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# Suction characteristics of polymer-treated and untreated bentonite GCLs

## Caractéristiques d'aspiration des GCL de bentonite traitée aux polymères et non traités

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ABSTRACT: Geosynthetic clay liner (GCL) is widely used as a hydraulic barrier due to its low hydraulic conductivity, but wet and dry cycles caused by diurnal and seasonal temperature changes induce cracks and thus hamper the efficiency of the GCL. Under this situation, the sodium carboxymethyl cellulose treated bentonite (HYPER clay) GCL has demonstrated better performance against thermal gradients compared to untreated clay GCL. Therefore, it requires the study of the unsaturated behavior of the HYPER clay GCL and untreated bentonite GCL. The paper presents the water retention curves of the GCLs across continuous dry to wet and wet to dry paths measured by the AQUALAB water activity meter. Deionized and seawater were used as wetting solutions. The results showed that the HYPER clay GCLs have a high water retention capacity compared to untreated clay. In short, the improved performance of HYPER clay GCLs under wet and dry cycles is due to enhanced suction characteristics.

RÉSUMÉ : Le revêtement d'argile géosynthétique (GCL) est largement utilisé comme barrière hydraulique en raison de sa faible conductivité hydraulique, mais les cycles humides et secs causés par les changements de température diurnes et saisonniers induisent des fissures et entravent ainsi l'efficacité du GCL. Dans cette situation, la GCL de bentonite traitée à la carboxyméthylcellulose sodique (argile HYPER) a démontré de meilleures performances contre les gradients thermiques par rapport à la GCL d'argile non traitée. Elle nécessite donc l'étude du comportement insaturé de l'argile HYPER GCL et de la bentonite GCL non traitée. L'article présente les courbes de rétention d'eau des GCL sur des trajets continus secs à humides et humides à secs mesurés par le compteur d'activité de l'eau AQUALAB. De l'eau désionisée et de l'eau de mer ont été utilisées comme solutions de mouillage. Les résultats ont montré que les GCL d'argile HYPER ont une capacité de rétention d'eau élevée par rapport à l'argile non traitée. En bref, les performances améliorées des GCL d'argile HYPER sous les cycles humides et secs sont dues à des caractéristiques d'aspiration améliorées.

KEYWORDS: AQUALAB water activity meter; geosynthetic clay liner; HYPER-clay; water retention curves.

## 1 INTRODUCTION

GCLs have been mostly used as a barrier against fluids in the last two decades due to their efficiency in controlling the liquid flow. GCLs are typically manufactured at thickness of 5 to 10 mm at 5 to 40% water content, which may increase or decrease depending upon the humidity conditions of the surroundings during storage and shifting before its intended use. The GCLs must contain moisture content of 80 to 100% before it is laid on the subgrade so that it can act as a hydraulic barrier (Liu et al., 2015). Besides, over the life span of GCLs, they are exposed to many environmental factors such as wet-dry cycles and thermal gradients. (Take et al., 2014) reported that due to daily thermal change, the temperature went up to 70ºC when the GCL composite liner was exposed to solar radiation, whereas, in the case of brine and solar ponds, it is even more, at 90ºC (Yu and El-Zein, 2019, Rowe and Shoaib, 2017). The high temperatures associated with these ponds are due to the insulation of the lower convective zone of the ponds by the non-convective salt gradient zone above (Suárez et al., 2010). As a result of this, cracks develop due to poor water retention of GCLs, which results in the rise of hydraulic conductivity. Besides, the effect of the interacting solution cannot be ignored. It has been observed that the ionic solution has more detrimental effects on the GCLs' performance (Di Emidio et al., 2015). In brief, the initial deterrence of the cracks due to thermal gradients and type of solution is crucial for the efficient performance of the GCLs.

(De Camillis et al., 2017) investigated the effects of dry and wet cycles by using sodium carboxymethyl cellulose (Na-CMC) polymer-based bentonite called HYPER clay (HC) within GCLs. The authors found that the HC GCLs exhibited three orders of magnitude lower hydraulic conductivity as compared to normal GCLs after the fourth wet-dry cycle in seawater. The process of the wet and dry cycle involves unsaturated behavior of the GCLs and thus requires the study of water retention of the GCLs.

The water retention behavior of GCL is quite difficult to measure due to its composite nature and wide range of suction. Different methods have been developed to measure this retention behavior. Contact and non-contact filter paper methods are convenient to quantify the wide range of water retention behavior (Acikel et al., 2015, Risken et al., 2016). However, in the case of contact filter paper, the capillary breaks are more likely to occur when the filter paper is in contact with the carrier geotextile (Acikel et al., 2015). (Beddoe et al., 2010, Hanson et al., 2013) measured water retention curves by humidity or vapor evaporation technique, but the technique is time-consuming (Rouf et al., 2020). Moreover, relative humidity-based methods are deemed reliable only for the dry end of the water retention curve (Agus and Schanz, 2007). (Seiphoori et al., 2016) used the dew point method to investigate GCL's water retention under free swell conditions. The method was proven to be fast and measured a range of suction, i.e., from 20 kPa to 110 MPa. In addition, the authors reported that at suctions exceeding 2 MPa, the water retention behavior of the GCL was totally controlled by the bentonite.

As mentioned above, the water retention behavior of the typical bentonite GCLs has been investigated by many researchers. However, according to the authors' knowledge, the water retention curves of the polymerized clay GCLs have not been investigated yet. Thus, the present study aims to illustrate the difference in water retention of the typical and HYPER-clay based GCLs under non-ionic and ionic solutions.

## 2 EXPERIMENTAL ANALYSES

### 2.1 *Materials*

Sodium bentonite (UC) was used, which was treated with Na-CMC to prepare the polymerized clay according to the procedure adopted by (Di Emidio, 2010). The method consisted of mixing the UC with 8% Na-CMC by weight of UC in deionized water for 30 minutes in a mechanical stirrer to make a slurry. The slurry was dried in the oven for 16 hours. After drying, the mixture was ground to powder form and named HYPER clay (HC). The properties of UC and HC are shown in Table 1. (De Camillis et al., 2017) used the same UC and HC.

The UC and HC, prepared in the lab, were sent to Naue Company to manufacture the prototype needle-punched GCLs. The GCLs contain the layer of UC/HC sandwiched between the non-woven cover and woven carrier geotextile.

Deionized water (DW) and seawater (SW) were used as wetting liquids. The properties of both the liquids are shown in Table 2. The SW was the same as used by (De Camillis et al., 2017).

Table 1. Properties of sodium bentonite (UC) and HYPER clay (HC) (De Camillis et al., 2017)

| Property | *UC* | *HC* |
|---|---|---|
| Specific gravity | 2.66 | 2.25 |
| Liquid limit (%) | 649.7 | 988.8 |
| Plastic limit (%) | 48.3 | 157.2 |
| Plasticity index | 601.7 | 831.4 |
| CEC (meq/100g) | 70.17 | 87.56 |
| Exchangeable cations | | |
| $Ca^{2+}$ (meq/100g) | 43.25 | 39.73 |
| $K^+$ (meq/100g) | 1.52 | 1.85 |
| $Mg^{2+}$ (meq/100g) | 15.56 | 13.31 |
| $Na^+$ (meq/100g) | 40.28 | 62 |

Table 2. Chemical properties of deionized water (DW) and seawater (SW)

| Parameter | *DW* | *SW* |
|---|---|---|
| EC (mS/cm) | 0.014 | 44.8 |
| *pH* | 6.57 | 7.42 |
| $Na^+$ (g/m$^3$) | - | 11518 |
| $K^+$ (g/m$^3$) | - | 469 |
| $Mg^{2+}$ (g/m$^3$) | - | 1281 |
| $Ca^{2+}$ (g/m$^3$) | - | 478 |
| $Cl^-$ (g/m$^3$) | - | 19897 |
| $SO_4^{2-}$ (g/m$^3$) | - | 2352 |
| $HCO_3^-$ (g/m$^3$) | - | 183 |
| $CO_3^{2-}$ (g/m$^3$) | - | 18 |
| $NO_3^{2-}$ (g/m$^3$) | - | 43 |

### 2.2 *Methods*

The GCL was cut approximately according to the size of the sample cup (3.64 cm in diameter) as shown in Figure 1a. For the wetting path of the water retention curve, the sample cups were placed in the 30$^o$C oven and subsequently wetting liquids were added with the help of a sprayer. After the addition of the liquids, the samples were covered with a lid and left for the conditioning period. Every 24 hours, the water activity and temperature were measured with the help of the AQUALAB water activity meter (Figure 1a) until the last measurement approximated the preceding measurement. For each measurement, it took 5 to 10 minutes to achieve the equilibrium value in the water activity meter. Afterward, the additional liquid was added to the sample and the same procedure was repeated until water activity approached the value of 1.

For the drying path of the water retention curve, the samples were placed at room temperature for drying as shown in Figure 1b. Every 24 hours, water activity and temperature were measured. The suction was calculated from the water activity by using Eq. 1.

$$h = -\frac{RT\rho}{M}.ln(R_h) \qquad (1)$$

where, $h$ is suction in kilo Pascals (kPa), $R$ is the universal gas constant, which is equals to 8.31 Joule per mole kelvin ($J.mol^{-1}.K^{-1}$), $T$ is the temperature in Kelvin ($K$), $R_h$ is the water activity, $\rho$ is the density of water in kilogram per cubic meter ($kg/m^3$) at temperature $T$ and $M$ is the molecular weight of the water, which is equals to 0.018 kilogram per mole ($kg/mol$).

Two samples were used for each test in the case of the dry and wet curves. Besides, it is worth mentioning that the samples were allowed to swell freely in the vertical direction in the case of the wetting path, whereas in the case of drying, samples were free to shrink in all dimensions. Free swelling and shrinkage imply a change in the void ratio. Preferably, the void ratio should be kept constant while quantifying water retention curves since the decrease or increase in void ratio tends to shift the water retention curves upward or downward, respectively (Ghavam-Nasiri et al., 2019). However, due to considerable change in the voids of GCL's geotextile and swelling of the clay in GCLs, it is difficult to keep the void ratio constant, or otherwise, accurately measure the volume change of the water retention curve samples. Hence, the present study is limited to free swell conditions.

Lu et al. (2017) conducted tests under restrained, partially restrained, and free-swelling conditions. The authors demonstrated that the free swell condition absorbed the maximum amount of water, up to twice as much as the constant volume condition, and that all the water retention curves may lie between the fixed volume and free swell for the same sample.

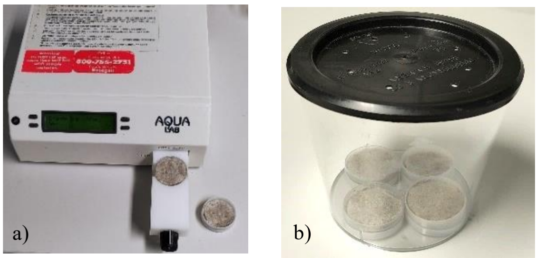

a) b)

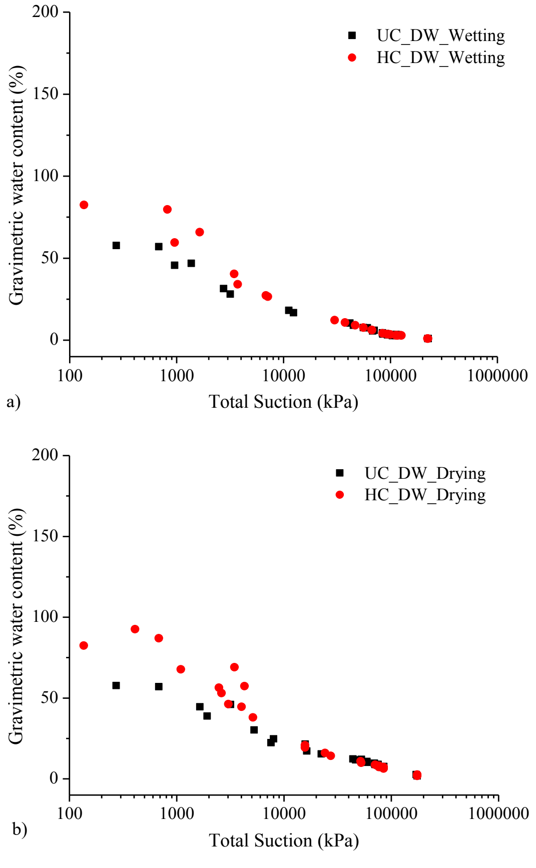
Figure 1. a) AQUALAB water activity meter along with sample in cup and b) samples placed for drying

## 3 RESULTS AND DISCUSSION

### 3.1 *Effect of clay type on the water retention curve of GCL*

The water retention curves for UC and HC GCL along wet and dry paths in DW and SW liquids are shown in Figure 2. The curves range from a maximum of 200 MPa to as low as 0.1 MPa. The figure presents typical water retention curves with suction decreasing with an increase in water content. Below 10 MPa, along both wetting and drying paths in DW and SW, the HC GCL curves shift upwards when compared to the UC GCL curve. However, for suction above 10 MPa, the trend is aligned for both UC and HC CGLs, depicting that the adsorption regime (Lu, 2016) is not being affected by the addition of the polymer. For the same suction, the water content is higher or for the same water content, the suction is higher in the case of HC GCL, thus, illustrating the higher water retention capacity of the HC GCL. The suction above 10 MPa is considered a tightly adsorbed regime where the water is tightly held to the particles and the mode of liquid flow is through evaporation and condensation. Below 10 MPa, the capillary regime is dominant and water flow occurs through the liquid phase (Tuller et al., 1999, Lu and Likos, 2004). Thus, the HC GCL can retain more water in the capillary regime.

The higher water retention of the HC GCL can be attributed to the type of polymer, as the geosynthetic type is the same in both the GCLs, when compared to the UC GCL. The Na-CMC is an anionic polymer that intercalates within the bentonite platelets and results in additional swelling (Di Emidio et al., 2010) and, ultimately, higher water retention.



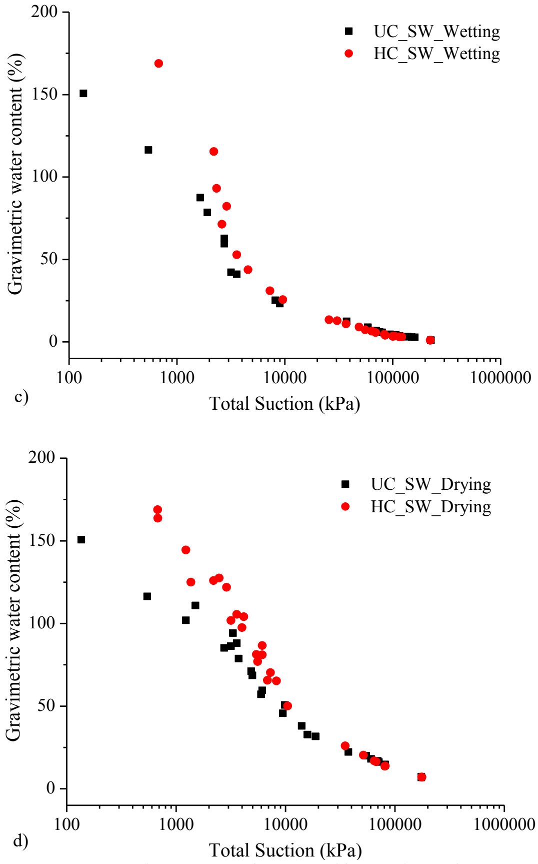


Figure 2. Water retention curves of untreated bentonite and HYPER clay along a) wetting path in deionized water, b) drying path in deionized water, c) wetting path in seawater, and d) drying path in seawater

### 3.2 *Effect of liquids on the water retention curve of GCL*

The effect of DW and SW on the retention curve is presented in Figure 3. The plot shows that the SW water retention curves of UC and HC GCLs diverge from DW along the wetting path from the beginning, and the divergence increases with the decline in the suction. The behavior is due to the increase in the osmotic suction because of the salt present in the seawater, which requires more water for the same suction as compared to DW.

By comparing the water retention curve along the drying path, a larger difference in DW and SW is depicted. The hysteresis effect is also observed between 1 MPa and 100 MPa in both UC and HC GCL samples. Typically, the hysteresis effect is primarily attributed to contact angle (Gao et al., 2021), but in the case of GCLs, the method of production and arrangement of geotextiles can have a substantial impact on the magnitude of hysteresis (Beddoe et al., 2011).

In both UC and HC SW retention curves, the hysteresis is more pronounced as compared to DW retention curves. This difference in hysteresis is due to the huge quantity of salts present in the drying curve samples compared to the wetting curve samples at the same water content. Since the drying curve samples were dried from a fully saturated state, the salts remained within the sample, but the water evaporated, which induced more osmotic suction (Miller and Nelson, 2006) in the drying curve samples than in the wetting curve samples. Subsequently, large hysteresis was observed in SW samples as opposed to DW samples.

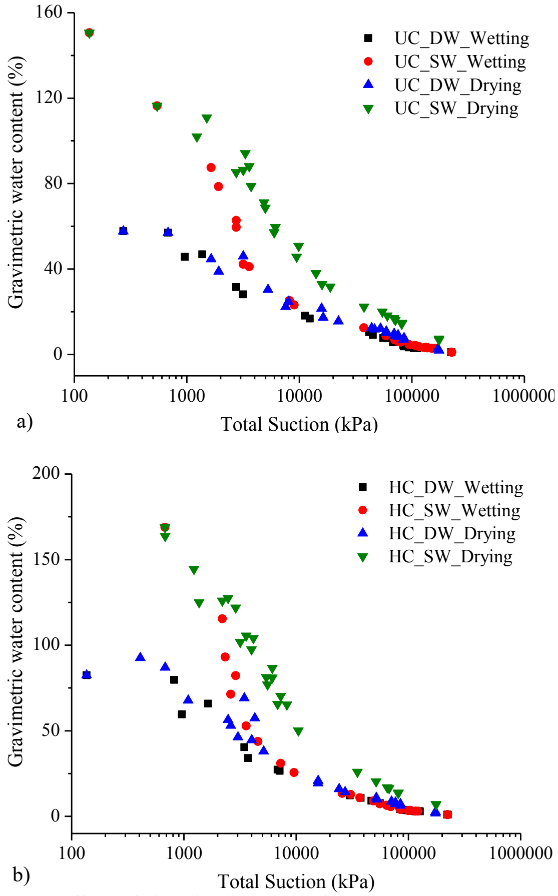


Figure 3. Effect of deionized water and seawater on water retention curves of a) untreated sodium bentonite and b) HYPER clay

## 4 CONCLUSIONS

The study aims to find the water retention curves of UC and HC GCLs. HC is a mixture of 8% Na-CMC polymer and UC. The results showed that the HC GCL has a higher water retention capacity below 10 MPa suction as compared to the UC GCL, which demonstrates higher water retention in the capillary regime due to the anionic nature of Na-CMC. However, the high saturated gravimetric water content of HC GCL as compared to UC GCL suggests representing the water retention curves in terms of degree of saturation or volumetric water content, but volume measurement in the case of GCLs is quite challenging. Therefore, a separate study is recommended to measure the water retention curve of the clays by keeping the volume constant. Besides, the higher ionic strength in seawater increased the osmotic suction of GCLs and thus enhanced the overall suction.

In short, the higher water retention capacity of HC GCL would provide better resistance against thermal gradients and hence act as a sustainable barrier, which would help in preserving underground water resources.

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