Comparison of 1-D and 2-D geotextile dewatering tests with fly ash slurry

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ABSTRACT: Coal ash is one of the largest industrial waste products generated in the United States. Coal ash is commonly stored as a slurry form in impoundments. Due to new Environmental Protection Agency (EPA) regulation of coal ash disposal, coal ash slurry must be dewatered to dispose of the ash safely. Geotextile tube dewatering is an important and sustainable method of dewatering coal ash slurry. There are multiple testing methods that are used to evaluate the dewatering performance of geotextiles. These tests can range from a one-dimensional Pressure Filtration Test (PFT) to a pressurized two-dimensional test (P2DT). The P2DT test setup simulates a cylindrical geotextile tube, where axial and radial flows can be measured and collected separately. Since, 1-D is a common small-scale test for researchers, a comparative study has been carried out to evaluate the difference in flow rate, filter cake properties and turbidity of filtrate in 1-D vs. 2-D dewatering tests. For this purpose, one monofilament/fibrillated tape yarn woven geotextile and one composite geotextiles were used, and 10% solid content was used with conditioned and unconditioned fly ash in both 1-D and 2-D tests. Based on the results it was found that the dewatering behavior of both geotextiles were almost similar in 1-D test. In 2-D test, a variation in dewatering rate and quality of the filtrate were noticed for both geotextiles, which represents the dewatering behavior of a geotextile tube. However, the average solid content of the filter cake for both tests was in similar range.

Keywords: geotextile, fly ash, geotextile tube, 1-D PFT, 2-D pressurized dewatering test, polymer, flow rate, filter cake, turbidity

1 INTRODUCTION

Coal ash is an industrial waste product from coal-fired power plants. Approximately 134 million tons of coal ash products (coal combustion residuals) were produced in the United States in 2009, which includes 63 million tons of fly ash (American Coal Ash Association). According to US EPA, in the US alone approximately 1600 coal ash impoundments are in active operation and almost 670 inactive impoundments contain coal ash slurry (US EPA, 2010). The failure of two coal ash impoundments at Kingston, Tennessee in 2008 and Eden, North Carolina in 2014, led to the passage of a final rule on the disposal of coal ash from electric utilities by the United States Environmental Protection Agency (the Coal Ash Management Act, 2014). The legislation proposed by the EPA led to either termination of all wet-disposal surface impoundments or ensure proper safety criteria with providing liners for both existing and new impoundments. The new regulation and voluntary safety measurement has led to an increased need for coal ash impoundments to be dewatered in USA.

The handling and transport of coal ash slurry requires an efficient process called dewatering, by which liquid is removed from the slurry to improve the percent solid content. Dewatering leads to weight and volume reduction of slurry, contributing them more easily transportable and disposable. The drawbacks of using mechanical presses and centrifuges includes high cost and long-term maintenance. Geotextile tube dewatering technologies have been used to dewater fly ash slurries recently. This method offers low cost handling and transporting of wet disposal fly ash and allows to reuse in the future engineering applications.

Geotextile tubes are large containers (1-10 m in diameter) made of high-strength polymeric woven and nowoven geotextiles. Geotextile tube dewatering is a technology in which the slurry is pumped hydraulically into a tube or series of tubes to release clean water and increase the solid content in the tube. The geotextiles used for the tubes should be permeable enough to drain the filtrate quickly and efficiently. Geotextile tubes are easy to transport from one place to another and significantly more economical and practical than mechanical systems (Lawson CR., 2008). Geotextile tube dewatering technology has already been applied successfully in dewatering coal ash slurry and many other waste slurries and sludges (Fowler et al., 2005, Watts et al., 2009). For a successful dewatering performance of geotextile tubes, three requirements must be addressed; the sediment slurry pumped into the tube should dewater efficiently, the retained sediments should have high solid content, and the filtrate should have minimal turbidity. To increase the dewatering rate and to ensure the fine sediments retention in the tube, synthetic flocculants are often used (Satyamurthy and Bhatia 2009, Koerner and Koerner 2010, Maurer 2011, Yee et al. 2012, Khachan et al. 2012). Synthetic flocculants are used to enhance the formation of flocs, therefore, decrease the dewatering time and improve sediment retention. Generally, three kinds of flocculants are used, including cationic, anionic and nonionic polyacrylamide (PAM)-based flocculants. The cationic flocculants are the most commonly used as flocculants because of the negatively charged nature of soil.

Geotextile tube dewatering performance is often evaluated by a range of small scale and medium scale lab or field tests. These tests include one-dimensional Pressure Filtration Test (PFT), two-dimensional Pressurized Dewatering Test (P2DT), three-dimensional tests including Hanging Bag Test (HBT), Geotextile-tube Demonstration Test (GDT) and Pressure Gravity Dewatering Test (PGDT). Although medium scale tests (HBT and GDT) can provide most information on dewatering rate, quality of effluent, final solid concentration, and effectiveness of chemical accelerant treatment (Gaffney, 2001), they are time consuming and require large volume of slurry (Koerner and Koerner, 2006; Grzelak et al. 2011). These tests can be performed both in the field and laboratories. Small scale tests include PFT and 2-D dewatering test (Driscoll et al. 2016, Ratnayesuraj 2017), which are time efficient and require only 0.5 to 5 liters of slurry volume. 2-D dewatering test has been recently described at Syracuse University which can evaluate both radial and axial flow together (Ratnayesuraj and Bhatia, 2018). This test is a convenient way to predict the performance of geotextile tube dewatering behavior in the field. Based on the results from 2-D dewatering test, it is possible to predict the performance of large scale test such as GDT (Ratnayesuraj and Bhatia, 2018).

Since, PFT is still the most common small-scale test performance, which is a 1-D dewatering test, a comparative study has been carried out to evaluate the difference in flow rate, filter cake properties and turbidity of filtrate in 1-D vs. 2-D dewatering tests. For this study, one monofilament/fibrillated tape yarn woven geotextile and one composite (a combination of woven and non-woven) geotextile were used, and fly ash (C) was used as sediment for dewatering.

2 EXPERIMENTAL INVESTIGATION

2.1 *Fly ash*

A dark gray color with a very powder-like texture fly ash (C) was used in this study. Table 1 shows the properties of fly ash (C).

Table 1: Properties of fly ash

	D_{10} (mm)	D_{15} (mm)	D_{30} (mm)	D_{60} (mm)	D_{85} (mm)	C_u	C_c	G_s
Fly Ash	0.0125	0.016	0.059	0.09	0.28	7.2	3.09	1.95

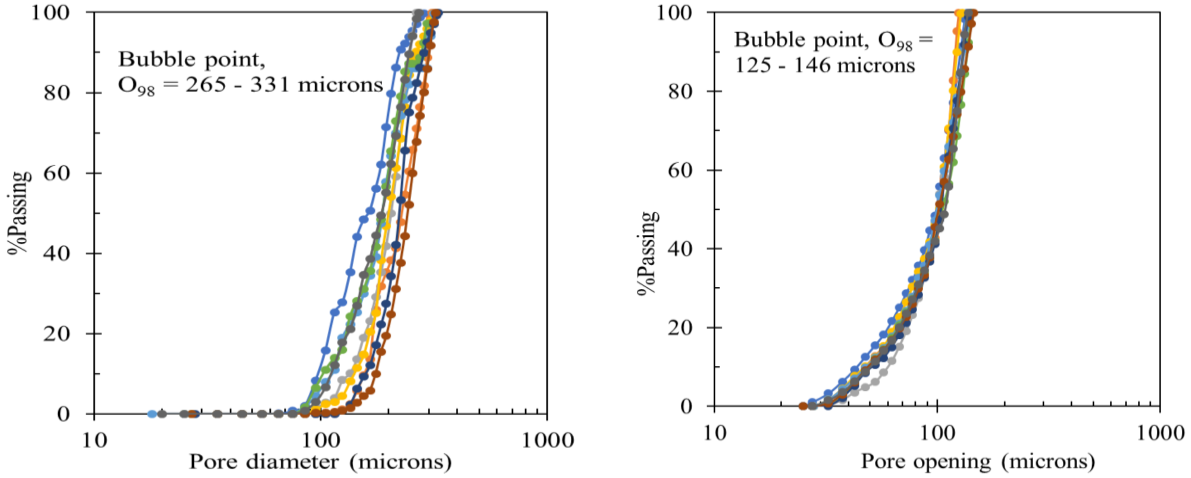
2.2 *Geotextiles*

The selected geotextiles include a monofilament/fibrillated tape yarn woven, high strength polypropylene geotextile (W) and a composite (a combination of woven and non-woven) geotextile (GC). Both geotextiles have been produced by geosynthetic manufacturers for geotextile tube dewatering applications for slurries. The mass per unit area and pore openings (bubble point, O_{98}) were measured following the ASTM Standards D5261-10 and D6767-16 respectively (Fatema, 2017). Table 2 provides the physical and hydraulic properties of the selected geotextiles. Capillary Flow Test was used to measure the bubble point (O_{98}) of both geotextiles. The pore size distribution of both geotextiles is plotted in Figure 1 (a and b). Figure 1 shows that woven geotextile has more variation in the pore size distribution compared to the composite geotextile. The woven geotextile has larger pore sizes as compared to the composite geotextiles, but similar permittivity. However, composite geotextiles have higher mass per unit area and thickness compared to woven geotextiles (see Table 2).

Table 2: Physical properties of geotextiles (Fatema, 2017)

Geotextiles	Weave type	Manufacturing process	Measured Mass/Area (g/m^2)	Measured Thickness (mm)	Permittivity* (sec-1)	Measured Bubble Point O_{98} (microns)
W	Monofilament	woven	308-408	1.04-1.24	0.37	265-331
GC	Geo-composite	combination of non-woven and woven	534-601	2.84-3.37	0.45	125-146

*Collected from the manufacturers



(a)W (b) GC

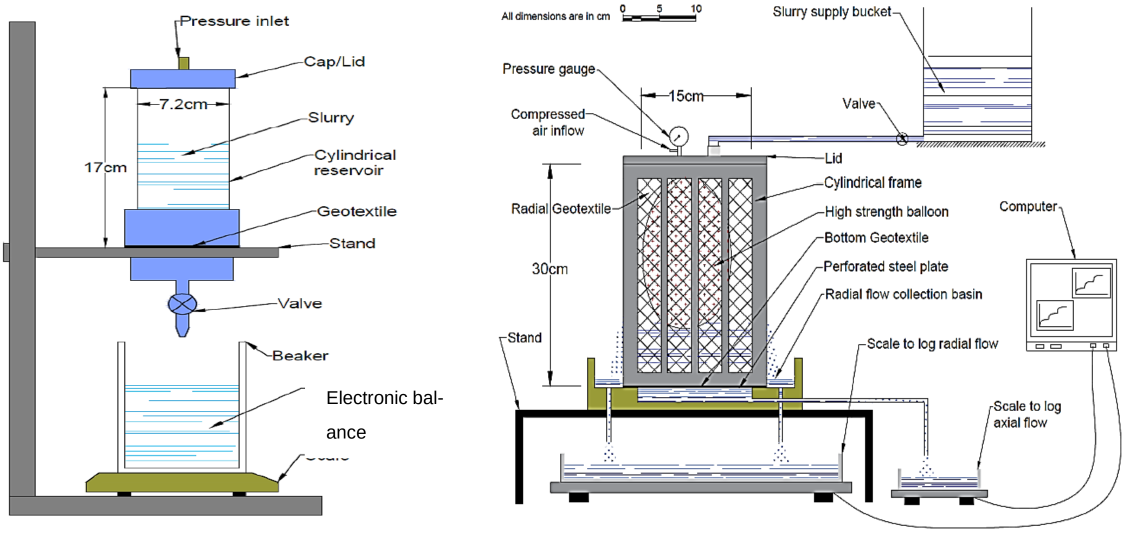
Figure 1: Pore size distribution of geotextiles (a) Woven geotextile (W), (b) Geo-composite (GC)

2.3 *Dewatering tests*

In this study, both 1-D and 2-D dewatering tests were performed.

2.3.1 *1-D pressure filtration test*

1-D Pressure Filtration test (PFT) apparatus consists of multiple parts, including a cone on the bottom with a stopper valve, a cylindrical reservoir (72 mm diameter and 170 mm height) that screws into the cone, a perforated steel plate and a pressure cap, which is screwed into the cylindrical reservoir and connected to a pressure hose (see Figure 2(a)). This test was described in detail by Khachan (2016). The perforated steel plate was first placed into the cone portion, followed by a geotextile cut to 8.5 cm in diameter. An electronic balance is connected to a laptop, and beaker to collect the filtrate. Before conducting this test, a fly ash slurry is made, and the geotextile is saturated with distilled water to ensure spontaneous flow of fluid. This test was performed using a slurry with 600 mL of water mixed with 68 grams of fly ash. This mixture created a slurry of 10% solid. The slurry was mixed using a jar tester that was set at about 210-220 rpm, for 3 minutes. After the slurry was fully mixed, it was poured into the cylindrical reservoir immediately and the valve was remained closed until the filling process was done. The pressure cap was then screwed on quickly and the pressure hose was attached, and the valve was opened. The pressure was set to 10 kPa. The effluent was measured in grams at 5 second intervals until the filtration was complete. The turbidity measurement was taken at the end of the filtration process for the entire filtrate volume. After the filtration process was completed, the filter cake was removed very carefully and the weight of both filter cake and filtrate were measured using an electronic balance. The filtrate and filter cake were placed in the oven for 24 hours. Using the dewatered weight and filter cake weight before and after drying, solid content of the filter cake was calculated.



(a) (b)

Figure 2: (a) Pressure Filtration Test Apparatus, (b) 2-D Pressurized Dewatering Test Apparatus

2.3.2 *2-D pressurized dewatering test*

The equipment used in the 2-D test consists of a cylindrical frame with an internal diameter of 15 cm and an internal height of 30 cm (see Figure 2(b)). In 2-D test, two pieces of geotextiles, a 20-cm diameter geotextile used at the bottom of the equipment for axial flow and a 58-cm by-36 cm geotextile bolted inside the cylindrical frame, were used. To secure the bottom geotextile, a perforated steel plate was used under it. Before starting the test, the geotextiles were saturated properly with tap water to ensure a continuous flow during the test. A high capacity (400 liters) balloon (Party Magic USA, L36-56729-3) was used to pressurize the slurry and promote the dewatering rate using 10kPa pressure. Since the balloon will be floating on top of the slurry and it is allowed to be inflated at the end of the filling phase, the balloon will not affect the dewatering behavior during the filling phase. Rubber gaskets were used to prevent any possible leakage through any connection. The further details of the experimental setup and test equipment can be found in Ratnayesuraj (2017). For the test, 3599 ml water was mixed with 400 gm fly ash to form fly ash slurry. After the mixing was completed, the slurry was poured into the system and the valve was remained closed until the filling process was done. After the filling process was completed, the pressure cap was open and 10 kPa pressure was applied. The dewatering was allowed to continue until no further axial or radial flow was measured. The axial and radial flows were measured using A&D EW-12KI and A&D FG-200KAL respectively, and flow ratio (a ratio of radial flow and axial flow) was measured for all geotextiles. The turbidity was measured after the end of the test of the filtrate of radial flow and axial flow separately. The filter cake was removed carefully, and the weight of filter cake and entire filtrate was recorded. The filtrate and filter cake were placed in the oven for 24 hours. Using the dewatered weight and filter cake weight before and after drying, solid content of the filter cake was calculated.

3 RESULT

Both 1-D pressure filtration and 2-D dewatering tests were conducted with fly ash slurry with and without polymer. The dewatering tests without polymer resulted in high fly ash loss (17% - 29%) and high filtrate turbidity (4149-99999 NTU) for both geotextiles. The high turbidity was due to the high fly ash loss during tests. Therefore, polymer was added to make the flocculated slurry to improve the fly ash retention and to reduce the turbidity of the effluent.

3.1 *Optimum dose of the flocculant*

The polymer used in this study was the Solve 137, a cationic polyacrylamide. The polymer was at 0.5% concentration of polymer. The optimum dose of the polymer was found by mixing a soil slurry of 500 mL of distilled water with 56 grams of fly ash and a dose of polymer. The polymer was mixed into the fly ash water slurry at 1 mL intervals, up to 5 mL. The polymer and fly ash were mixed by a jar tester at about 180-200 rpm for 1 minute. Then, the fly ash was allowed to settle for 30 seconds. After the settling, a supernatant sample was taken from the beaker using a syringe and placed into a vial for turbidity measurement and allowed to settle another 30 seconds in the vial. The turbidity of the sample was then measured using a Hach 2100N Turbidimeter. The optimum dose of Solve 137 polymer was measured to be 2.3 mL, 21.81 ppm for the 500-mL fly ash slurry. The optimum dose was then converted to 22.89 ppm for the 620-mL slurry (2.85 mL optimum dose for 1-D PFT) and 3750 mL slurry (17.25 mL optimum dose for 2-D dewatering test) used in both 1-D and 2-D tests.

3.2 *1-D dewatering test*

The test procedure in terms of with and without is same. However, for 1-D test with polymer, after mixing the slurry for 3 minutes the optimum dose of the polymer for a 620-mL slurry, 22.89 ppm was added, and then it was mixed for another minute. After the slurry was fully mixed, it was poured into the cylindrical reservoir and the test was started. Similar to the test without polymer, turbidity of the entire filtrate, fly ash loss and solid content of the filter cake were calculated.

3.3 *2-D dewatering test*

In 2-d dewatering test with polymer, 3599 ml water was mixed with 400 gm fly ash to form fly ash slurry and 22.89 ppm Solve-137 polymer was mixed properly into the slurry. After the mixing was completed, the slurry was poured into the system and the test was started. Similar to the test without polymer, turbidity of the radial and axial filtrate, fly ash loss and solid content of the filter cake were calculated.

3.4 *Comparison of results between 1-D and 2-D tests*

Both 1-D (PFT) and 2-D (P2DT) tests were conducted with unconditioned fly ash. It was found that a major portion (17%-29%) of unconditioned fly ash piped through the both geotextiles. Therefore, the optimum dose of a cationic polyacrylamide was used in the further tests to retain fly ash. Tests were performed with fly ash slurry (10% solid) and both types of geotextiles. The effect of polymer and filter cake properties were evaluated. In Figure 3, the dewatering rate results from PFT were plotted as effluent volume (% of total slurry volume) vs. dewatering time (min) for both woven and composite geotextiles. Those results indicated that most of the dewatering was completed for both geotextiles within 2.5 minutes. Since polymer was added to the slurry, larger particle sizes (flocs) were formed which results into faster dewatering time. The variability in the dewatering rate of woven geotextile is noticed in Figure 3, which is due to the variation in pore size distribution of woven geotextile. The dewatering rate of composite geotextile was recorded as more consistent. Figure 3 shows that almost 90% water came out from the slurry through both geotextiles.

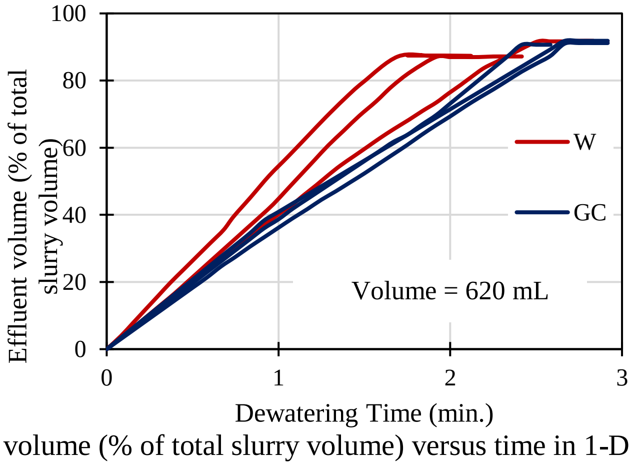
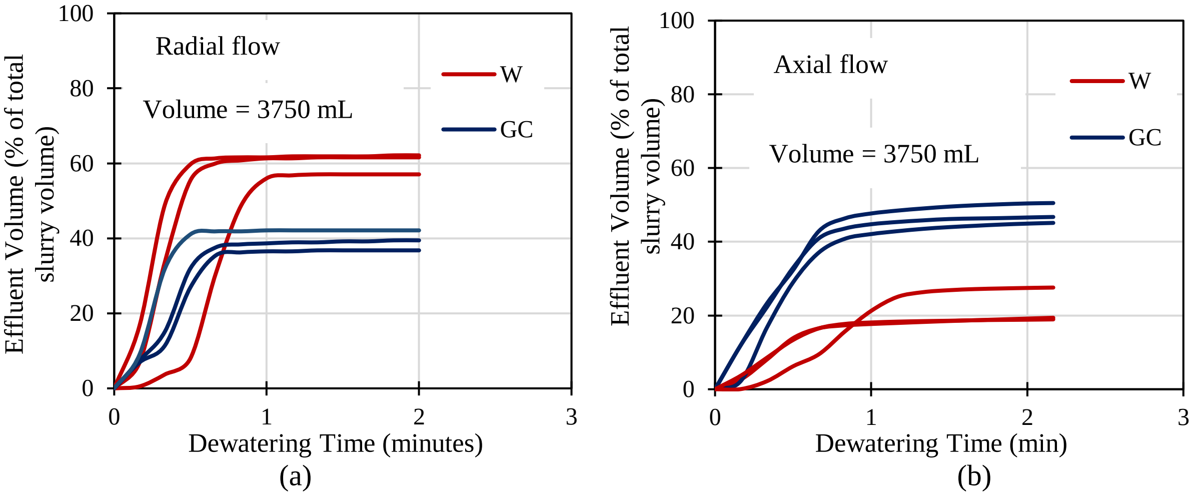


Figure 3: Effluent volume (% of total slurry volume) versus time in 1-D Pressure filtration test

Figure 4 (a and b) show the results of 2-D pressurized dewatering tests. In these figures, effluent volume (% of total slurry volume) vs. dewatering time (min) are plotetd for radial and axial flow. It was found that within 1.5 minutes most of the dewatering in radial direction was completed. As soon as the test started, a high radial flow was noticed for woven geotextile. However, the composite geotextile showed a lower rate in the radial flow. It is due to the formation of a thin filter cake on the radial surface of the composite geotextile, which reduced the permeability of geotextile and had lower radial flow (see Figure 4). However, No filter cake was formed on the radial surface of woven geotextile and the filtrate came through the cleangeotextile.



(a) (b)

Figure 4. Effluent volume (% of total slurry volume) versus time 2-D Dewatering test (a) Radial flow (b) Axial flow.

It can noticed that woven geotextile has a lower axial flow rate (almost 40% lower than radial flow). However, the axial flow of composite geotextile is almost similar to its radial flow (40%). For both woven and composite geotextiles, a thick filter cake (2 inch) was formed on the bottom surface and the filter cake started building as soon as the slurry was pumped in the test setup (see Figure 4). Similar to the PFT, a variation in flow was noticed for woven geotextile which is likely due to to more variation in its pore size distribution.

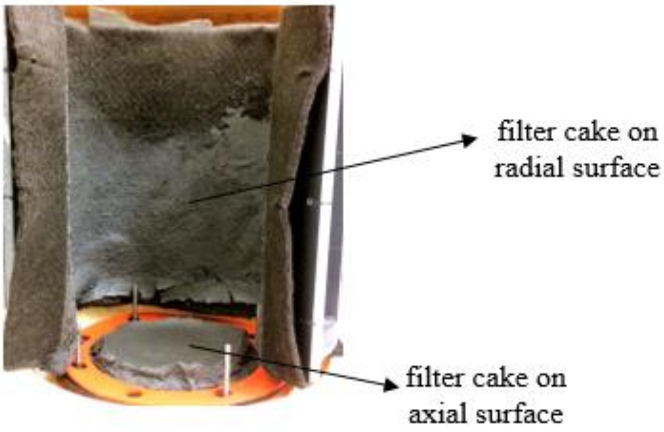
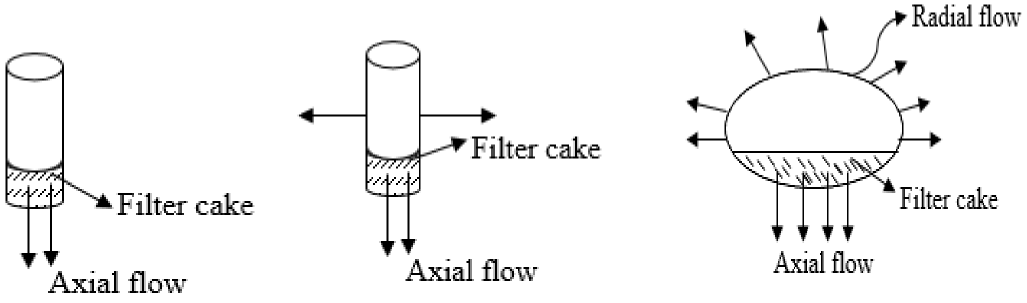


Figure 4: Filter cake formed on the radial surface of composite geotextile

Table 3 shows the results of solid content (%) of the retained fly ash and turbidity (NTU) for both 1-D and 2-D tests. The tests started with 10% slurry content and the average solid content of the filter cake was 52-56%. The increase in the solid content is due to the addition of polymer to slurry which made the flocs and allowed fly ash to retain on the geotextile as a filter cake. It can be noticed that the average solid content of filter cake for both 1-D and 2-D tests is in similar range. The effect of pore size distribution or permittivity was not noticed in the filter cake properties. However, a variation in turbidity is noticed for both geotextiles and in different tests. In 1-D test, no fly ash piping occurred with both geotextiles. Therefore, the turbidity of entire filtrate was almost negligible (0-6 NTU). As soon as the test started in 1-D test, filter cake formed on top of the geotextile, which retained subsequent fine particles from piping and allowed to dewater a filtrate with less turbidity. However, in 2-D test, a high flow was noticed in radial direction which piped some portion of fly ash and increased the turbidity of radial filtrate. Therefore, higher turbidity was notice in radial flow (15-68 NTU). Whereas, the turbidity in axial direction was found negligible. The dewatering in radial and axial directions in 2-D test resembles more to field condition where filtrate comes out from a geotextile in radial and vertical direction.

Table 3: 1-D and 2-D test results

Geotextiles	1-D pressure filtration test		2-D pressurized dewatering test		
	Solid content (%)	Turbidity (NTU)	Solid content (%)	Turbidity (NTU) in radial filtrate	Turbidity (NTU) in axial filtrate
W	52.59	4.41	52.11	44.3	0.0
	53.77	5.88	54.42	49.1	0.0
	56.44	2.94	54.67	15.4	2.0
Average	54.17	3.68	53.74	36.3	0.67
GC	58.10	0.00	55.34	61.0	0.0
	52.96	0.00	55.94	67.4	0.0
	57.56	0.00	55.12	50.7	0.0
Average	56.20	0.00	55.46	59.7	0.0



(a) (b) (c)

Figure 6: Test condition of (a) 1-D, (b) 2-D and (c) Field tests

Figure 6 shows the test conditions of three types of tests including 1-D pressure filtration test, 2-D dewatering test and a geotextile tube. In 1-D test: filtrate comes through the filter cake and geotextile in axial direction only, in 2-D test: flow occurs in both radial and axial direction, and in the field test: flow occurs in all direction in a geotextile tube. In this study, same solid content was used in both 1D and 2-D tests. However, different dewatering rates and different quality of filtrate were noticed in 2-D tests. The role of geotextiles was observed in 2-D test only which can affect the performance. Therefore, the 2-D dewatering is more representative to the field test where variation in the flow direction can be noticed. In 1-D test, with the biased results of axial direction, it is not possible to visualize the scenario of a geotextile tube.

4 CONCLUSIONS

A comparison of 1-D Pressure filtration test and 2-D Pressurized dewatering test with a woven and a composite geotextile was established in this study. Tests were conducted with unconditioned fly ash, but due to the high fly ash loss, an optimum polymer dose was added in the slurry. The difference in flow rate, filter cake properties and turbidity of filtrate was evaluated for this conditioned fly ash. Based on the results, the following conclusions can be drawn.

- Most of the dewatering from both 1-D and 2-D tests were completed within 1.5-2.5 minutes for both geotextiles. The flow rate for both woven and composite geotextiles in 1-D test were similar. In 2-D test, a high radial flow and low axial flow was noticed with woven geotextile as compared to woven geotextile. However, the composite geotextile showed a similar rate in both radial and axial flow. It is due to the formation of a thin filter cake on the radial surface and a thick filter cake on axial surface of the composite geotextile. No filter cake was formed on the radial surface of woven geotextile which led to a high radial flow.
- For both geotextiles, the average solid content of the filter cake from both 1-D and 2-D tests were in same range (52-56%). The effect of pore size distribution or permittivity was not noticed in the filter cake properties.
- Due to the high radial flow in 2-D test, the turbidity in radial direction was recorded as 15-68NTU, whereas, in 1-D test the average turbidity is negligible.

- The variation in the flow rate and turbidity in 2-D test is more pragmatic and reliable, which resembles the dewatering behavior of a geotextile tube where the filtrated water would come out from all direction.

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