HANGING BAG TEST OF SLUDGE FILTER THROUGH GEOTEXTILES

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ABSTRACT

The study conducts hanging bag tests for understanding the filter behaviors of fine soil particles flowing through geotextiles. Four types of fine particles including reservoir sediment, sludge from sewage plant, river bed sediment and laterite are tested in this study. The study starts with jar tests to select the appropriate polymer coagulants. Different sizes of hanging bags composed of different geotextiles are subsequently used for fine particles filtering through. Moreover, the backwashing and refilling process is also conducted to study its effect on the filtering behaviors. During the tests, the flow rate, sludge water content and water quality of leachate are monitored. Some conclusions are reached from these tests. The hanging bag of multifilament plain weave geotextile retains sludge particles more than the hanging bag of monofilament geotextile does because the multifilament plain weave geotextile is characterized with a smaller pore opening ratio that provides more contact area with sludge particles. The water quality of leachate filtering through multifilament plain weave geotextile is better but the dewatering ability is worse because the clogging phenomenon is more significant. The dewatering effect for reservoir sediment and river bed sediment filtering through geotextiles is significant for the water content of the filter cake deposits in hanging bags reduces considerably. The water content of filter cake is even less than the water content of the sediment processed by belt press device. However, the dewatering effect for sludge from sewage plant filtering through geotextiles is poor for its fine particle has an affinity for water which is too strong to be expelled from gravity drainage. Geotextiles are functional to cleanse water quality of sludge as the suspended solid (SS) is reduced by more than 90 % while the chemical oxygen demand (COD) is reduced by about 75 % to 80 %. The backwashing process that pours water on the outer surface of hanging bags can break the sludge membrane that adheres on the surface of geotextile. Consequently, the service life of hanging bags can be prolonged to some extent. However, the effect of backwashing process is limited because the filter cake deposits in hanging bags basically remain there.

Keywords: Hanging bag test, geotextiles, polymer coagulants, flow rate, sludge

INTRODUCTION

The mountainous geography and young geology provide Taiwan a developing environment for the occurrence of landslides. Furthermore, most rivers in Taiwan are featured with steep gradient (average gradient is about 3 %). Therefore, significant amount of sediments are transported by rivers to deposit on riverbeds and reservoirs in lower reaches. The removal of sediments from riverbeds and from reservoirs is an important issue to economy, livelihood, and even disaster management. The sewage treatment process produces a lot of sludge. The dredge of sludge is also important to appropriate function of sewage plant.

The traditional approach to dredge sediments and sludge in Taiwan is to put them into a sediment pond to wait for subsidence by gravity. The sediments and sludge on the bottom of the pond is further processed by mechanical compression, solarization, or heating. The process is time and effort consuming. The sewage sludge and riverbed sediments contain high percentage of water between fine particles. Moreover, they usually contain high percentage of organic materials. These characteristics elucidate the key points, filtering and purifying, in removing riverbed and reservoir sediments, and sewage sludge efficiently.

In recent years, geotextile bag technology has shown much potential in accelerating dewatering. In general, geotextile tubes serve both functions of filtering and dewatering. The water content of sludge in the bag can be rapidly removed under the effect of hydraulic filling. This is extremely effective in separating and dewatering sludge with high water content and with pollutants. When assessing the performance of filling sludge filterng through geotextile, the hanging bag test results are superior to the material property of the geotextile or sludge itself. Gaffney (2009) indicated that the hanging bag test is typically conducted in the field, with the bag hanging on a prepared support and filled with a large amount of sludge. This allows for direct on-site observation. Following the clog of the apertures in the textile with the sludge, the filter cakes accumulate, and the weight of the sludge causes stress on the bag. The permeability of the bag changes over time.

If the hanging bag test results indicated that the processing efficiency was poor, some alternatives including adding chemicals to the sludge, changing geotextile type, or adjusting the geometry of the geotextile tubes could be considered. The main function of hanging bag test is to examine the compatibility between geotextile bag and filling sludge. Fowler (1994, 1996) pioneered the hanging bag tests in US Army Corps of Engineers at Vicksburg, Mississippi to assess the dewatering behaviors before putting the geotextile tube into practice application. Kutay and Aydeilek (2004) study the filtering behaviors of single-layer and double-layer woven and non-woven geotextiles by testing on fly ash mortar and harbor-dredged silt. The results of performing a series of pressure filtering and hanging bag tests reveal that virtually all geotextiles can successfully withhold more than 90 % of the mass. They also found that the existing filtering standards for most geotextiles fail to describe the fitering bahaviors of fly ash mortar and dredge silt appropriately. George et al. (2006) conducted hanging bag test on shoreline protection soil, dredged harbor sediment, and lagooned industrial ash against four geotextiles to assess the appropriate geotextiles for filtering different sediment. The technology of using geotextile tubes to accelerating dewatering and to filter sediments has been proved powerful for sludge treatment. This technology is especially of potential to replace the traditional approach to dredge the abundant sediments and sludge in Taiwan. The theme of this study is to conduct a series of hanging bag tests to understand more about the filtering behaviors of sludges against hanging bags. During the test, the changes in the permeability of the hanging bag-soil system; the changes in the sludge water content in the bag; the effect of purifying the water quality; and the influence of backwash and backfill in the bag on system usage lifespan are observed to identify the appropriate application of the geotextile bags for filtering sludge.

TEST MATERIALS

Four types of sludge of different grain size distribution and different pollutant content are used in this study. They are sludge produced by the National Chi Nan University sewage treatment plant, silt from the Shimen Reservoir in Taoyuan and sediment from the Nankang River in Puli and the laterite excavated from National Chi Nan University campus. The grain size distribution curves of these sludges are shown in Fig. 1.

It is noted that the grain size distributions of the test material range widely in this study because Weggel (2010)indicated that the gradation of sediment has effect on the behavior of sediment drain through hanging bags. For sediments of well gradation, it has a smaller porosity and drainage path, thus the drainage is worse. However, the sediments of poor gradation drain though hanging bag better because its porosity is larger.

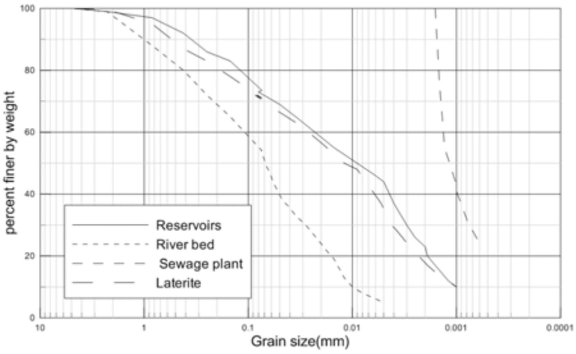


Fig. 1 Grain size distribution curve for sediments

In this study, the weight percentage concentration of sludge specimen is controlled to simulate its status in field. The weight percentage concentration is defined as the weight of solute (i.e., solid particles) divided by the total weight of solution (i.e., the sludge). The average weight percentage concentration in sediment ponds to receive the sediment retrieved from Shimen Reservoir is about 20%. The average weight percentage concentration in the digestion tank in sewage treatment plant at National Chi Nan University is about 2 %. The average weight percentage concentration for the sediment retrieved from Nankang River bed is about 24 %.. The weight percentage concentration of laterite specimen is controlled to be 20%.

Three types of woven geotextiles were used to weave into bags for sludge filtering through. These geotextiles are woven from polypropylene yarns. After being processed into slit strips, they are manufactured with circular weaving and coated with black carbon. They are denoted as W1 to W3 in this study. The fundamental properties of these geotextiles are listed in Table 1. W1 is a twill weave geotextile of round filaments and multifilaments in warp and weft directions, respectively. W2 is also a twill weave geotextile, but it is composed of flat filaments and round filaments in warp and weft directions. W3 is a plain weave geotextile of multifilaments in both warp and weft directions. The outlook of these geotextiles are shown in Fig. 2

Table 1 Fundamental properties of geotextiles

No.	Apparent open size O95 (mm)	Permeability (s^{-1})	Thickness (mm)	Danier in machine direction	Danier in cross-machine direction	Filament yarns/inch
W1	0.3	0.43	2.26	1300	2700	29×23
W2	0.2	0.49	0.41	1000	950	27×25
W3	0.075	0.46	1.70	3000	3000	34×10


W1

W2

W3
Fig. 2 Outlook of geotextiles

JAR TESTS

The jar test is a testing method that examines the effect of dosing and mixing process on coagulation, gelatinization, and precipitations of solutions. This test is common in waterworks and sewage treatment plants as a pilot test conducted in laboratory for the optimal effect of gelatinization and coagulation. It is becoming popular in hanging bag tests recently. For example, Worley (2008) used a chemical modifier aluminum sulfate and one polymer to accelerate the solid-liquid separation process to dewater lagoon sludge from dairy product factories. The polymer acts with sludge to form coagulation thus to decrease fitering time. The chemical modifiers also hold many organic pollutants in the bag. Satyamurthy and Bhatia (2009) applied the jar test technique before conducting the pressure dewatering test of silt filtering through five geotextiles. They found that adding polymers can resolve the problem of the frequent clogging of textiles, and decreases silt dewatering time. However, adding too much can also cause the opposite effect.

In this study, because the fundamental properties of each type of sludge are different, the jar test is also conducted to investigate the corresponding optimal type and additive amounts of polymer. The sludge is put into a graduate cylinder with the addition of different types and different amounts of cationic polymer powders. The cation sludge solution is rested for at least 24 hours allowing it to be fully hydrated. The optimal type and additive amount of polymer can be found according to the degree of coagulation, as shown in Fig. 3 The optimal polymer used in this study was white powdered polyacrylamide (PAM) with a molecular weight of approximately 7,000,000 and a specific gravity of 0.60 to 0.70. Its suitable pH range is 3 to 11. The optimal additive amounts estimated from the jar test results are shown in Table 2.

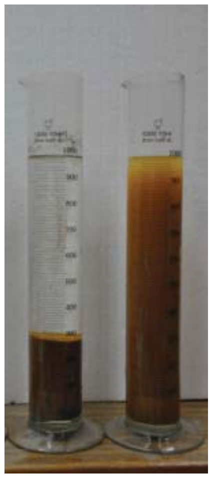


Fig. 3 Jar test results showing the comparison of laterite solution with the addition of different polymers.

Table 2. Optimal polymer additive amounts

sludge	Optimal polymer additive amount
Reservoir sediment	4 mg/L
River bed sediment	5 mg/L
Sewage plant sludge	8 mg/L
Laterite	3 mg/L

HANGING BAG TESTS

The hanging bag tests are performed according to the test standards proposed by the Geosynthetic Research Institute (GRI GT14 The hanging bag test for field assessment of fabrics used for geotextile bags, containers and tubes). The illustration of hanging bag test is shown in Fig. 4. In this study, three sizes of hanging bags are tested. To sew these hanging bags, the geotextiles of 43 cm x 35 cm, 50 cm x 50 cm, and 100 cm by 50 cm in width and length are used. The volumes for filling sludges of these hanging bags are 15 L, 40 L, and 80 L, respectively shown in Fig. 5. These sizes are termed as S1, S2, and S3, respectively.

Fig. 4 Illustration of the hanging bag test

Fig. 5 Hanging bags of different sizes

Before the test, the sludge is preprocessed by adding the appropriate amount of polymers. The well mixed sludge is then poured into the hanging bags. A half-transparent plastic container is put underneath the hanging bag to receive the sludge filtering out of the bag. During the test, the filtering process is filmed to record the test duration and volume of sludge flowing out of bags. The volume of sludge is indicated by the calibration marks on the container. As defined by the American Society for Testing and Materials (ASTM), permeability is the indicator for evaluating the water permeation capacity of a fabric and it refers to the degree of water conductivity of fabric per degree of fabric thickness as water passes through it. The system permeability (v, in unit of cm^3/sec) is defined as the volume (Q, in unit of cm^3) of sludge filtering through the bag during measured time range (t, in unit of sec).

The test is paused when geotextile bags are almost clogged by the mud cakes formed on the interior of the bags while few leachate is allowed to drain out of the bag. A backwashing process is then conducted by applying pressurized tap water on the periphery of the bags to break up the mud cakes inside. Another stage of hanging bag test of pouring sludge into bags and to measure the flow volume per unit time is resumed. The whole process of hanging bag test is terminated as there is few leachate flows out of the bag after one cycle of backwashing process.

After the test, the mud cakes retained in the bag is taken out for the measurement of moisture content. The water quality, specifically the suspended solids (SS) and chemical oxygen demand (COD) of leachate, is measured to investigate the effect of geosynthetic hanging bags on purifying the water quality of sludges.

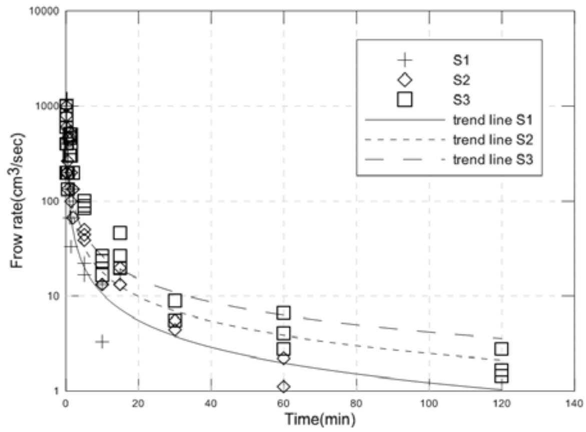
TEST RESULTS

The research focuses on performing hanging bag test to study how the sludge type, bags of weaving patterns, size of bags, and backwashing process on affecting the sludge filtering behavior and the water quality of the leachate. The test results are described in the following sections.

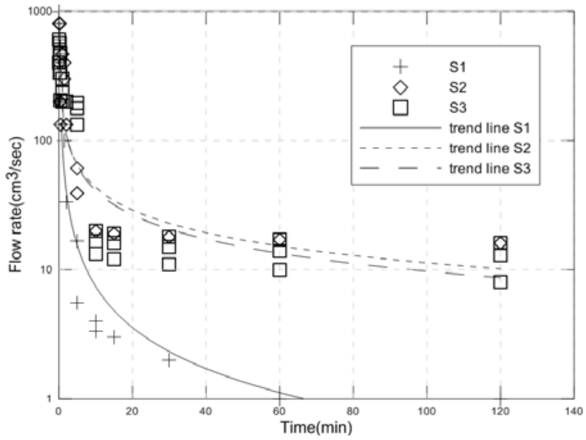
The Behavior of Sediment Infiltrating through Hanging Bag

Figure 6 shows the relationship of the flow rate of different sediments with changes over time. The relationship is generally similar for different sediments. The flow rate was very high (in the orders of 100s cm^3/sec) during the early stage of the test while it decays exponentially to order of about 1 cm^3/sec before almost no sediments infiltrates from hanging bag. This behavior is attributed to the shielding phenomenon produced by the filter cake accumulated on the interior perimeters of hanging bag. The filter cake is formed by the clogging of sediment particles on pores of geotextiles.

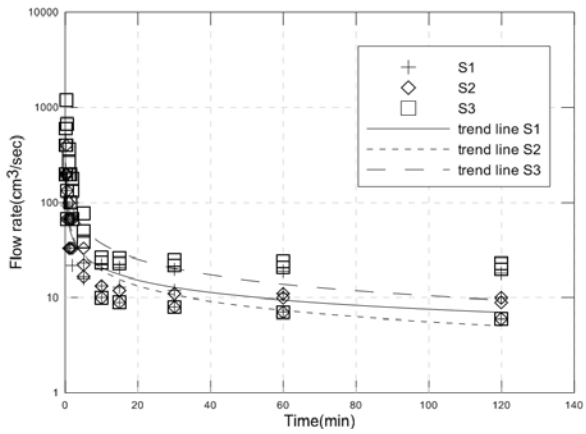
Sediment type is one factor affecting the infiltration behavior of the system. Obviously, compared with the other three types of sludge which lose most infiltration capability after two hours of hanging bag test, the sewage plant sediment remain an infiltration rate of about 10 cm^3/sec after two hours test duration. It is attributed to the water is trapped in a stronger interaction with the relatively small pores in sediments of sewage plant. The size of hanging bag is also a factor affecting the infiltration behavior. As the size of the hanging bag and the fill amount decreased, the infiltration capability of hanging bag tends to lose earlier. It indicates a larger bag could provide a better capability of sludge treatment if the procedure of infiltrating sludge though hanging bag is applied.



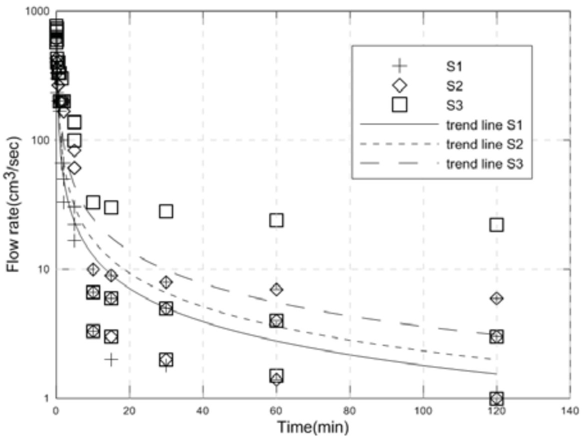
(a) Reservoir



(b) River bed



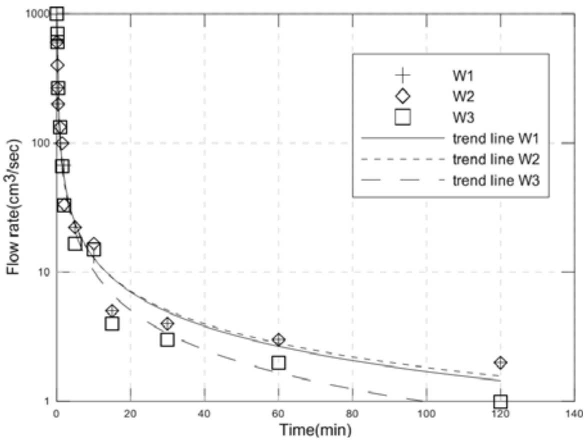
(c) Sewage plant



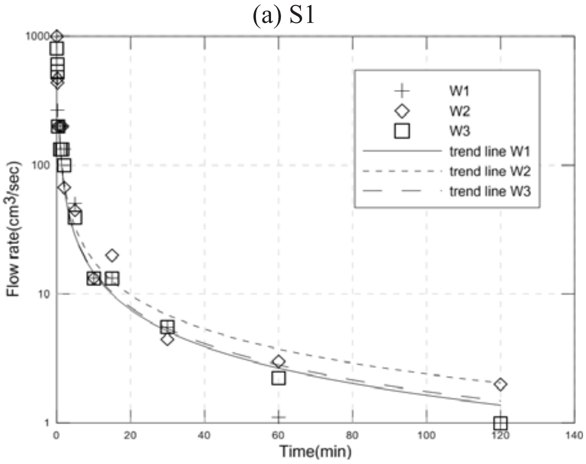
(d) laterite

Fig. 6 Drainage behavior for hanging bags

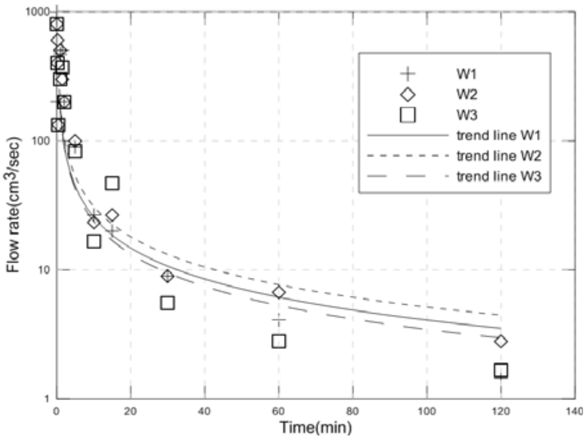
The influence of the weave type on the infiltration behavior is shown in Fig. 7 As seen from the change in the flow rate, weave W3, which is a multifilament plain knitted geotextile, decreases more dramatically faster than the other two types of monofilament weave do. It indicates that the geotextiles of more complex knitted and more filament structure will trap fine grains in sludge thus to form clogging in the apertures of hanging bag earlier.



(a) S1



(b) S2



(c) S3

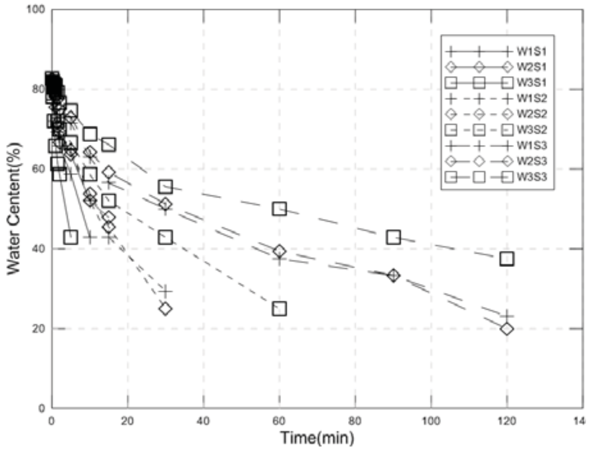
Fig. 7 Infiltration behavior for reservoir sediment through different type and size of hanging bags.

Sludge Water Content

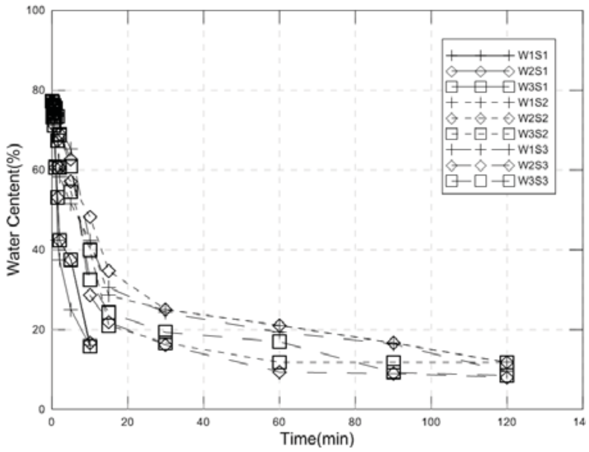
Because the leachate from the hanging bag test contains few solid components (detailed description will be present in next section), the water content of the sludge in hanging bag during test can be roughly calculated as the solid portion divided by the sludge volume retained in hanging bag.

The water content results of sludge for each test are shown in Fig. 8 As expected, the water content of sludge decreases as infiltration time increases. For reservoir sludge, the water content drops from 80 % to about 20-40 % in two hours, depends on the hanging bag size. As the size of hanging bag increases, the water content of the final filter cake decreases because the larger drainage gravity comes from the larger amount of sludge in a larger bag. The common range of water content for reservoir sludge after condense pond treatment is about 30-50 %. The dewatering effect is more obvious for river bed sludge. The water content for filter cake retained in hanging bag after two hours infiltration is in the range between 10 and 16 %. The dewatering effect is also similar for laterite sludge though the size of hanging bag does not have much effect on the water content of filter cake. In general, it indicates the hanging bag treatment is able to provide the dewatering effect for reservoir sludge and for river bed sludge. Another general trend is that the dewatering effect for hanging bag weaved from multifilament fiber (W3) is not as well as the hanging bags sieved from monofilament fiber (W1 and W2)

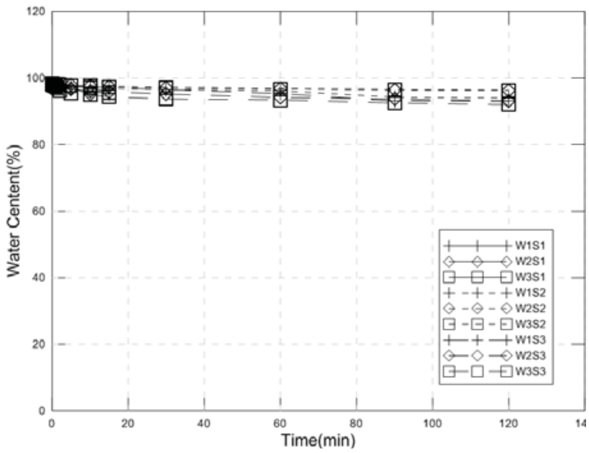
The effect of dewatering effect is not significant for sewage plant sludge. The water content remains more than 90 % even after two hours hanging bag infiltration. The common practice for the sewage plants in Taiwan use belt, plane, or frame press device to dewater sludge by the application of low operating pressure. The sludge water content after press dewatering is about 70 % to 80 %. It indicates the gravity drainage in hanging bag is not as functional as the pressure drainage to remove the water trapped in fine pores of sewage plant sediments.



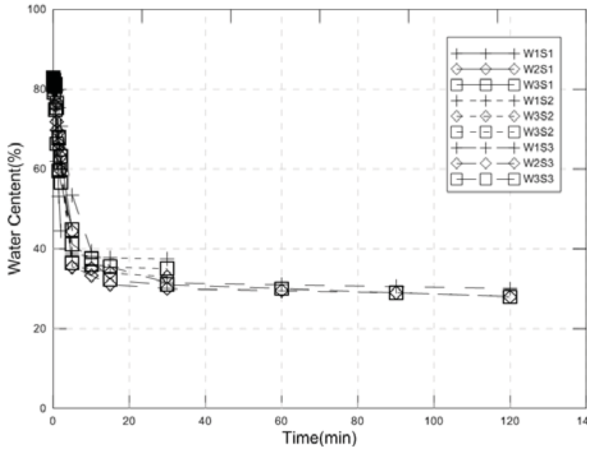
(a) Reservoir sediment



(b) River bed sediment



(c) Sewage plant



(d) laterite

Fig. 8 Water content of sediments retained in hanging bags.

Filtrate Suspended Solids Quantity

The suspended solids (SS) of leachate of sediments filtering through hanging bags are examined. The method of inspection follows NIEA W 210.50A standard. The test results of the SS for each leachate are plotted in Fig. 9 It indicates the leachate from W1 bags has a higher SS concentration. It is attributed from the fact that W1 owns a larger pore size and a weaker blocking function than other weaves thus more suspended solids can filter out of W1 bags. The SS concentration for sewage plant and for river bed sediments are higher because of their finer particle components infiltrate out of hanging bags. It is also noted that no matter what combination of sediment/bag infiltration system, the SS concentration of leachate is in the order of 0.1 mg/L. This concentration is much less than the standard for suspended solid of effluent water (30 mg/L) in Taiwan. The test results indicate the hanging bag leachate can meet even harsher regulation of effluent water.

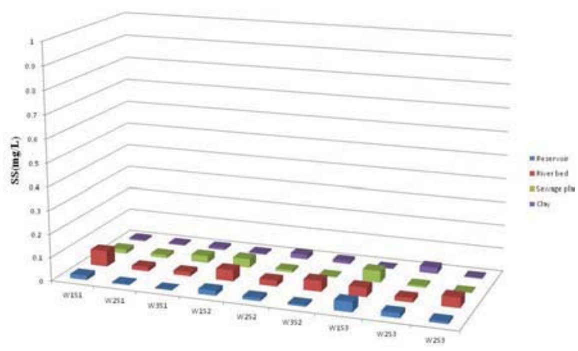


Fig. 9 SS concentration of leachate

Filtrate Chemical Oxygen Demand

Generally, when measuring the pollution caused by organic substances in the river bed and water treatment plant effluent, the chemical oxygen demand (COD) is an important indicator. Therefore, this study conducted COD test of the leachate of reservoir sediment, river bed sediment, and sewage plant sediment infiltrating through hanging bags. The test method for COD follows NIEA W515.54A.

Before adding polymer coagulator, the COD concentrations for reservoir sediment, river bed sediment, and sewage plant sediment are 200 mg/L, 350 mg/L, and 800 mg/L, respectively. Adding the polymer coagulator can generally remove half of the COD concentration, as shown in Fig. 10

The COD concentration for the leachate of reservoir sediment and river bed sediment ranges between 20 and 60 mg/L, it can meet the effluent water standard. There is about 17 % contaminant retained in the leachate. The removal rate is not affected by bag size. The COD concentration for the leachate of sewage plant sediment ranges between 90 and 150 mg/L. The water quality does not meet the effluent water standard though the removal rate through hanging bag is higher. There is about 12 % contaminant retained in the leachate.

This study indicates that the hanging bag has good ability in the removal of suspended solids. It is also functional in removing the pollution caused by organic substances by an amount of about 80%. For the sludge with high concentration of pollutants, such as sewage plant sludge, the leachate may not meet the regulation standard. However, for sludges of common extent of pollution, such as river bed or reservoir sludges, hanging bag infiltration is able to provide leachate clean enough to meet regulation standard.

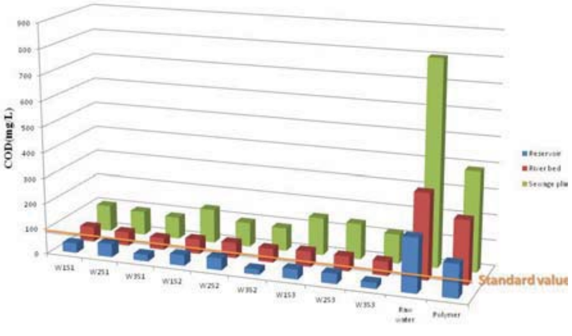


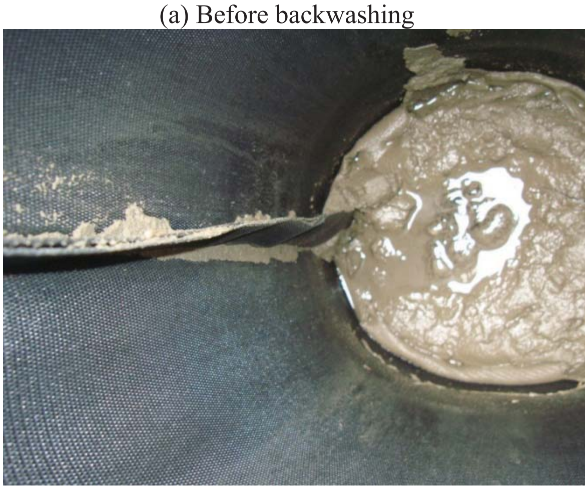
Fig. 10 COD data

Backwashing Process

A high pressure water jet is applied to backwash the exterior perimeters of the hanging bags that had been clogged and no infiltration allowed. The purpose of this procedure is to examine if the filter cake formed in the bag could be broken and thus increase infiltration capacity of hanging bag.

The test results indicate that for sediments of sewage plant, river bed, and laterite, the formation of filter cake is basically located at the bottom of hanging bag that make the bag a sagging shape. The backwashing process is not able to break the filter cake at the bag bottom though a large amount of fine grains infiltrate out of the bag. For reservoir sediment, a thin layer of filter cake is formed as a membrane on the interior and partly on the exterior perimeters of hanging bag. The backwashing process is able to break the filter cake, as shown in Fig. 11 Again, the bag can provide ability for infiltrating sediment and thus to extend its lifespan. However, the ability is not as good as original bag has because the filter cake formed at the bottom of bag is not able to be broken.

(a) Before backwashing



(b) After backwashing

Fig. 11 Interior perimeter of hanging bag for reservoir sediment

CONCLUSIONS

This study conducted a series of tests of sediments filtering through hanging bags. The following conclusions can be drawn from the test results:

1. A phenomenon of flow rate decreases at the early stage of the sediment filtering through hanging bag test. At the final stage, the filtering rate of the whole system soil is controlled by the type of sediment. For the sediment contains a large portion of fine particles (ex, sewage plant sediment), the clogging phenomenon is less significant thus it has a residual flow of about 10 cm^3/sec. The size of hanging bag also affects the filtering behavior. As the size of the hanging bag increases, the shielding phenomenon produced by the filter cake is relatively minor thus the filtering ability of hanging bag can last longer.
2. The type of geotextile is an important factor affecting the filtering behavior of sediment/hanging bag system. For hanging bag weaved from multifilaments geotextiles, it has a good capability for removing the sludge, and has a better capability for trapping grains due to larger contact area with the filer cake. This weave can filter smaller grains, but it results in the pores being easily blocked. The dewatering effect is not as significant as that weaved from monofilament though the plain weaved fine monofilaments will eventually twist into a wad to act as more compact gauze, during the filtering test.
3. Hanging bag is functional in removing suspended solids, while it is not so functional in removing COD of sediments. Even though the overall function in purifying sediment is not consistent, the water quality of leachate from different combination of sediment/hanging bag system is satisfactory to meet the regulatory standards.
4. The backwashing process can break the sludge membrane that adheres on the interior perimeter of hanging bag thus to extend the service life. However, the effect is limited because the filter cake deposits on the bottom of hanging bags basically is not broken by the backwashing process.
5. If a large amount of dewatering is required for reservoir and river bed sediment, the use of a monofilament plain weave geotextile is appropriate in terms of dewatering effect. Since sewage plant has a very strong affinity for water, the gravity-style dewatering procedure such as hanging bag infiltration cannot be solely operated.

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