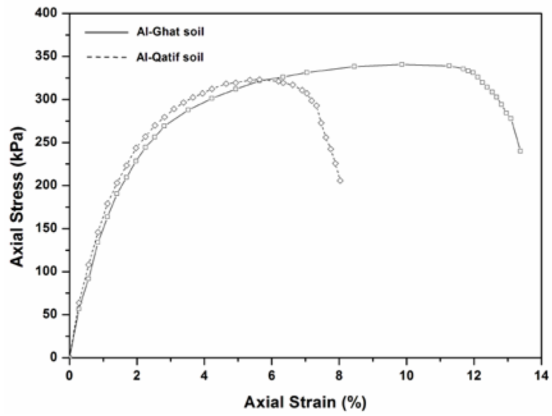


Fig. 6 Unconfined compression strength behavior of Al-Ghat and Al-Qatif soils

2.4.5 Hydraulic Conductivity Behavior

Hydraulic conductivity is an important parameter in the design of liners to contain leachate migration, dykes to predict the loss of water, embankments as well as the stability of slopes and as a sub-base material [19]. For hydraulic conductivity study, the samples were prepared and tested as per ASTM –D5856 [20]. The hydraulic conductivity values of Al-Ghat and Al-Qatif soils were found to be $6.77 x10^{-7}$ and $7.36 x10^{-8}$ cm/s, respectively. The ranges of values obtained in this case are typically experienced for highly plastic clays. Both the selected soils satisfy the criteria for hydraulic conductivity when they are used as both primary and secondary landfill liner materials.

2.5 Geo-Environmental Characterization

Complex environmental problems associated with urban sprawl have an impending effect on the environment. Toxic pollutants, whether discharged directly or indirectly into water bodies with inadequate treatment, adversely affect the surrounding environment. Containing these pollutants from entering the mainstream water bodies can be a daunting task and is achieved by using individual barriers and control technologies that provide a system of engineered control. Containment technologies are potentially applicable to any circumstance in which contaminants exist in the subsurface (e.g., uncontrolled landfills or dumps, chemical spills or leaks, pond or lagoon contaminant seepage) and can provide a safe and highly cost-effective mechanism for environmental control. Containment is accomplished using physical, hydraulic, or chemical barriers that prevent or control the outward migration of contaminants [21].

For the purpose of this study, the two selected soils are investigated for their retention characteristics of hexavalent chromium, Cr (VI) and copper. Chromium can be found in air, soil, and water after release from industries that use chromium, such as industries involved in electroplating, leather tanning, textile production, and the manufacture of chromium-based products. Chromium can also be released into the environment from the burning of natural gas, oil, or coal. A higher exposure level of Cr (VI) is extremely dangerous as it could lead to allergic dermatitis as well as cancer. On the other hand, copper is widely distributed in water since it is a naturally occurring element. The major sources of copper in drinking water are corrosion of household plumbing systems; and erosion of natural deposits. Higher exposure levels of copper may lead to gastrointestinal distress and with long-term exposure may experience liver or kidney damage [22].

Copper nitrate and potassium dichromate salts supplied by Nice Chemicals of analytical grade type were used to prepare solutions of standard concentrations. pH adjustments were carried out by using 0.1N hydrochloric acid (HCl) and 0.1N sodium hydroxide (NaOH).

2.5.1 Batch adsorption studies

Samples with S/L ratios of 1:20, 1:30, 1:40, 1:100, 1:200, were taken and shaken for 24 hours. Then, 100mg/l of contaminant was added proportionally to all samples and again shaken for 24 hours. The samples were then removed, filtered and the filtrate was analyzed for its concentration. For pH dependent tests the procedure was the same as mentioned except for the pH of the contaminant which was first adjusted to the required pH and then the adsorbent was added maintaining a constant S/L (solid /liquid) ratio of 1:20 which was maintained constant for all the tests. This was done to prevent neutralization reaction from taking place because of the presence of lime in the adsorbent (natural free lime as hydroxide) and also to mimic field conditions similar to a landfill. For different initial concentrations, about 5grams of adsorbent was taken in 100ml of solution maintaining a S/L ratio of 1:20 and was subjected to shaking for 24 hours , then 10mg/l of contaminant was added to all samples and again subjected to shaking for 24 hours. The samples were then removed, filtered and the filtrate was analyzed for its concentration ASTM – D4646 [23].

2.5.2 Leaching Tests

A known percentage by weight of heavy metal such as copper and chromium as contaminant was mixed with soil and allowed to dry naturally for 7 days and also further extended to cure for 28 days. The standard procedures followed were as per ASTM – D3987 [24]. A load ratio of 100mg/kg and 50 mg/kg was maintained (1000ml of 100 ppm contaminant solution was added to 1 kg of soil to give a load ratio of 100mg/kg). Batch leaching test was done by taking a known weight of dried mixture and mixing it in a known volume of distilled water maintaining a solid to liquid (S/L) ratio of 1:20, and subjecting it to shaking for a period of 18 hours in a sample shaker at a speed of 30 RPM. The leachate was taken and after centrifuging and filtering the sample the contaminant concentration (Concentration of the metal ion under consideration) was determined. The concentration of copper and chromium ions was measured using Atomic Absorption spectrophotometer supplied by Perkin Elmer PnAAcle 900T THGA. The experimental results were then correlated with empirical models such as Langmuir and Freundlich isotherms.

From Fig. 7, it can be seen that a plot of sorption coefficient to dilution ratio converted to concentration reveals that at lower concentration the adsorption of both copper and chromium was maximum and with increase in concentration the adsorption decreased, hence concentration and dilution ratio are inversely related for the metal ions under consideration. This is due to the fact that, at lower concentrations, the sorption sites are relatively more and as the concentration increases competition for sorption sites increases and some of the sorbed ions may even be subjected to desorption from other competing ions, resulting in reduced sorption efficiency. From Fig. 8, it can be further seen that with increase in initial concentration the sorption coefficient increases for both copper and chromium metal ions respectively. The variation is relatively linear and seems to be directly proportional to the concentration within the tested range. At higher concentration the energy of adsorption is higher and hence more adsorption takes place for both the metal ions considered in the present study.

The effect of pH on the sorption coefficient of copper and chromium has been presented in Fig. 9. It is observed that the sorption coefficient increases with increase in pH for copper. Under alkaline pH conditions, maximum copper adsorption takes place due to formation of OH^- ions which aids in precipitation of copper to its hydroxide form. However, in case of chromium (Fig. 9), it has been observed that the sorption coefficient decreases with increase in pH. Maximum adsorption takes place at acidic pH and due to protonation (defined as the attachment of H^+ ions forming complexes in acidic media). If the concentration of H^+ ions is more it would lead to better protonation [1, 25].

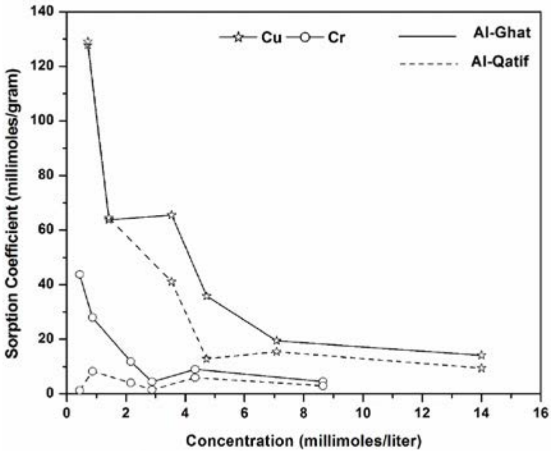


Fig. 7 Variation of sorption coefficient at different dilution ratios

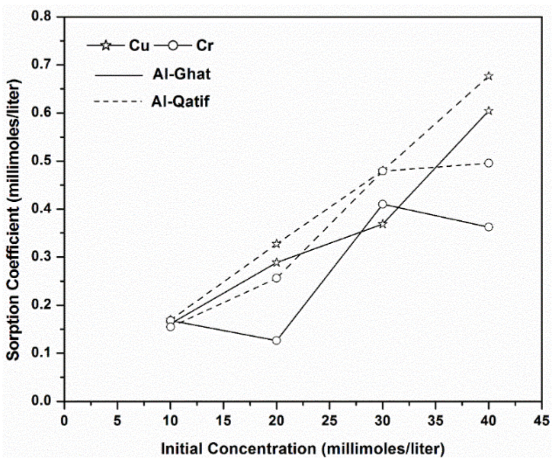


Fig. 8 Variation of sorption coefficient at various initial concentrations

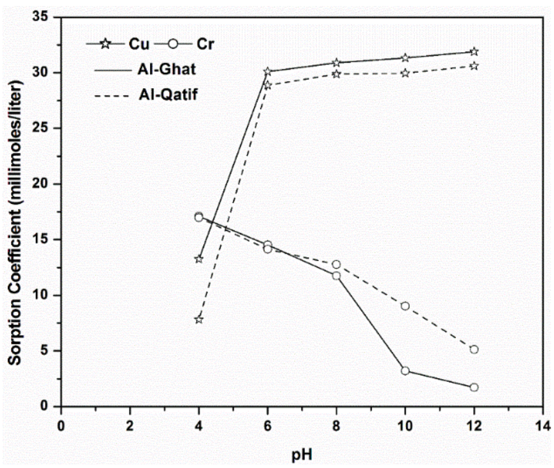


Fig. 9 Variation of sorption coefficient with pH

From Fig. 2, the X -ray diffraction analysis reveals that, for Al-Ghat soil the predominant clay minerals include kaolinite (known to induce moderate swelling), as well as quartz, calcium sulfate hydrate, sodium aluminium silicate, and dickite. In case of Al-Qatif soil, montmorillonite, palygorskite, illite, halloysite, and muscovite are detected, which are known to induce significant amount of swelling upon interaction with water [3-9]. In order to study the desorption response, leaching tests were conducted in accordance with ASTM – D3987 [24] maintaining load ratios of 100mg/kg and 50 mg/kg for both copper and chromium metal ions. This load ratio is consistent and it is not expected to influence any major change in leaching rate [1]. It can be observed from Fig. 10 that, both copper and chromium are retained in the selected soils. However, relatively better retention levels were achieved in case of copper compared to chromium for the soils under consideration at the fixed load ratio values. The reduction potential of copper (+0.34v) is higher than that of chromium (-0.4 v), and as a result copper gets reduced easily compared to chromium (‘Reduction potential’ gives a measure of the reducing tendency of an electrode) [22].

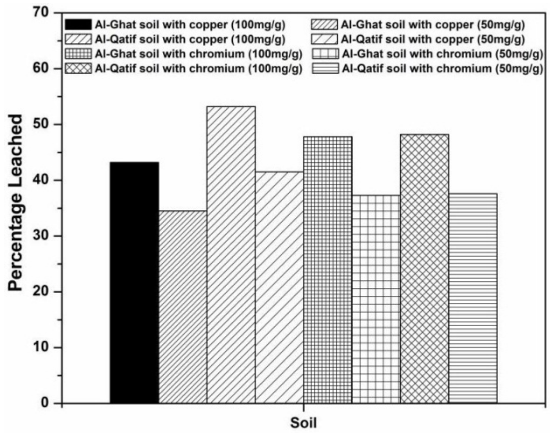


Fig. 10 Leaching behavior of selected soils for the targeted metal ions

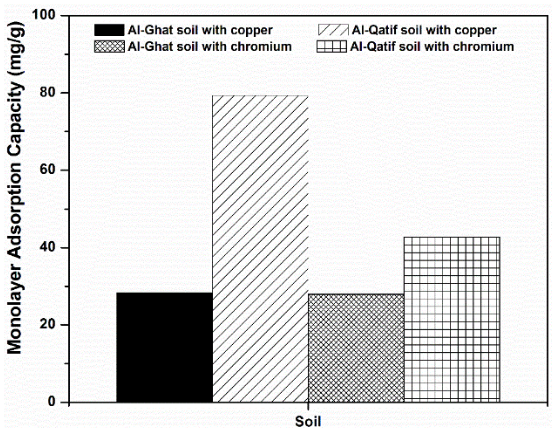


Fig. 11 Variation of monolayer adsorption capacity of selected soils for copper and chromium

From Fig. 11, it can be seen Al-Qatif adsorbs the maximum amount of copper compared to all other materials. The results obtained after applying the experimental data into Langmuir isotherm and in turn calculating the Langmuir monolayer adsorption capacity confirms well with the experimental results obtained. This also shows that Langmuir isotherm fits well for the selected soils.

3. CONCLUSIONS

The current study was carried out on two different soils originating from diversified terrains of Saudi Arabia (Al-Ghat and Al-Qatif), as they represent the extreme types of clay minerals and any selected natural soil from the Kingdom is likely to behave in between these two extremes. The physical characterization of the soils revealed that, both the soils had a major portion of gradation ranging from 0.1 to 100 µm. For Al-Ghat soil the predominant clay mineral was kaolinite whereas for Al-Qatif soil, it was montmorillonite which caused relatively higher swelling upon inundation with water. Both the soils exhibited relatively lower permeability values ($<10^{-7}$cm/s) satisfying the hydraulic conductivity criteria for both domestic and industrial landfill liner material. In order to evaluate their relative performance in retaining the heavy metal ions, copper and chromium, standard batch equilibrium tests were carried out. The adsorption pattern was validated using available standard empirical models and a good correlation was observed. It is concluded that Al-Qatif soil is a better material compared to Al-Ghat in attenuating the selected heavy metal ions and is due to the difference in their chemical composition and particle gradation. It is recommended that Al-Qatif soil be used as a filter material and Al-Ghat soil as the main liner material in attenuating the selected heavy metals (copper and chromium) for an industrial landfill.

4. ACKNOWLEDGEMENTS

This project was funded by the National Plan for Science, Technology and Innovation (MAARIFAH), King Abdul Aziz City for Science and Technology, Kingdom of Saudi Arabia, Award Number (12ENV2583-02).

5. REFERENCES

[1] Moghal, A.A.B., Mohammed, S.A.S., Al-Shamrani, M.A., & Zahid, W.M. (2014). Performance of Soils and Soil Lime Mixtures as Liners to Retain Heavy Metal Ions in Aqueous Solutions. *ASCE Geotechnical Special Publication No. 241*, 160-169.

[2] ASTM (2002) Standard Test Method for Particle Size Distribution of Metal Powders and Related Compounds by Light Scattering. B822-02. West Conshohocken, Pa.

[3] Al-Mhaidib, A.I., & Al-Shamrani, M.A. (1996). Swelling Characteristics of Lime-Treated Expansive Soils. *Geotechnical Engineering Journal*, 27(2), 37-53.

[4] Al-Shamrani, M.A., & Dhowian, A.W. (2003). Experimental Study of Lateral Restraint Effects on the Potential Heave of Expansive Soils. *Engineering Geology*, 69(1-2), 63-81.

[5] Aiban, S.A. (2006). Compressibility and Swelling Characteristics of Al-Khobar Palygorskite, Eastern Saudi Arabia. *Engineering Geology*, 87(3-4), 205-219.

[6] Pedarla, A., Chittoori, S., Puppala, A.J., Hoyos, L., & Saride, S. (2010). Influence of Lime Dosage on Stabilization Effectiveness of Montmorillonite Dominant Clays. *ASCE Geotechnical Special Publication No. 199*, 767-776.

[7] Moghal, A.A.B., Obaid, A.A., & Refeai, T.O. (2014). Effect of Accelerated Loading on the Compressibility Characteristics of Lime Treated Semi Arid Soils. *Journal of Materials in Civil Engineering*, 26(5), 1009-1016.

[8] Moghal, A.A.B., Al-Obaid, A.K., Refeai, T.O., & Al-Shamrani, M.A. (2015). Compressibility and Durability Characteristics of Lime Treated Expansive Semiarid Soils. ASTM Journal of Testing and Evaluation, Vol. 43, No. 2, pp. 255-263.

[9] Moghal, A.A.B., Abbas, M.F., Al-Mahbashi, A.M., & Shaker, A.A. (2016). Effect of Structure Anisotropy and Compaction Method on the Swelling Behavior of Al-Qatif Soil. International Journal of Geomate, Vol. 11, No. 26, pp. 2600-2605.

[10] BS (1990) Stabilized Materials for Civil Engineering Purposes. Methods of Tests for Cement- Stabilized and Lime-Stabilized Materials. British Standards Designation 1924 Part 2. British Standard Institution, London.

[11] ASTM (2010) Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. D4318. West Conshohocken, Pa.

[12] ASTM (2004) Standard Test Methods for Shrinkage Factors of Soils by the Mercury Method. D 427. West Conshohocken, Pa.

[13] ASTM (2002) Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer. D 854. West Conshohocken, Pa.

[14] ASTM (1997) Standard Test Methods for Precipitated Silica-Surface Area by Multipoint BET Nitrogen Adsorption. D 1993. West Conshohocken, Pa.
[15] Brunauer, S., Emmett, P.H., & Teller, E. (1938). Adsorption of Gases in Multi-Molecular Layers. *Journal of the American Chemical Society*, 60(2), 309-319.
[16] Sridharan, A., & Sivapullaiah, P.V. (2005). Mini Compaction Test Apparatus for Fine Grained soils. *Geotechnical Testing Journal*, 28(3), 240-246.
[17] ASTM (2004) Standard Test Methods for One Dimensional Consolidation Properties of Soils Using Incremental Loading. D2435. West Conshohocken, Pa.
[18] ASTM (2006) Standard Test Methods for Unconfined Compressive Strength of Cohesive Soil. D2166. West Conshohocken, Pa.
[19] Sivapullaiah, P.V., & Moghal, A.A.B. (2011). Gypsum Treated Fly Ash as a Liner for Waste Disposal Facilities. *Waste Management*, 31(2), 359-369.
[20] ASTM (2007) Standard Test Method for Measurement of Hydraulic Conductivity of Porous Material Using a Rigid-Wall, Compaction-Mold Permeameter. D5856. West Conshohocken, PA.
[21] Chien, C.C., Inyang, I.H., and Everett, L.G. (2006). Barrier Systems for Environmental Contaminant Containment and Treatment. Taylor and Francis Group, New York, NY.
[22] Moghal, A.A.B., & Sivapullaiah, P.V. (2012). Retention Characteristics of Cu^{2+}, Pb^{2+} and Zn^{2+} from Aqueous Solutions by Two Types of Low Lime Fly Ashes. *Toxicological and Environmental Chemistry*, 94(10), 1941-1953.
[23] ASTM (2008) Standard Test Method for 24h Batch-Type Measurement of Contaminant Sorption by Soils and Sediments. D4646. West Conshohocken, PA.
[24] ASTM (2012) Standard Practice for Shake Extraction of Solid Waste with Water. D3987. West Conshohocken, PA.
[25] Moghal, A.A.B., Reddy, K.R., Mohammed, S.A.S, Al-Shamrani, M.A., & Zahid, W.M. (2017). Retention Studies on Arsenic from Aqueous Solutions by Lime Treated Semi Arid Soils. International Journal of Geomate. Vol. 12, No. 29, pp. 2836-2843.

International Journal of GEOMATE, Jan., 2017, Vol. 12, Issue 29, pp. 115-123.
MS No. 44861 received on May 14, 2016 and reviewed under GEOMATE publication policies.
 Pertinent discussion including authors' closure, if any, will be published in Dec. 2017 if the discussion is received by June 2017.
Corresponding Author: Arif Ali Baig Moghal