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Effect of Temperature on the Water Retention Capacity of Liner Materials

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Abstract**—**Mixtures of sand and clay are frequently used to serve for specific purposes in several engineering practices. In environmental engineering, liner layers and cover layers are common for controlling waste disposal facilities. These layers are exposed to moisture and temperature fluctuation specially when existing in unsaturated condition. The relationship between soil suction and water content for these materials is essential for understanding their unsaturated behavior and properties such as retention capacity and unsaturated follow (hydraulic conductivity). This study is aimed at investigating retention capacity for two sand-natural expansive clay mixtures (15% (C15) and 30% (C30) expansive clay) at two ambient temperatures within the range of 5 -50 °C. Soil water retention curves (SWRC) for these materials were determined at these two ambient temperatures using different salt solutions for a wide range of suction (up to 200MPa). The results indicate that retention capacity of C15 mixture underwent significant changes due to temperature variations. This effect tends to be less visible when the clay fraction is doubled (C30). In addition, the overall volume change is marginally affected by high temperature within the range considered in this study.

Keywords**—**Soil water retention curve, sand-expansive clay mixture, suction, temperature.

I. INTRODUCTION

THE clay materials used for liners influence the flow and water retention capacity. It was very common in environmental engineering to investigate the soil water characteristics. The water retention capacity of a liner material is an essential property when sand clay mixtures are used in environmental protection works such as hydraulic barriers or landfill cover layers in waste management facilities. As these layers generally exist in a partially saturated state, the material parameters and characteristics are very important for the study of fluid flow. These layers could be defined using the water retention characteristics. The retention capacity of soil is defined as the ability of soil to retain water at specific level of suction, as obtained from soil water retention curve (SWRC). SWRC is determined in the laboratory by imposing suction to soil specimen until equilibrium conditions is attained. The relationship between applied suction and water content in soil specimen at equilibrium state is called soil water retention curve (SWRC).

The moisture and temperature fluctuate during different season in semi-arid regions. Near-ground layers interact with ambient temperature and influence the geotechnical profile. Isothermal issues can arise in some cases such as storage and disposal of radioactive waste [1]. In this case, coupling thermal effect with hydro-mechanical behavior is very important in order to achieve accurate design, reliable modeling, and good interpretation of soil-water behavior of the materials used [2], [3].

Limited studies were found in the literature regarding retention capacity of clayey/volume-change soils under different temperatures. Most of these studies reported that the retention capacity is significantly reduced with the increase of temperature within the range between 20 and 120°C [4]-[9]. On the other side, [10] investigated the soil water retention capacity of Gaomiaozi bentonite under different ambient temperature. The results indicated decrease in retention capacity with increase of temperature at high ranges of suction, while, at low ranges of suction the effect of temperature are minor. Similar behavior was also reported by [11] for two expansive clays.

The effect of temperature on the retention capacity could be interpreted by considering low as well as high suction range [12], [3], [10]. At low suction range, the retention capacity is mainly governed by the capillary action. The increase in temperature induces changes in the surface tension and consequently decreases water content at the same level of suction. At high suction level, the retention capacity is governed by micropores (intra-aggeregate). At this level of suction, the temperature has been proven to have significant effect on the soil fluid and the soil fabric.

Recently, the effect of temperature on the different mixtures of sand with high contents of bentonite (i.e., 90 to 50% bentonite) was investigated by [13]. The results of SWRCs (at range of temperature from 20º to 60°C) indicated that temperature may not have influence on the retention capacity of these mixtures. [5] also evaluated the effect of temperature (from 20 to 120°C) on the water retention capacity of bentonite, the study reported that there are no significant changes in the retention capacity of bentonite with the increase of temperature up to 60 °C.

From the previous literature it could be inferred that, the effect of temperature on the water retention capacity is not unique. Further investigations of retention capacity are required with consideration of the entire range of suction. In this paper, the soil-water retention curves (SWRCs) of the compacted sand-expansive clay (SEC) mixtures under two ambient temperatures (7 °C and 48 °C) are presented over the entire range of suction. When the expansive soil used as liner

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materials with sand, volume changes during suction measurement are expected. The volume changes associated with SWRC measurement were detected, and the effect of temperature on the volume change behavior is presented.

II. EXPERIMENTAL WORK

This section presents the characterization of sand-expansive clay used in this study. The testing procedures for measurement of the water retention curves for these materials at different ambient temperature are also presented.

A. Materials Used

Two different mixtures of sand and expansive clay were prepared to form liner materials in this study. The sand was obtained from the northern side of Al-Riyadh city, the capital of Saudi Arabia. According to basic characterization in laboratory, the grain size is in the range from 0.6 to 0.1 mm classified as (SP) poorly graded sand according to the unified soil classification system [14]. The specific gravity of the sand was 2.68.

The expansive clay used in this study was obtained from the eastern province of Saudi Arabia (Al-Qatif city). The basic characterization of expansive clay was summarized in Table I. According to the characterization data, this clay is classified as highly plastic and expected to introduce high swelling potential due to the presence of smectite minerals and montomorellonite [15], [16].

TABLE I
CHARACTERIZATION FOR EXPANSIVE CLAY

Characteristic	Value
Specific Gravity, G_s	2.71
Liquid Limit, w_L (%)	160
Plastic Limit, w_P (%)	60
Shrinkage Limit, w_{sh} (%)	11-14
% passing Sieve No. 200	94
Unified soil classification	CH
Maximum dry unit weight (kN/m^3)	12
Optimum water content (%)	38
Swelling potential [17]	15-18%
Swelling pressure [17]	250-400 $/m^2$

B. Mixtures Preparation

Two different SEC mixtures were prepared by mixing dry sand with 15% and 30% expansive clay. These mixtures will be denoted as C15 and C30 respectively. The selected percentages of clay have been proven to satisfy hydraulic conductivity for liner materials [18]. The mixtures were prepared at different moisture contents to perform the standard compaction test in accordance with [19]. The compaction curve obtained from the tests indicated 17.73 kN/m^3, 14% and, 18.02 kN/m^3, 13.7% as a maximum dry density (MDD) and optimum water content (OWC) values for C15 and C30 respectively. All specimens were statically compacted to the maximum dry density in a 38 mm diameter and 10 mm height ring.

C. Testing Procedures

Soil water retention curves for the considered mixtures C15 and C30 were performed in the laboratory over a wide range of suction using vapor equilibrium technique. Different salt solutions were prepared to impose suction from low range up to 115 MPa. The ambient temperatures considered in this study are 7 and 47 °C. The first test series conducted using heating room to measure suction under the constant temperature 47±0.3 °C and a cooling room with ambient temperature 7±0.5 °C was utilized for second test series.

At the beginning, different saturated salt solutions and different concentrations of NaCl were prepared in accordance to [20]. Accurate values of suction obtained from different salt solutions were verified using potentiometer WP4C device by Decagon® [21] at temperature 24 °C. The device works on the principle of chilled-mirror dew point technique to measure the relative humidity inside a sealed-chamber that contains salt solution. Small amount of salt solution inside plastic cap was inserted to the sealed chamber, the relative humidity in the surrounding air and salt solution are assumed to be the same at equilibrium.

For 7 and 47 °C, the same salt solutions were used. The calibration of these salt solutions was performed under each temperature. The amount of salt solution (i.e. 300 ml was placed inside sealed box, the box provided with SonBest®-digital sensor connected to computer to measure the relative humidity and temperature with time. The setup (salt solution inside box) was placed in the temperature-control room, the continuous profile of humidity with time for each salt solution under each temperature was obtained. The period of time depends on when the relative humidity reached constant value. Depending on the measured value of relative humidity (RH), the value of suction is calculated using Kelvin equation [22] as follows:

$$\psi = \frac{RT\rho_w}{w} \ln\left[\frac{1}{RH}\right] \tag{1}$$

where, Ψ = soil suction (kPa), R = molar gas constant (8.314462 J/(mol K)), T = absolute temperature (K); w = molecular mass of water vapour (18.016 g/mol); ρ_w = is the mass density of water (kg/m3); RH = relative humidity.

Table II summarises the set of saturated salts and salt solutions used in this study and their corresponding suction values under different temperatures.

Measurement of SWRCs for mixtures under different temperatures was performed by preparing amount of salt solution inside tightly-sealed jars. The compacted specimen of soil placed above the salt solution (over plastic mesh) to get equilibrium with the salt solution. Different boxes were prepared with different salt solutions (suctions) to get the tests running at the same time. In order to prevent the effect of condensation the specimen was covered by cone-shaped plastic cap, similar procedure was used by [6].

During the period of equilibrium, the specimen was immediately weighed in periods to examine equilibrium. This process has been done in short time (less than 15 seconds) to

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prevent any change in the moisture content of specimen due to evaporation/absorption [4]. Equilibrium time versus water content for specimens under different salt solutions are presented in Figs. 1 and 2 for temperatures 7 and 47°C respectively. From these figures it could be inferred that the specimens under high temperature come to equilibrium faster. At equilibrium the soil specimen was immediately weighed and water content corresponding to the imposed suction was gravimetrically determined.

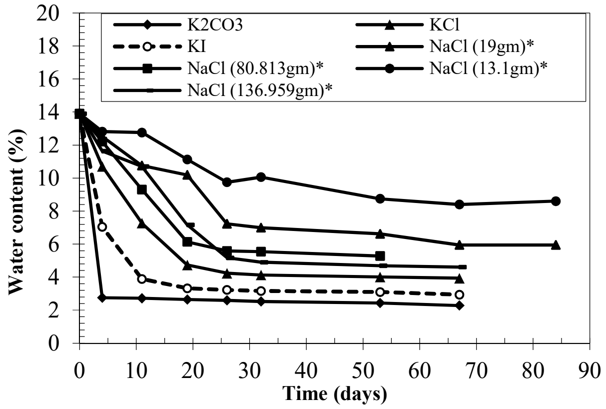

Fig. 1 Equilibration process of soil specimens under different salt solutions at 7 °C

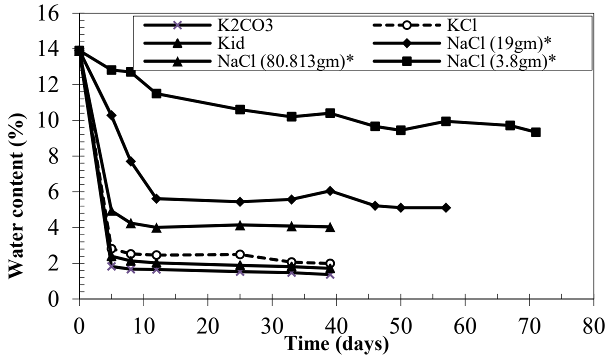

Fig. 2 Equilibration process of soil specimens under different salt solutions at 47 °C

TABLE II
SALT SOLUTION WITH CORRESPONDING SUCTIONS UNDER DIFFERENT TEMPERATURES AMBIENT

	Suction (kPa)	
Salt solution	7°C	47°C
K_2CO_3	104024	116293
KI	48035	58887
KCl	15405	32503
NaCl (136.959*)	8168	16800
NaCl (80.813*)	5158	6246
NaCl (38.266*)	1823	2984
NaCl (19*)	1169	1933
NaCl (13.10*)	765	815

*gm of NaCl for each 1000ml of water.

Volume changes experienced in soil specimens during suction measurements were traced using digital caliber with accuracy of 0.01mm, the results were presented along with suction under different temperatures.

III. RESULTS AND DISCUSSION

Test results obtained from the experimental work of SWRCs have been formatted in terms of gravimetric water content versus suction in Figs. 3 and 4. Fig. 3 presents the SWRCs for variable temperatures (7 and 47) for the mixture consisting of 15%-expansive clay (C15), while, Fig. 4 presents the SWRCs for the mixtures with 30% clay content (C30) at 7 and 47 degrees.

Looking at Fig. 3, SWRCs for C15 mixture underwent significant changes due to temperature variations. Specifically, at high range of suction (greater than 2000 kPa) the SWRC shifted downward as the temperature increased from 7 to 47 °C. In other words, at constant water content, the increase in temperature is associated with reduction in soil suction and consequently reduction in retention capacity. At this level of suction, the reduction of soil suction is mainly attributed to the phisco-chemical interaction and movement of water from micro pores (inter-aggregate) toward the macro-pores (intra-aggregate) with increasing ambient temperature [23], [5].

At low suction, the difference between SWRCs at different temperature tends to be marginal and all measured points converge to one curve excluding few odd points. This behavior indicates that at high moisture content the effect of temperature is low. Similar behavior also reported by [11], [3]. At this level of suction, retention capacity is governed by macro-pores and the capillary action is the most dominant mechanism.

When the clay fraction was doubled (C30), the effect of temperature on SWRCs was less significant at high suction range as shown in Fig. 4. This is in consistent with the literature presented for volume-change materials, such as [13] and [9] for mixtures of sand with 90-40 percent bentonite. [5] also reported that variation in suction with increase of temperature up to 60 ˚C is insignificant for bentonite material.

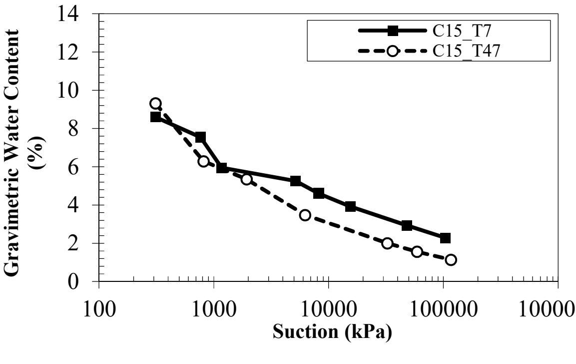

Fig. 3 Soil water retention curves of C15 under different temperatures

It is worth to state that, at low suction range the SWRC for specimens conducted at high temperature located slightly higher than other curves. This is also noticed in [5] for compacted bentonite when temperature was below 60 °C. Furthermore, increasing clay fraction showed significant changes in the shape of SWRCs, the bimodal shape of SWRC was noticed with two distinguished air-entry values (i.e., AEV1= 3000 and AEV2=17000 kPa). In the overall evaluation, the shape of SWRC is independent of temperature range considered in this study.

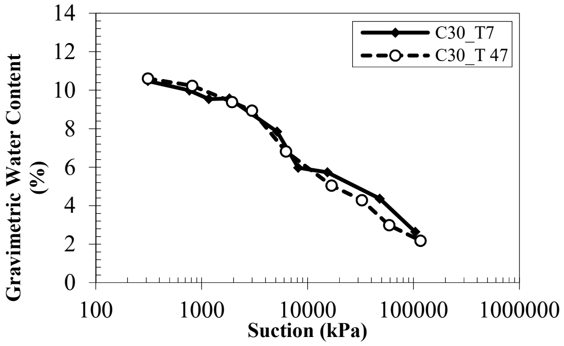

Fig. 4 Soil water retention curves of C30 under different temperatures

Volume changes observed during suction measurement for considered mixtures (C15 and C30) at different temperatures (7 and 47°C) are presented in Fig. 5 in terms of void ratio versus suction. The results in Fig. 5 indicates that the temperature has limited effected on the volume change of tested materials. Specimens tested at higher temperature induced more reduction in void ratio, this is clearer at C30 than C15, especially for C30 mixture.

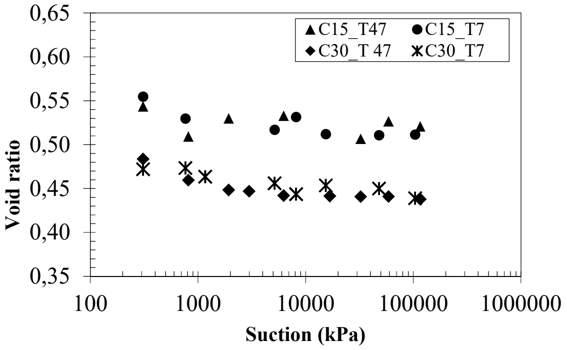

Fig. 5 Variation in void ratio versus suction for C15 and C30 under different temperatures

IV. Summary and Conclusions

The study was centered at investigating the retention capacity of sand-expansive clay liners under two different ambient temperatures, of 7°C and 47°C. Two mixtures were considered with 15% and 30% clay percent (C15 and C30). The measurement of SWRCs for liner mixtures was performed using different salt solution to cover the entire range of suction. Volume changes induced during suction measurement were recorded and evaluated.

The results obtained from this study indicated that the effect of temperature on retention capacity of SEC liners is suction-range dependent and more evident in the high range of suction. For C15, the SWRC shifted downward at high range of suction (greater than 2000 kPa) as the temperature increased from 7 to 47 °C, while, effect of temperature at low suction range was found low and marginal.

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