# Water retention curves of geosynthetic clay liners

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ABSTRACT: A typical geosynthetic clay liner (GCL) consists of a bentonite layer sandwiched between two geotextiles. The engineering function of a GCL is to act as a hydraulic barrier for leachate or other liquids and sometimes gases in solid waste landfill systems. As such, they are used as replacements for either compacted clay liner or geomembrane, or they are used together with the compacted clay liner and the geomembrane. The effectiveness of a GCL depends on the hydration of the bentonite layer during service. Normally the GCL is laid dry and is wetted by the underlying soil. Hence the water retention curve of the GCL is an important design parameter in a solid waste landfill system. The objective of this paper is to determine the water retention curve of one type of GCL using two experimental techniques. The water retention curve of the GCL at low suction showed more variability compared to the water retention curve of the GCL at high suction. The water retention curve of the GCL was found to be bimodal. The implication of the water retention curve on its application is also discussed.

## 1 INTRODUCTION

Geosynthetic clay liner (GCL) is an alternative to conventional compacted clay liner (CCL) in solid waste landfill systems (Figure 1). There are several advantages of GCL over CCL: it is fast and easy to install, have self-healing capabilities due to the swelling properties of the bentonite on wetting, more economical in locations where clay is not readily available, is thin (5-10 mm) compared to CCL (600-900 mm) and hence maximizes landfill capacity. In other solid waste landfill system designs, the GCL is used as replacement for the geomembrane, or it is used together with the compacted clay liner and the geomembrane.

The GCL typically consists of a layer of bentonite sandwiched between two layers of geotextile. The top geotextile layer is known as the cover layer while the bottom geotextile layer is the carrier layer. An important property of the GCL is its low permeability and thus it acts as a barrier to the leachate preventing it from flowing into the underlying soils. The GCL owes its low permeability to the bentonite that it contains. Generally, the bentonite in the GCL is in a loose form (~ 3 to 6 kg/m$^2$) and needs to be hydrated to form the barrier. The hydration depends on the water retention characteristics of the GCL.

The water retention characteristics of the GCL that is of interest spans from saturation to the as-rolled water content (~6-20%). Water retention curves (WRCs) of various GCLs have been determined by others (e.g. Daniel et al. 1993, Barroso et al. 2006, Southen and Rowe 2007, Bedoe et al. 2010, 2011). However, determination of the WRC of GCL is not simple as the bentonite is not confined, the range of suction for the WRC of the geotextile is small compared to the range of suction for the WRC of the bentonite, and the GCL is usually under some normal stress during service.

The objective of this paper is to examine the WRC of one type of GCL using capillary rise and chilled mirror hygrometer techniques and to discuss the implication of the GCL's WRC on its application.

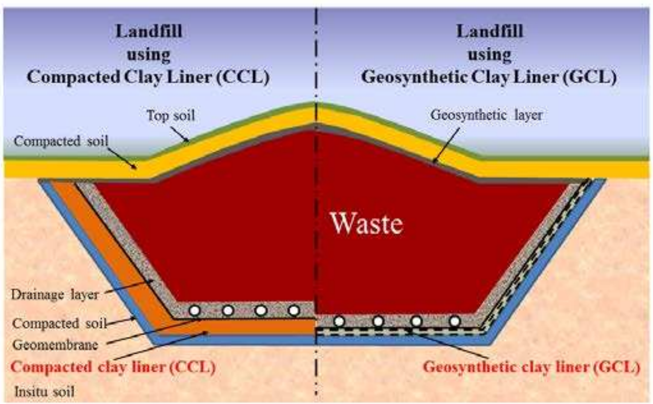


Figure 1. Schematic diagram of landfill systems using compacted clay liner and geosynthetic clay liner.

## 2 MATERIALS AND METHODS

### 2.1 *GCL*

The properties of the GCL used in the study as given by the manufacturer are shown in Table 1. The measured thickness of the GCL under 2 kPa stress ranges from 5.8 to 6.4 mm; the measured weight of the GCL ranges from 4138 to 4452 g/m$^2$; the water content of the as-rolled GCL ranges from 6 to 10%.

Table 1. Properties of GCL

| Property | |
|---|---|
| Montmorillonite content | ≥ 80wt.% (XRD) |
| Carbonate content | ≤ 1-2 wt.% |
| Bentonite form | Natural Na-bentonite |
| Particle size | Powdered (i.e., 80% < 75 μm) |
| CEC | ≥ 70 meq/100 g (or cmol/kg) |
| Free swell index | ≥ 24 ml/2g |
| Fluid Loss | ≤ 18 ml |
| Mass per unit area | ≥ 4200g/m$^2$ at w=0% |
| Thickness | ≥ 5.4 mm |
| Peel strength (N/m) | ≥ 360 |
| Static puncture strength | ≥ 1800N |
| Hydraulic Conductivity @ 35 kPa | ≤ 2 x 10$^{-11}$(m/s) |
| Cover nonwoven | ≥ 200 g/m$^2$ |
| Carrier woven (PP) | ≥ 100 g/m$^2$ |
| Powder sodium bentonite | ≥ 3700 g/m$^2$ at w = 0% |

### 2.2 *Water Retention Curve Tests*

#### 2.2.1 *Capillary rise tests*

Capillary rise tests were performed on strips of the GCL that were cut with a sharp knife. The dimensions of each GCL strip are 150 mm in width and 1 m in length. Two different initial conditions of the GCL strip were used in the tests, dry and wet. For the initially dry condition, the GCL strip was used at its as-rolled water content condition and for the initially wet condition, the GCL strip was wetted using a water spray. Each of the GCL strip was then wrapped with cling film to prevent the bentonite powder from falling out of the strip and to minimise evaporation during the experiment. The cling film at one end of the GCL strip was cut to allow water to enter the GCL strip. The GCL strip was then suspended at one end and the other end, where the cling film was cut, was immersed into a bucket of water. To keep the GCL strip taut, a small weight was hung at the end of the GCL strip. The GCL strips were left for either, 2, 4 or 7 days. After which, the GCL strips were removed and cut with a sharp knife at 1 cm intervals from the water level for water content determination.

A schematic diagram of the capillary rise test is shown in Figure 2.

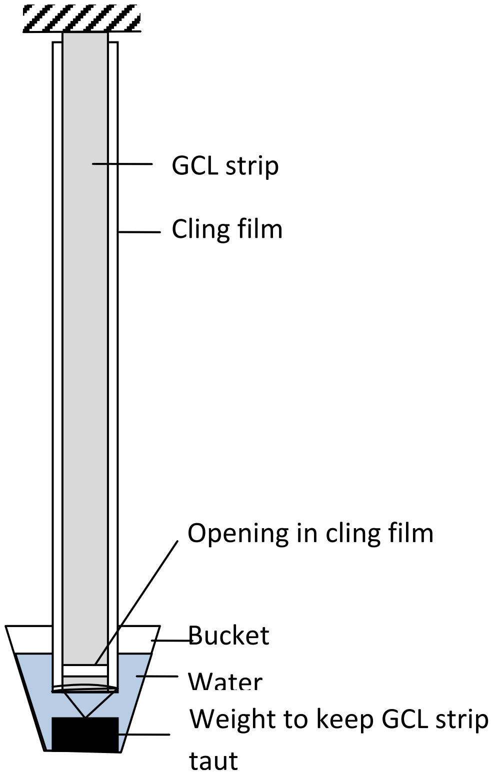


Figure 2. Schematic diagram of capillary rise test.

#### 2.2.2 *Chilled mirror hygrometer*

The chilled mirror hygrometer is listed in ASTM 6836-16 as method D. The chilled mirror hygrometer used in this study is the WP4C from Decagon Inc. The approach used in the test follows that described in Lu et al. (2017). The WRC of the GCL can be determined under either free swell or constant volume condition using a modified sample holder in the WP4C. Lu et al. (2017) found minimal difference between the WRCs of GCL under free swell and constant volume conditions due to the high internal mobilised confining pressure generated by the reinforcing fibres of GCL under the free swell condition. The constant volume condition was selected for this study. To apply the constant volume condition, a threaded perforated metal lid (1.5 mm thick) was added to the sample holder of the WP4C to allow wetting of the GCL specimen under constant volume condition as shown in Figure 3. More details about the modified WP4C sample holder and WP4C calibration can be found in Lu et al. (2017). The GCL specimen placed into the modified WP4C sample holder was 38 mm in diameter and was cut using a sharp knife.

The test procedures consist of injecting the GCL specimen with an incremental amount of distilled water using a syringe; storing it under sealed condition for 10 to 15 days to achieve moisture homogenization (Bouazza and Vangpaisal 2003); measuring the suction of the conditioned specimen using WP4C. For injection of distilled water, the penetration depth of the syringe's needle was limited to the thickness of the cover geotextile layer to keep the bentonite layer intact during the wetting process. The procedures of injecting, storing and measuring suction were repeated for the GCL specimen until the WRC was obtained. The gravimetric water contents of the GCL were in the range of 5 to 80%.

## 3 RESULTS AND DISCUSSION

### 3.1 *Capillary rise test*

The gravimetric water contents of the GCL strip at various heights above the water level are plotted in Figure 4. The matric suction above the water level is assumed to be hydrostatic. Results are shown for GCL strips after 2, 4 and 7 days. The initially wet GCL strips are indicated as drying and the initially dry GCL strips are indicated as wetting.

Generally, the wetting WRC of the GCL is below the drying WRC of the GCL. The WRCs of the GCLs showed that equilibrium was established for the 4 and 7 days tests. The hysteresis between the drying and wetting WRCs is small and the residual water content of 8 to 9% occurs at matric suction of about 0.5 kPa. The residual water content appears to be within the as-rolled water content of the GCL which ranges from 6 to 10%.

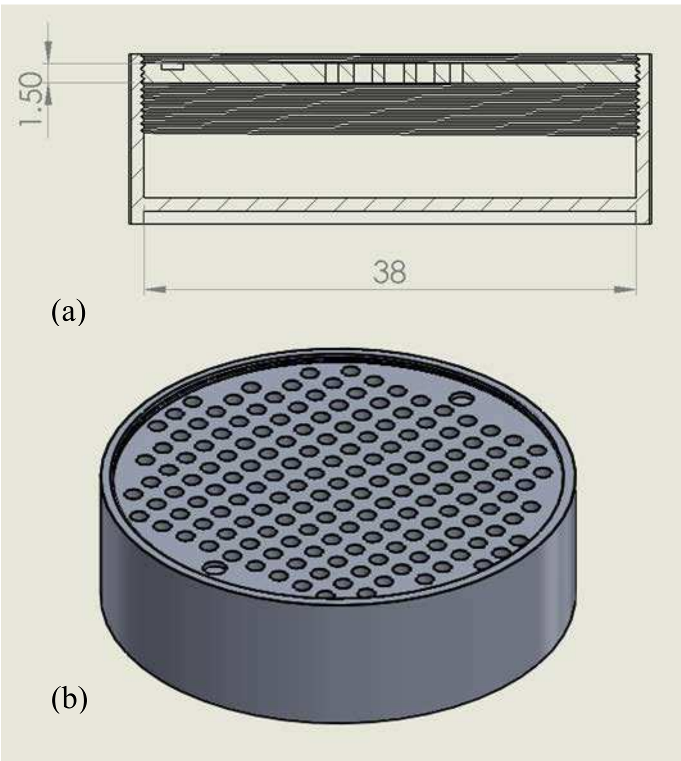


Figure 3. Schematic drawing of WP4C modified sample holder (a) cup cross-section (dimension in mm); (b) 3D view of the cup and lid (from Lu et al. 2017).

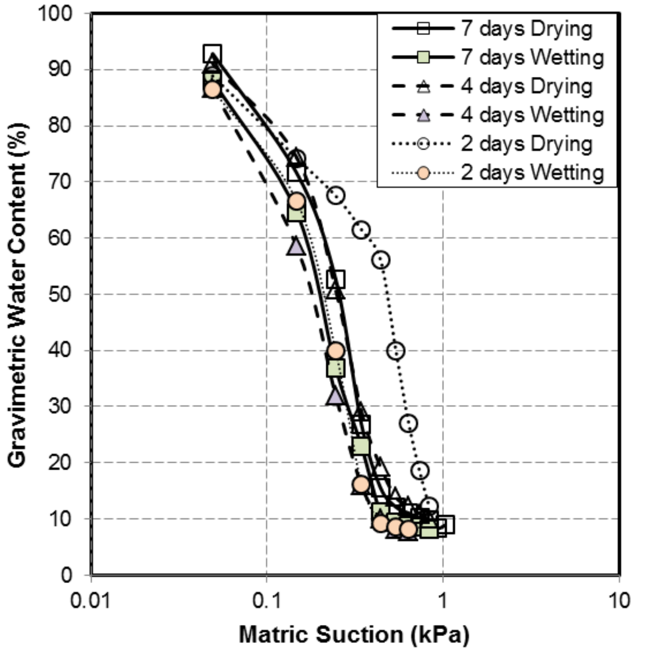


Figure 4. Capillary rise test results for initially wet and initially dry GCL strips.

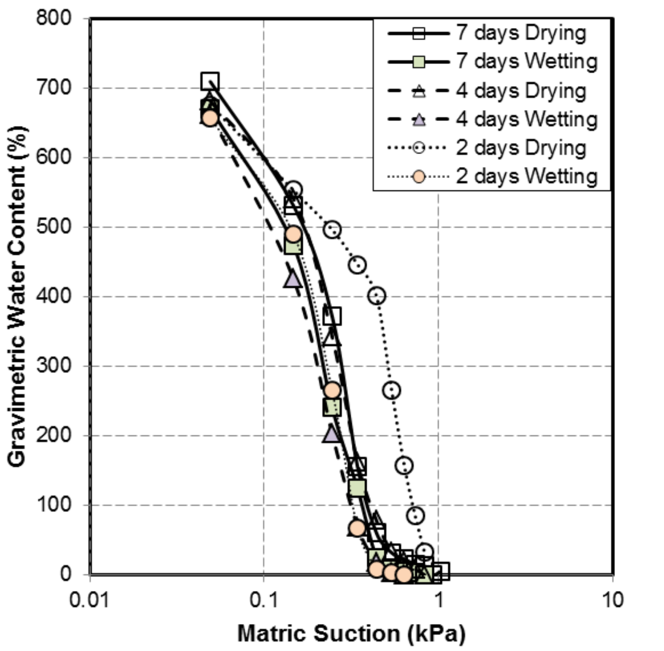


Figure 5. Water retention curves of cover and carrier geotextile layers calculated from capillary rise tests of initially wet and initially dry GCL strips.

If the residual water content is the as-rolled water content, the capillary rise tests appear to measure the WRC of the cover and carrier geotextile layers only. Hence, it is possible to obtain the WRC of the cover and carrier geotextile layers by considering that the bentonite layer is at the as-rolled water content at the equilibrium condition. Removing the contribution of the bentonite to the WRC, the calculated WRC of the cover and carrier geotextile layers are shown in Figure 5.

### 3.2 *Chilled mirror hygrometer tests*

The WRC of the GCL specimen obtained using the WP4C is shown in Figure 6. The WRC of free-swelling MX-80 bentonite granules from Seiphoori et al. (2016) is also shown in Figure 6 for comparison. The MX-80 bentonite consists of 85% Sodium Montmorillonite content, very similar to the bentonite in the GCL used in this study. The two WRCs appear to be almost identical except at gravimetric water contents greater than 40%. The deviation is due to the confinement of the bentonite in the GCL due to the geotextiles.

Comparing the WRC of the cover and carrier layers in Figure 5 with the WRC of the GCL in Figure 6, it can be concluded that the WRC of the GCL shown in Figure 6 is only that of the bentonite layer as the cover and carrier geotextile layers were completely dry at suctions greater than 1 kPa. Hence knowing the void ratio of the bentonite in the GCL, the saturated gravimetric water content of the bentonite can be calculated. The contribution of the cover and geotextile layers is removed from the WRC of the GCL in the same manner as described in the previous section. The WRC of the bentonite in the GCL is indicated by the shaded markers in Figure 6. For the GCL used in this study whose average dry density is 900 kg/m$^3$, the saturated water content of the bentonite is estimated to be about 110%. Thus, the WRC of the bentonite in the GCL can be obtained as shown by the solid curve in Figure 6.

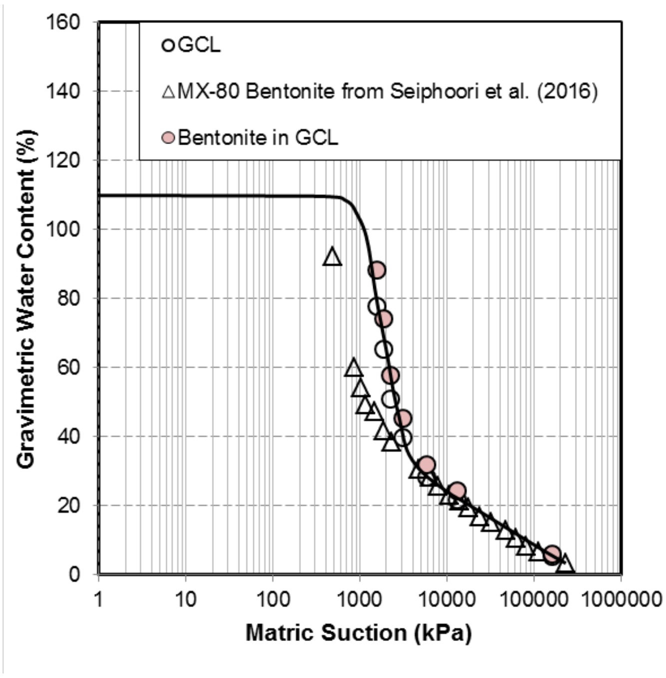


Figure 6. The WRC of bentonite in GCL.

### 3.3 *Water retention curve of GCL*

The GCL is a composite of three different materials: the cover geotextile, the bentonite and the carrier geotextile. Hence, the WRC of the GCL can be obtained as a superimposition of the WRCs of the cover geotextile, the bentonite and the carrier geotextile. The WRC of the cover and carrier geotextile layers and the WRC of the bentonite are shown in Figure 7. By considering their composition by dry weights per unit area of the GCL, the WRC of the GCL can be constructed as shown in Figure 7. The WRC of the GCL is bimodal.

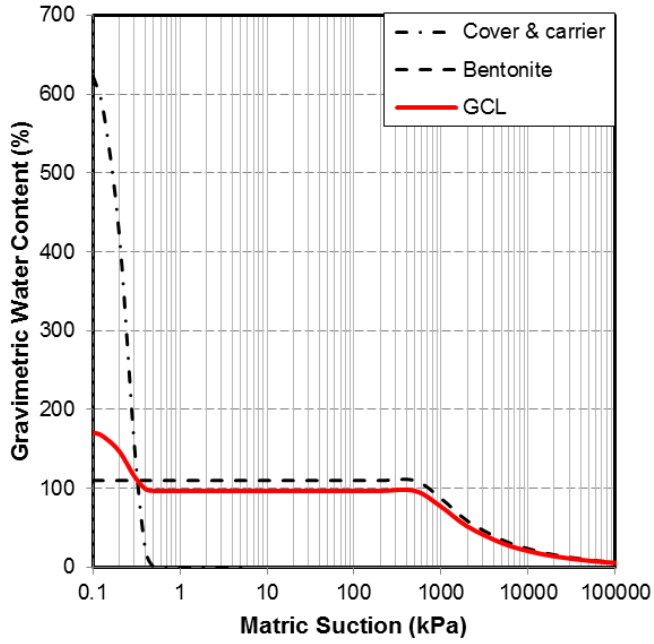


Figure 7. Deriving the WRC of GCL from superposition of the WRCs of the cover and carrier geotextiles and bentonite.

### 3.4 *Implications*

It is quite common to treat the GCL as a single material in determining its WRC. However, there is no single equipment that can measure the complete WRC of the GCL. In past studies, the WRC of the GCL at suctions less than 1000 kPa shows great scatter (e.g. Southern and Rowe 2007, Acikel et al. 2015) due to the difficulty in ensuring the uniformity of the GCL specimens, the possible variability of bentonite in the GCL geotextile layers, and the accuracy of the techniques used to measure the WRC in this suction range. It has been shown in this study that the capillary rise tests only give the WRC of the cover and carrier geotextiles while the chilled mirror hygrometer only gives the WRC of the bentonite. Ignoring the WRC of the cover and carrier geotextiles will effectively give the WRC of the GCL as unimodal. The cover and carrier geotextiles act to impede the flow of water and thus slow the hydration or dehydration process of the bentonite. In numerical modelling, the GCL is often treated as a single material whereas in reality, it is a three-layered system. When treated as a single material, the WRC of the GCL is essentially governed by the WRC of the bentonite as the cover and carrier geotextiles de-saturate completely at a very low suction. For the GCL in this study, the cover and carrier geotextiles de-saturate completely at a suction of 0.5 kPa. However, if it is needed to model the rate of water movement through the GCL, it is better to treat the GCL as a three-layered system.

## 4 CONCLUSIONS

The water retention curve (WRC) of geosynthetic clay liner (GCL) is an important design parameter in a solid waste landfill system. In this study, the WRC of one type of GCL was determined using two experimental techniques: capillary rise and chilled mirror hygrometer. Using only the chilled mirror hygrometer only gives the WRC of the bentonite and results in a unimodal WRC for the GCL. Incorporating the WRC of the cover and carrier geotextiles obtained in the capillary rise tests shows that the WRC of the GCL is bimodal. More research is needed to investigate the effect of treating the GCL as a three-layered system versus the effect of treating the GCL as a single layer system for different problems.


## ACKNOWLEDGEMENT

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