Clogging Potential of Tire Shred-Drainage Layer in Landfill Cover Systems

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Abstract: This paper investigates the clogging potential of shredded scrap tire drainage layers in landfill covers. Laboratory clogging tests were conducted using soil and shredded tire profiles in a large-scale permeameter. In each test, a layer of shredded tire overlain by a soil layer was subjected to flow under a constant hydraulic gradient condition. Two types of shredded tires were used for this study and they contained individual tire chips with sizes ranging from 2.5 cm to 50 cm. The soil layer consisted of silty clay that is commonly used as cover soil in landfill cover systems. Tests were also conducted by placing a geotextile filter between the soil and the shredded tire layers. During the testing, the outflow from the bottom of the shredded tire layer was measured. After a specified number of days, the inflow was stopped and the soil layer was removed. The soil was dried and weighed. If a geotextile was used, it was also removed, dried and weighed. The mass of the soil that remained after completion of testing was compared with the initial mass of the soil used to determine the extent of soil infiltration into the underlying shredded tire layer. The hydraulic conductivity of the shredded tires was measured before and after soil infiltration. Overall, the test results showed that flow through the cover soil was very low, and the extent of soil infiltration into the shredded tires ranged from 4 to 15%, depending on the presence of a geotextile and the thickness of the soil layer. Despite partial clogging of tire shred voids with the infiltrated soil, the hydraulic conductivity of the shredded tires still remained the same as the initial value of 3.5 to 6.5 cm/s demonstrating that shredded tires can be used as an effective drainage media in landfill cover systems.

Keywords: clogging, cover system, drainage, hydraulic conductivity, landfill, recycling, tires

Introduction

Over 280 million used automobile, truck and specialty tires are discarded each year nationwide. The State of Illinois alone contributes approximately 12 million scrap tires each year to this figure. Disposal of whole tires in landfills was the common practice for many years. However, whole tires disposed in landfills tend to “float” to the surface, breaking the landfill cover and causing increased leachate production, which can contaminate groundwater. Because of this, many states have banned the disposal of whole tires in landfills. The State of Illinois requires tires to be shredded before being placed in landfills. This requirement has caused an increase in scrap tire stockpiling. Currently, 2 to 4 billion tires are stockpiled nationwide and approximately 40 to 50 million scrap tires are stockpiled at numerous locations in Illinois (IDENR, 1994). These stockpiled tires represent an aesthetic nuisance, a public health hazard, and waste of a valuable resource. A scrap tire stockpile or dump provides an ideal breeding ground for mosquitoes, rats and other disease carrying vermin. Mosquito-born diseases associated with the stockpiling of scrap tires costs approximately $5.5 million per year. Scrap tire stockpiles can self-ignite, which has detrimental effects on air quality, groundwater quality, and public health due to liquid and gaseous emissions from the burning tires. The annual cost of extinguishing used tire fires exceeds $2 million.

The best way to reduce the environmental and health hazards associated with used and waste tires is to minimize, and ultimately eliminate, stockpiling. Numerous studies have been conducted to investigate and develop alternative methods to landfilling and stockpiling such as using shredded tires for tire-derived fuel (TDF), the creation of barrier reefs, and crumb rubber asphalt surfaces. TDF appears to consume the largest quantity of tires in Illinois as well as nationwide. However, such usage has a number of limitations including: (1) the need to shred tires into small, uniform chips (usually less than 5 x 5 cm), which results in high processing costs; (2) a marginal cost advantage as compared to other competing fuels such as coal; (3) the need for major environmental permit modifications to burn tires; (4) high costs of conducting permit required tests for compliance; (5) reliability of supply in remote locations; (6) transportation cost for remote locations; and (7) local community opposition to tire burning. Other uses include retreading, pyrolysis, rubber-modified asphalt, and molded rubber products; however, these applications currently consume a very small amount of the stockpile. In addition, or as an alternative to TDF, the State of Illinois is searching for other beneficial uses for waste tires. The State is seeking to develop additional statewide, large-scale, and cost-effective uses for large size (greater than 10 cm) tires shreds. The larger the shredded tire, the lower the processing cost and the more viable the recycling option. Large-scale uses of shredded tires have been identified by several researchers for civil engineering applications such as highway embankments, pavements, retaining structures, and lightweight fill material (e.g., Ahmed and Lovell, 1993; ASTM, 1998; Bernal et al., 1996; Bressette, 1984; Cecich et al., 1996; Edil and Bosscher, 1992; Edil and Bosscher, 1994; Foose et al., 1996; Humphery and Manion, 1992; Humphery and Sandford, 1993; Humphery et al., 1993; Masad et al., 1996; Newcomb and Drescher, 1994).

We propose to use shredded tires as drainage material in cover systems for waste containment facilities. The cover system of a landfill is designed to prevent infiltration of precipitation into the waste; promote good surface drainage; resist erosion; restrict landfill gas migration or enhance recovery; prevent animals, insects and rodents from contact with the waste; minimize long-term maintenance; and protect human health and the environment (Daniel and Koerner, 1992; USEPA, 1994; Sharma and Reddy, 2004). Typical cover systems consist of a low permeability barrier layer underlying a vegetative cover soil layer. A drainage layer may be placed between the barrier and cover soil layers. The drainage layer causes lateral drainage of the infiltrated rainwater. If a drainage layer is not provided, the rainwater eventually infiltrates the waste causing excessive leachate production inside the landfill. In addition, the drainage layer prevents build-up of pore water pressures in the final cover system, leading to increased stability of slopes. The drainage layer in cover systems is typically constructed from granular soil such as sand. However, shredded tires have great potential because they possess a hydraulic conductivity that is higher than sand. This application has significant potential for utilizing large quantities of shredded tires (160,493 to 395,061 tires per hectare) and providing economic advantages over conventionally used materials without compromising engineering performance (Reddy and Saichek, 1998a, b). This application also has the potential for immediate field implementation as compared to other civil engineering applications, thus alleviating the growing problem of management and disposal of scrap tires in a timely fashion.

Along with the infiltrating rainwater, soil particles from the clay soil cover layer may migrate into the tire-shred drainage layer. Such migration of soil particles can clog the drainage layer, leading to inefficient drainage performance. In conventional drainage layers, where sand and/or gravel are used as drainage material, the initial porosity of these drainage materials is too small to allow significant migration of soil particles from the overlying cover soil layer. However, when tire shreds are used as drainage material, the porosity of the tire shreds is very high (approx. 60%) which has the potential for a greater amount of soil migration from the overlying cover soil layer. As a result, the tire-shred drainage layer may become significantly clogged and its drainage performance may be compromised.

This paper presents a laboratory research program undertaken to assess the clogging potential of tire-shred drainage layer in a landfill cover system. Controlled laboratory simulation experiments were conducted in a large-scale permeameter with various cover soil and tire-shred drainage layer conditions. Three different series of experiments, each consisting of four experiments, were conducted to evaluate the extent of the clogging potential of tire-shred layers as well as to assess the benefits of using a geotextile filter at the interface between the cover soil layer and the tire-shred drainage layer to reduce soil infiltration and the clogging of the tire-shred drainage layer. Based on the experimental results, the usefulness of employing tire-shred drainage layers in cover systems was assessed.

Experimental Methodology

Experimental Setup

A large-scale permeameter setup was used to simulate the tire-shred drainage layer and cover soil layer system and to study the clogging potential of tire shreds. Figure 1 shows a schematic of this setup. The same permeameter setup was used in a previous study to determine hydraulic conductivity of tire shreds under different normal stresses (Reddy and Saichek, 1998a). The permeameter was made of a rigid PVC cylindrical pipe 30 cm in diameter and 83 cm in height. An inlet was constructed at the top of the permeameter to allow water inflow. Outlets with control valves were constructed at the top and bottom of the permeameter. The top outlet maintained a constant hydraulic head and it was located at a height of 76 cm from the base of the permeameter. The bottom outlet consisted of two openings of diameter 3.8 cm and 1.9 cm which were located at a height of 8.1 cm from the base of the permeameter. The purpose of the smaller opening was to measure low outflow volumes. A flow meter was connected to the bottom outlets to record outflow volume. A metal screen was placed at the bottom of the permeameter at a height of 11.4 cm from the base. The screen was supported on a set of bearing spacers that transfer the load uniformly onto the base. The screen was rigid enough to support the tire shreds, soil, and any additional applied normal stress. Adhesive plastic measuring tape was fixed to the inner wall of the permeameter to measure the depth of tire shreds, thickness of the soil layer, and the hydraulic head over the soil layer.

Materials Used

Tire Shreds

Two different sizes of tire shreds, obtained from two different sources, were used in this study. These tire shreds were designated as TS-1 and TS-2 and were tested for their size distribution, unit weight, and hydraulic conductivity. A standard sieve analysis could not be performed to determine the size distribution of the tire chips present in the tire shreds. Instead, the tire shreds were characterized by randomly selecting samples from a tire shred pile. Approximately 10 kg of tire shreds were chosen per sample. The weight and the maximum and minimum size of each individual tire chip in the tire shred sample were measured and recorded. The size distribution of TS-1 and TS-2 are shown in Figure 2.

The unit weight of tire shreds was determined by filling the tire shreds in a large cylindrical container and measuring their weight and volume. Using the specific gravity (1.02 to 1.27) for tire shreds, the void ratio (e) and porosity (n) were calculated. The average density, void ratio and porosity were varied from 416 to 502 kg/m^3, 1.28 to 1.5, and 50% to 58%, respectively.

The hydraulic conductivity (K) of the tire shreds was determined by using the same permeameter shown in Figure 1. The tire shreds were placed in the permeameter without any compaction. The initial thickness of the tire shred layer in the permeameter was 30 cm. Hydraulic conductivity was measured consecutively under three different stress conditions: (a) under zero normal stress, (b) 5.7 kPa normal stress, and (c) 11.5 kPa normal stress. The normal stress of 5.7 kPa simulated one-foot soil layer overlying the tire-shred drainage layer, while the normal stress of 11.5 kPa simulated a 61 cm soil layer overlying tire-shred layer. During each testing stage, the amount of water discharged from the bottom outlet for a specified time period (t) was measured. Initial head (H_1) and the final head (H_2) in the permeameter were recorded. The hydraulic conductivity (K) was calculated using:

$$K = \frac{L}{t}\ln\left(\frac{H_1}{H_2}\right)$$

where L is the thickness of the tire-shred layer in the permeameter. Based on these experiments, the hydraulic conductivity of the TS-1 tire shreds with no normal stress was found to be 2.65 cm/s. The hydraulic conductivity of tire shreds was slightly decreased to 2.27 cm/s and 1.83 cm/s and compression increased to 23% and 37% under normal stresses of 5.7 kPa and 11.5 kPa respectively. The compressibility and hydraulic conductivity of TS-2 tire shreds are reported by Reddy and Saichek (1998a). These results show that both TS-1 and TS-2 tire shreds possessed higher hydraulic conductivity than the standard drainage materials such as sand and gravel; therefore, they are as the most suitable drainage material in a landfill final cover system.

Cover Soil

A silty clay soil obtained from the Carlinville Landfill in Carlinville, Illinois, USA, was used as cover soil in this study. The soil was tested for specific gravity, Atterberg limits, grain size distribution, hydraulic conductivity, and moisture-density relationship. Table 1 summarizes the testing procedures and the property values for the soil.

Geotextile

A geotextile was used at the interface between the tire shreds and the cover soil in select experiments to assess the possibility of minimizing soil infiltration and clogging of the tire-shred layer. A non-woven geotextile (270 g/m^2) was chosen in this study and its properties are summarized in Table 2.

Testing Program

Table 3 shows the testing variables selected and the number of tests conducted in this study. Three different series of simulation experiments, designated as Series I, II and III, were conducted to assess the clogging potential of tire shreds when using them as drainage layer in a landfill cover. In each series, the initial thickness of the tire shreds was maintained constant at 30.5 cm simulating the minimum drainage layer thickness in a landfill cover.

In the Series I experiments, tire shreds TS-1 were used, which correspond to tire chips ranging in size from 1.3 cm to 22.9 cm with an average tire chip size of approximately 16.5 cm. The thickness of the soil layer over the shredded tire layer was 7.6 cm, which created a hydraulic head of 16.5 cm over the soil layer. In this series, four experiments were conducted starting with the most critical condition. The experiments in Series I were labeled as 1, 2, 3, and 4 as shown in Table 3. In experiment 1, a normal stress of 5.7 kPa, which is equivalent to a 30.5 cm thick soil layer in the landfill cover, was applied. A geotextile was not used at the interface of the drainage layer, meaning the shredded tire layer and the overlying cover soil layer were in direct contact. In Experiment 2, a geotextile was not used at the interface of the soil and tire-shred layers and zero normal stress was applied. Experiments 3 and 4 were identical to experiments 1 and 2 except that a geotextile was used at the interface between the tire shreds and the cover soil layer. Each experiment was conducted for 150 to 200 hours. At the end of the experiment, the cover soil was removed and the hydraulic conductivity of the tire shreds was measured and compared with their initial hydraulic conductivity to assess the influence of clogging. The flow rate versus elapsed time was plotted and the flow pattern was observed. The amount of soil infiltration due to inflow through the cover soil layer was calculated in each experiment.

The tire shreds TS-1 were also used in the Series II experiments as shown in Table 3. The testing program adopted and the methodologies followed were the same as in Series I. The only difference between the Series I and Series II testing was the thickness of the soil layer. In this series, a 15.2 cm thick soil layer was placed over the tire shred layer instead of a 7.6 cm thick soil layer. The increased soil thickness of 7.6 cm reduced the hydraulic head over the soil layer to 8.9 cm. The 15.2 cm soil layer was used to study the effect of the hydraulic head on the flow rate and the amount of soil infiltration into the voids of the tire shreds.

In Series III, tire shreds TS-2, with the size of the tire chips ranging from 1.3 cm to 14.0 cm, with an average size of 7.6 cm, were used. The size of these tire shreds were almost half the size of tire shreds TS-1 used in Series I and II. A soil layer thickness of 7.6 cm was used and the testing program and methodology was the same as Series I and II. The amount of soil infiltrated and thus clogging of tire shreds, the magnitude of the flow rate and its pattern, and the hydraulic conductivity of tire shreds after clogging were evaluated and then compared with data obtained in the first two series of experiments conducted with tire shreds TS-1. This comparison was performed to examine the effects of tire shred size on soil infiltration and the clogging of the tire shreds.

Testing Procedure

Approximately 8.0 kg of tire chips were weighed and placed in the permeameter. This amount was required to create an approximately 30.5 cm thick tire-shred layer in the permeameter. The tire shreds were placed carefully to ensure that no large void(s) existed in the layer. No compaction effort was applied while placing the tire shreds. The exact thickness of the shredded tire layer was measured. Then, the required amount of dry silty clay soil to yield a 7.6 or 15.2 cm soil layer in the permeameter was weighed. Water was added to the soil so that the placement water content was equal to the optimum moisture content. The soil was mixed thoroughly until it became uniform in color and consistency. The soil was placed over the tire-shreds in layers and was slightly tamped after each layer was applied. In select tests, a non-woven geotextile was placed on the top of the shredded tire layer before placing the cover soil layer. The geotextile was cut into a circular shape with a diameter slightly greater than that of the permeameter cell to avoid direct soil migration from the edges of the permeameter. The dry weight of the geotextile was measured prior to placement in the test setup. Where required, a normal stress of 5.7 kPa was applied to simulate a one foot thick soil layer in a landfill cover system.

Tap water was allowed to enter over the soil layer through the inlet. The inflow rate was adjusted in such a way that it did not exceed flow in the outlet, thus a constant head was maintained in the setup during the experiment. The starting time of the experiment was noted.

The outflow was collected for a specified time interval and the total outflow volume was recorded. Experiments were conducted for a total duration of 150 – 200 hours.

At the end of experiments, the inflow was stopped and the applied normal stress was removed. The soil layer was taken out of the permeameter and was allowed to dry. Its dry weight was then measured. If present, the geotextile used at the soil and tire shred interface was also taken out and dried and its dry weight was also measured. The hydraulic conductivity of the tire shreds was measured as explained previously. This was done to assess potential reduction in hydraulic conductivity due to the compression of tire shreds and clogging of tire shreds with soil. Finally, the tire shreds were removed from the permeameter and dried.

Results and Discussion

Figure 3 shows the results of the four experiments conducted in Series I using the TS-1 tire shreds with 7.6 cm of soil cover. As shown in Figure 3, the flow rate is low in all tests and it ranges from 2.8×10^{-4} m^3/s to 2.8×10^{-7} m^3/s. In experiment 1, a geotextile was not used under the soil layer and a normal stress of 5.7 kPa was applied. This experiment was conducted for a longer duration, being the first and most critical of the experiments. Initially, the outflow was in the range of 2.8×10^{-6} m^3/s to 2.8×10^{-7} m^3/s. As time progressed, the outflow rate reduced to a value in the range of 2.8×10^{-7} m^3/s to 2.8×10^{-8} m^3/s. In experiment 2, a geotextile was not used underneath the soil layer, and no normal stress was applied. The self-weight of the 7.6 cm soil was the only stress applied. There was only a slight difference in the flow rate between the beginning and the end of the experiment. The flow rate was 2.8×10^{-7} m^3/s at the beginning of the test and was approximately the same at the end of the test. The initial flow rate in experiment 2 was expected to be higher than that of the initial flow rate in experiment 1 because the permittivity of the tire shreds should be more under zero normal stress than the permittivity under a normal stress condition of 5.7 kPa. However, the flow rate was observed to be higher in experiment 1 in which normal stress was applied when compared to the flow rate in experiment 2 in which there was no application of normal stress. The possible reason for the low flow rate with zero normal stress may be due to the presence of larger voids in the top portion of the tire shred layer, which may have held a larger amount of migrated soil. This increased soil may have created a barrier that acted as a less porous layer. During experiment 3, initially there was a relatively high outflow as shown by the high flow rate. The high outflow may have resulted from the flow of water from the space between the geotextile and the sides of the permeameter. The flow rate decreased as the soil layer settled at the interface area within a very short period of time. As the test progressed, the flow rate remained almost constant with minor fluctuations around 2.8 x 10^{-6} m^3/s. Experiment 4 was conducted in a manner similar to experiment 3, except that there was no applied normal stress. The results obtained were also similar to those obtained in experiment 3. In this experiment, the flow rate was slightly higher throughout the duration of the experiment than in experiment 3, and it remained almost constant after 35 – 40 hours. In the later part of the experiment, as seen from Figure 3, minor fluctuations in the flow rate were observed. However, the flow rate is almost constant and is in the range of 2.8 x 10^{-5} m^3/s to 2.8 x10^{-6} m^3/s. The hydraulic conductivity of the tire shreds was less under higher normal stresses, which means water can permeate more freely under lower normal stress conditions. This may explain the higher flow rate in this experiment when compared to experiment 3.

The percentage of soil infiltration, in the form of soil clogged in the voids of the tire shreds during each experiment, is presented in Table 4. Due to soil migration, there was about 27% soil infiltration by weight from the cover soil layer into the tire shreds in experiment 1. In experiment 2, the amount of soil infiltration or the amount of soil that migrated into the tire shred voids is about 15%. In experiments 3 and 4, the amount of soil infiltration was less than 5% because of the presence of a geotextile, which acted as a filter layer. Table 4 also shows the hydraulic conductivity of tire shreds after the completion of clogging experiments and reflects the effects of soil clogging on reduction in hydraulic conductivity. In experiment 1, 25% reduction in hydraulic conductivity value was observed as a result of a significant soil clogging (27%); however, the hydraulic conductivity value was still higher than the minimum requirement for the drainage material in a landfill cover. There was a potential for washing of soil out of the tire shreds resulting partial clogging of the tire shreds. The hydraulic conductivity decreased by 17% in experiment 2, by 15% in experiment 3, and by 6% in experiment 4. The presence of the geotextile at the interface in experiments 3 and 4 minimized any soil from clogging the voids of the tire shreds. Thus, the amount of soil infiltration (less than 5%) was probably in the form of fine soil particles that passed through the fine interstices of the geotextile. These fine soil particles were then washed through the large voids of the tire shreds. A small amount of soil migration may have also occurred along the sides of the permeameter wall and the geotextile into the tire shred layer because it was difficult to create water tight edges in the permeameter. It was also found that there was an increase of about 167% to 190% in the weight of the geotextile at the end of the experiment because of clogging of the geotextile by fine soil particles.

The Series I experimental results show that although the tire shreds are highly permeable, the overlying soil layer possesses low hydraulic conductivity that results in low flow rates. In all tests, the flow rate was generally high initially and it gradually reduced with time. The reduction in the flow rate may be due to gradual migration of soil particles into the tire shred layer that lead to the clogging of the tire shreds. In the experiments in which the geotextile was not used, the soil infiltration is 27% and 15% under the application of 5.7 kPa and 0 kPa, respectively. This indicates that the applied stress increased soil migration and caused greater clogging of the tire shreds. The flow was higher in the tests with the use of a geotextile, indicating that the geotextile was effective in minimizing the migration of soil particles into the tire-shred layer. Moreover, the soil infiltration significantly reduced and it varied from 4.5% to 5% for tests with and without the application of normal stress of 5.7 kPa. The geotextile served as a filter and effectively contained the migration of soil particles and minimized the clogging of tire shreds. The hydraulic conductivity of tire shreds decreased due to clogging of tire shreds. The reduction in hydraulic conductivity of tire shreds ranged from 25% for experiment 1 (test with no geotextile and with applied 5.7 kPa normal stress) to 6% for the experiment 4 (test with geotextile and no normal stress). In spite of this reduction in hydraulic conductivity, the tire shreds still possessed hydraulic conductivity that is higher than the conventional drainage materials (granular soils). Thus, the influence of clogging on the hydraulic performance of the tire shreds was not compromised. The voids in the tire shreds were large and were only partially reduced by clogging. This allowed enough void space for flow to occur easily.

Figure 4 shows the results of the four experiments conducted in Series II. In this series, four experiments are conducted with the same variables as in the Series I experiments except that a 15.2 cm instead of a 7.6 cm soil layer was placed over the tire-shred layer. The results of these experiments helped assess the effects of variable hydraulic gradient across the soil cover layer on the drainage performance of the underlying tire-shred layer. Table 4 shows the percentage of soil infiltration and the change in hydraulic conductivity of the tire shreds after the completion of the clogging experiments. These results showed that flow under applied normal stress and the absence of the geotextile (experiment 1) was the most critical condition. A significant amount of soil infiltration (23%) was observed in this experiment. The lower flow rate and the higher soil infiltration (i.e. high soil clogging) in this test were responsible for approximately 27% reduction in hydraulic conductivity of the tire shreds. However, the hydraulic conductivity of partially clogged tire shreds was still adequate to meet the hydraulic conductivity required for a landfill cover system drainage layer. Experiment 2 also represents a critical condition; however, since no vertical stress was applied in this test, the voids in the tire shreds remained large and the migration of soil did not significantly clog the tire shreds. This produced higher flow rates and soil infiltration (14%) and lower reduction in hydraulic conductivity of tire shreds (22%) when compared with the results from experiment 1. Using the geotextile filter at the soil and tire shred interface yielded higher flow rates, lower soil infiltration, and lower reduction in hydraulic conductivity of tire shreds (see Figure 4 and Table 4). Overall, the Series II experiment results show that a minor change in hydraulic gradient across the soil cover does not significantly affect the hydraulic performance of tire shred drainage layers in a landfill cover system. Despite partial clogging, the tire shred layer possesses a very high porosity to allow efficient drainage.

In Series III experiments, TS-2 tire shreds were used which consisted of tire shreds ranging from 1.3 cm to 14.0 cm with an average size of 8.9 cm. All other experimental variables were the same as those used for Series I experiments. The flow rates, percent of soil infiltration, and reduction in hydraulic conductivity of tire shreds obtained in this experiment series were shown in Figure 5 and Table 4. The results obtained in this series are helpful to assess the effect of tire shred size on clogging and drainage in the tire-shred layer. The results of all four experiments conducted in Series-III are compared to those obtained in Series I and it was observed that the results were similar in both series. These results clearly show that the experimental conditions used in experiment 1 were the critical condition because experiment 1 yielded the lowest flow rate, the highest soil infiltration, and the highest reduction in hydraulic conductivity of tire shreds. As previously stated, in Series I and II, tire shreds TS-1 were used, which consisted of tire shreds ranging in size from 1.3 cm to 22.9 cm with an average tire chip size of approximately 16.5 cm. Thus, the smaller size of TS-2 tire shreds may have created relatively lower initial porosity. Thus, for a given situation (no geotextile and a normal stress of 5.7 kPa), the smaller tire shreds are likely to yield a lower flow rate. In this series, the flow rates of experiments 2, 3, and 4 were similar. Even though the flow rates were similar, the percentage of soil infiltration and the tire shred hydraulic conductivity reduction (which was partially dependant on the soil infiltration) was different in each experiment. These parameters were largely controlled by the presence of a geotextile at the interface of the drainage layer and the soil cover layer. Overall, the use of different tire shred sizes in this series did not show a significant difference in the flow rates or percentages of soil infiltration. The results obtained were similar to those obtained in Series I and II and indicate that tire shreds with the size ranges considered in this study can serve as effective drainage material. However, it is important to use a non-woven geotextile at the soil and tire-shred layer interface to minimize soil infiltration and maintain high hydraulic conductivity of tire shreds.

Summary and Conclusions

Three series of experiments were conducted to determine the degree and importance of soil clogging in tire shreds due to migration of soil from the soil cover layer overlying the tire-shred drainage layer in a simulated landfill final cover system. Clogging of the tire shreds is important because it will be used to determine whether or not tire shreds are a suitable drainage material for landfill cover systems. Four different experiments were performed in each of the three series of experiments. In Series I, a 7.6 cm soil layer was used over 30.5 cm of tire shreds with an average tire shred size of 16.5 cm. In Series II, a similar size of average tire shred was used, but the thickness of the soil layer was increased from 7.6 cm to 15.2 cm. In Series III, an average tire shred size of 7.6 cm was used to observe the effects of a smaller tire shred size on the measured outcomes.

The presence of 7.6 cm of soil above the tire shreds results in a hydraulic head of 16.5 cm, which is an important variable because the hydraulic head governs the hydraulic gradient and flow rate and thus to some extent clogging potential. The flow rate under the critical test condition, i.e., experiment 1 in all three Series, is similar. Thus, the difference in the hydraulic head applied in Series I (16.5 cm) and II (7.6 cm) did not significantly affect the flow rate. The flow rate of the critical experiment in each series remained in the range of 2.8×10^{-6} m^3/s to 2.8×10^{-8} m^3/s. The amount of soil infiltration, expressed by percentage of weight, is also almost the same, but is large for the smaller area tested. The greater the soil infiltration in the cover soil layer, the greater the potential for slope stability problems and the greater the reduction in the flow rate values. A reduction in flow rate affects the drainage potential of the tire shreds. To enhance the flow potential of a shredded tire layer, it is recommended that a non-woven geotextile be installed above the tire-shred layer to reduce the migration of the soil into the tire shreds. A geotextile was not used in the critical test condition, i.e., experiment 1 in each Series, and thus soil migration into the shredded tire layer occurred.

The Series I and III experiments were similar in all aspects except for the size of tire shreds used, which were an average of 16.5 cm and 7.6 cm, respectively. However, the test results obtained for the two series of tests were similar and thus tire shred size did not have a large impact on the drainage potential of the tire shreds. Both the Series I and III flow rate and percent loss of soil results are comparable with the Series II results even though the soil cover layer in Series II had a greater thickness (15.2 cm versus 7.6 cm). The presence of a 15.2 cm soil layer provided less hydraulic head but more opportunity for permeation of soil into the tire-shred layer.

The high hydraulic conductivity of the tire shreds even without a non-woven geotextile is sufficient to accommodate the flow rate that is likely to be encountered in a landfill final cover system. However, soil migration from the cover soil into the tire shreds can cause clogging in the drainage layer, increased pore water pressures, and reduced slope stability of the cover systems. The test results show that inclusion of a non-woven geotextile at the cover soil and tire shred interface will reduce the soil migration and possible slope stability problems. The geotextile acts as a separator between the cover soil layer and the drainage layer and prevents soil particles from migrating into the tire shreds.

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Table 1. Properties of soil used to simulate cover soil layer

Property	Test Methods	Value
Specific Gravity	ASTM D 854	2.65
Atterberg Limits	ASTM D4318	Liquid Limit=46%
		Plastic Limit=25%
		Plasticity Index=21%
Grain Size Distribution	ASTM D422	Gravel=0.0%
		Sand=11.4%
		Fines=88.6%
Hydraulic Conductivity	ASTM D2342	2.4 x 10^{-8} cm/s
Optimum Moisture Content	ASTM D698	15.4 %
Maximum Dry Density		4.9 kN/m^3
Soil Classification	ASTM D2487	Silty Clay, CL

Table 2. Properties of the geotextile used

Property	Units	Test Method	Value
Fabric Weight	g/m^2	ASTM D3776	254
Thickness	mm	ASTM D1777	2.75
Grab Strength	N	ASTM D4632	1334/1045
Grab Elongation	%	ASTM D4632	75/85
Trapezoid Tear Strength	N	ASTM D4533	467/423
Puncture Resistance	N	ASTM D4833	512
Mullen Burst Strength	kPa	ASTM D3786	2757
Water Flow Rate	(m^2/sec)	ASTM D4491	0.031
Permitivity,□Ψ	Sec^{-1}	ASTM D4491	2.01
Permeability, k=Ψ□t	cm/sec	ASTM D4491	0.56
AOS	Sieve Size, mm	ASTM D4751	70-100 0.210-0.149

Table 3. Testing program to study the clogging potential of tire shreds

Test Series	Experiment Number	Average Tire Shred Size (cm)	Cover Soil Layer Thickness (cm)	Geotextile Used (g/m^2)	Normal Stress (kPa)
I	1	16.5	7.6	None	5.7
	2			None	0
	3			271	5.7
	4			271	0
II	1	16.5	15.2	None	5.7
	2			None	0
	3			271	5.7
	4			271	0
III	1	8.9	7.6	None	5.7
	2			None	0
	3			271	5.7
	4			271	0

Table 4. Soil infiltration and change in hydraulic conductivity of tire shreds

Test Series	Test Number	Geotextile	Normal Stress (kPa)	Cover Soil Infiltration (% by wt.)	Tire Shred Hydraulic Conductivity Ratio (Final/Initial)
I	1	None	5.7	27	0.75
	2	None	0	15	0.83
	3	270 g/m^2	5.7	5	0.85
	4	270 g/m^2	0	4.5	0.94
II	1	None	5.7	23	0.73
	2	None	0	14	0.78
	3	270 g/m^2	5.7	2	0.76
	4	270 g/m^2	0	4.8	0.99
III	1	None	5.7	25.3	0.79
	2	None	0	13.5	0.88
	3	270 g/m^2	5.7	2.5	0.78
	4	270 g/m^2	0	1.5	0.93

Figure Captions

Figure 1. Schematic of Clogging Experimental Test-up

Figure 2. Size Distribution of Tire Shreds TS1 and TS2

Figure 3. Clogging Test Series I with TS1 Tire Shreds and 7.6 cm-Cover Soil Layer

Figure 4. Clogging Test Series II with TS1 Tire Shreds and 15.2 cm -Cover Soil Layer

Figure 5. Clogging Test Series III with TS2 Tire Shreds and 15.2 cm-Cover Soil Layer

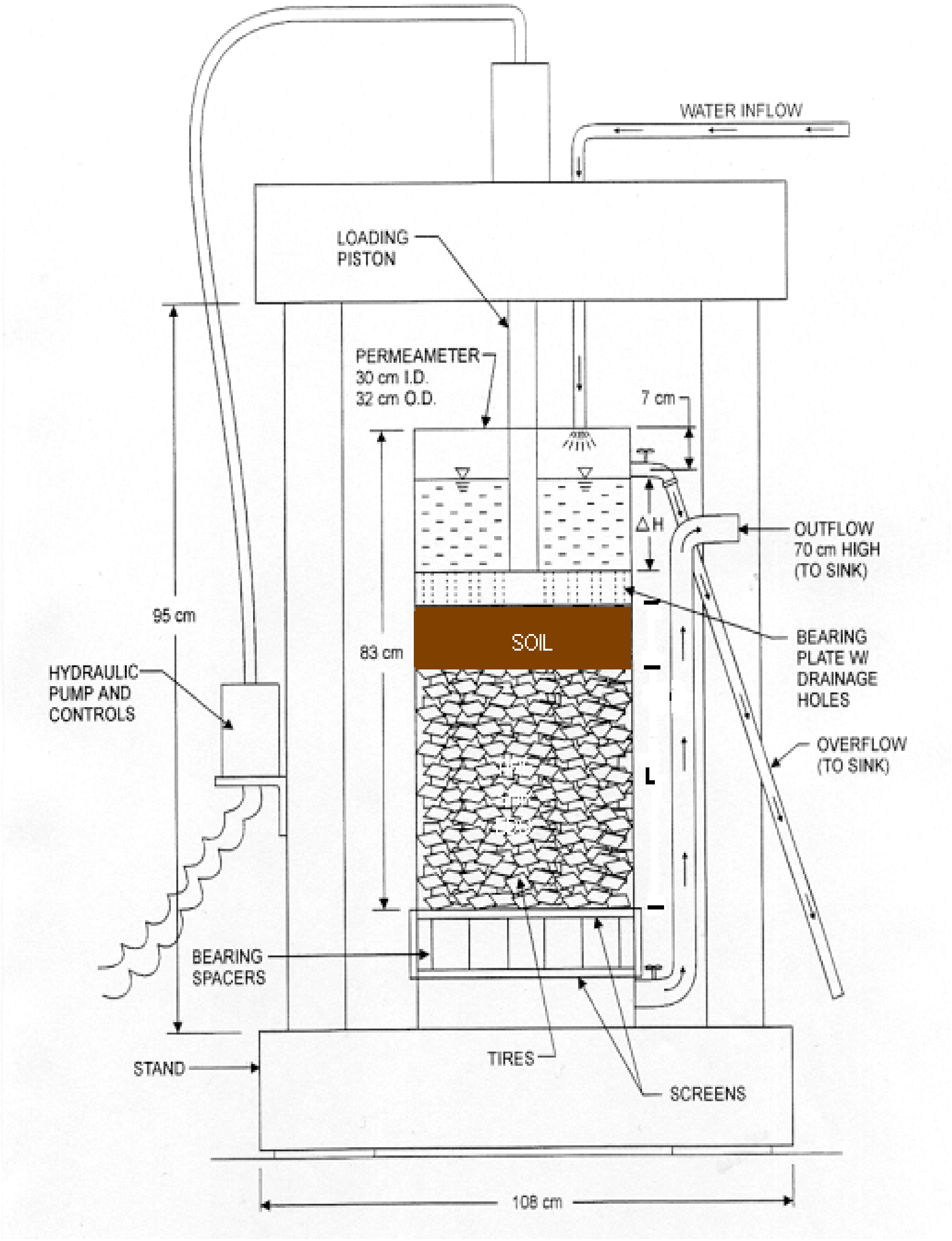

Figure 1. Schematic of Clogging Experimental Test-up

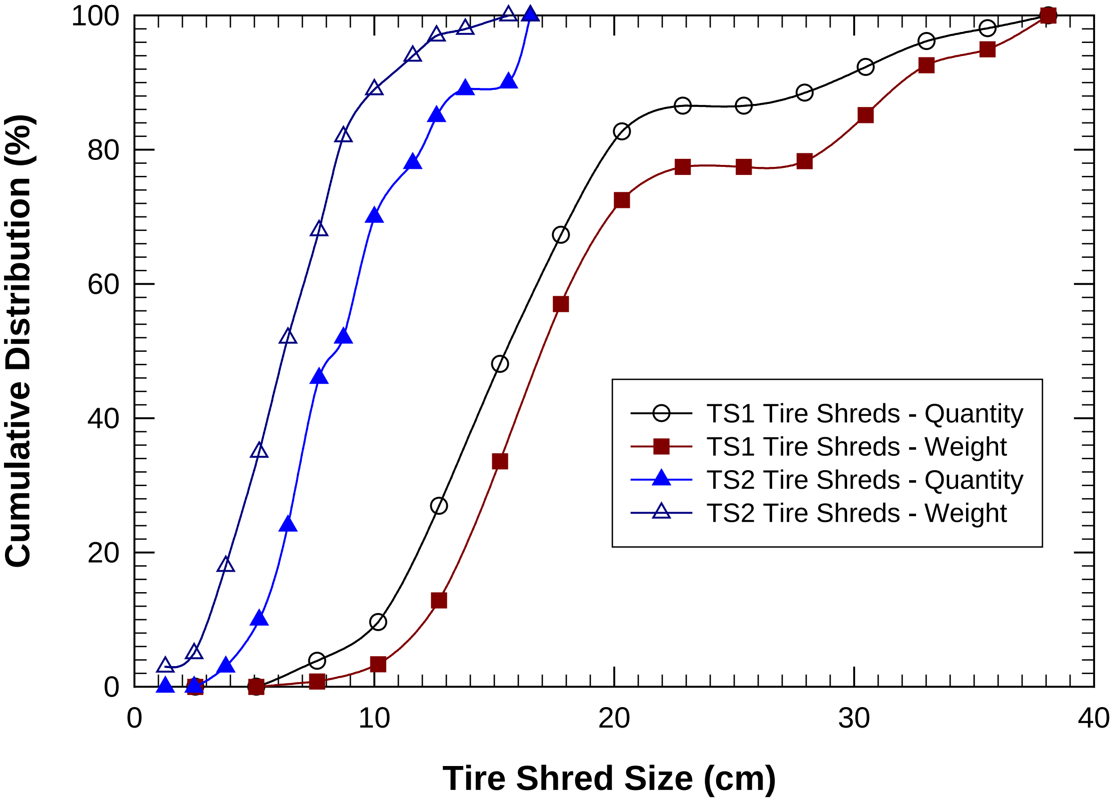

Figure 2. Size Distribution of Tire Shreds TS1 and TS2

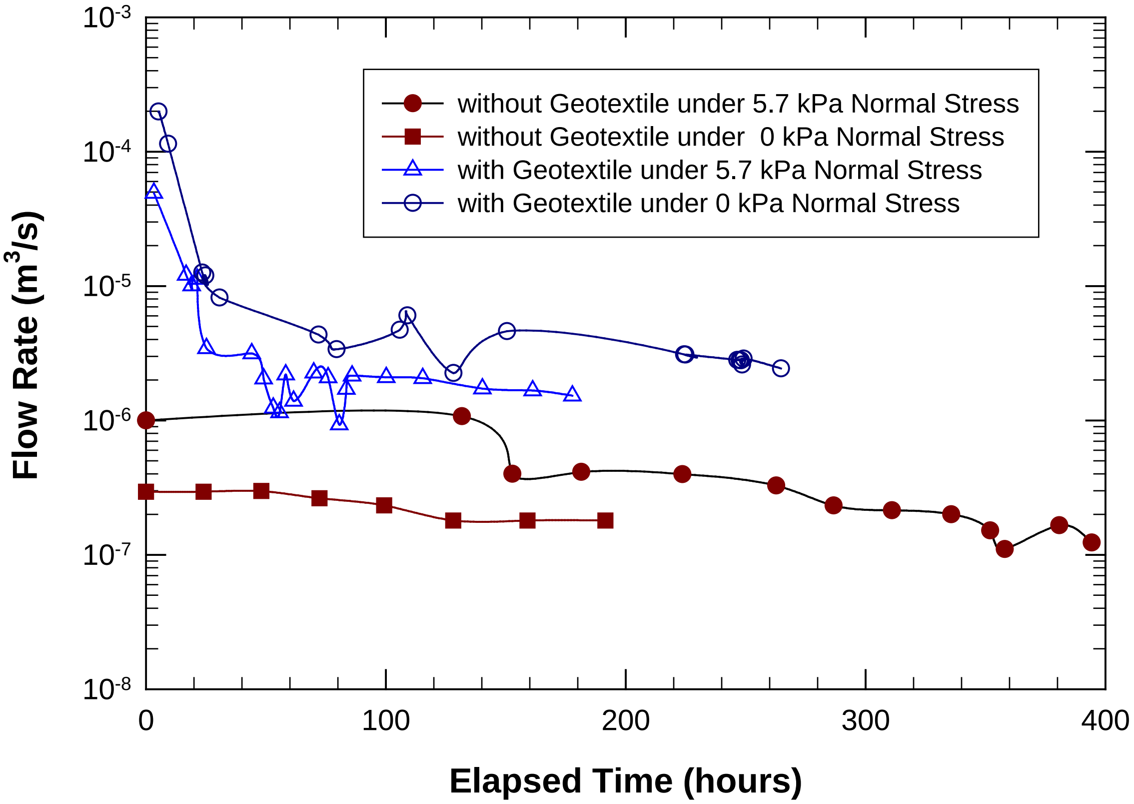

Figure 3. Clogging Test Series I with TS1 Tire Shreds and 7.6 cm-Cover Soil Layer

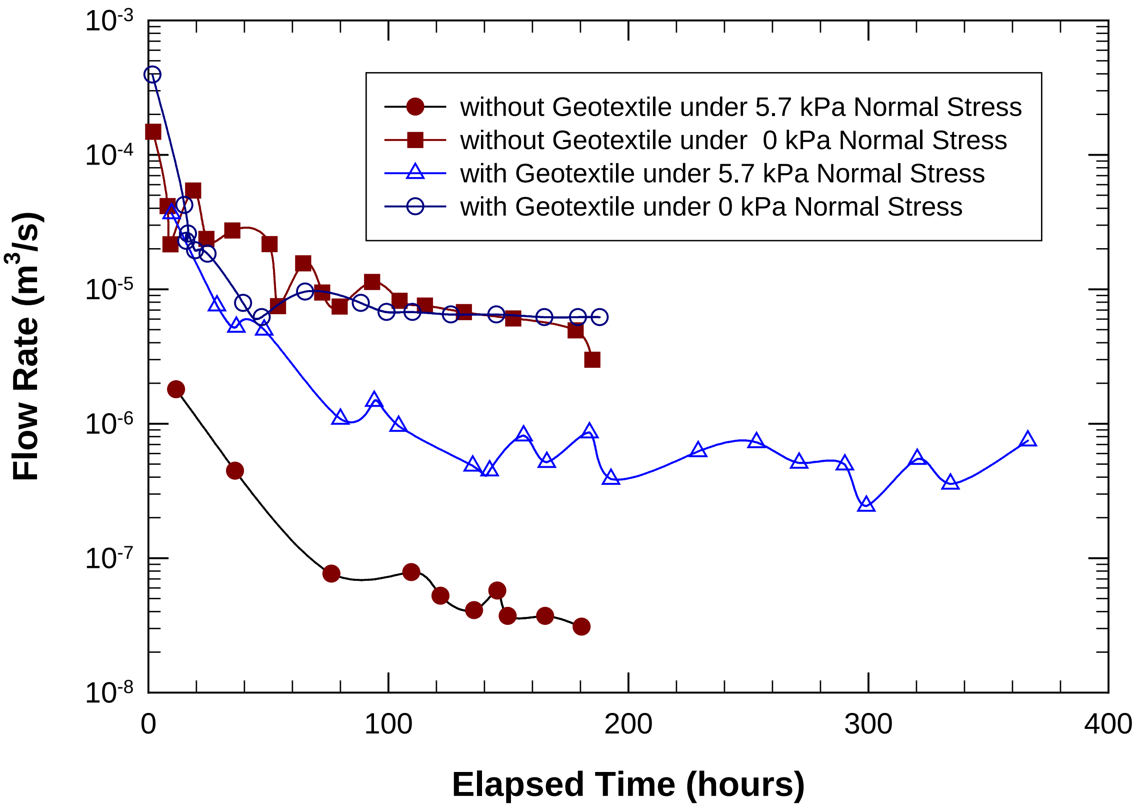

Figure 4. Clogging Test Series II with TS1 Tire Shreds and 15.2 cm-Cover Soil Layer

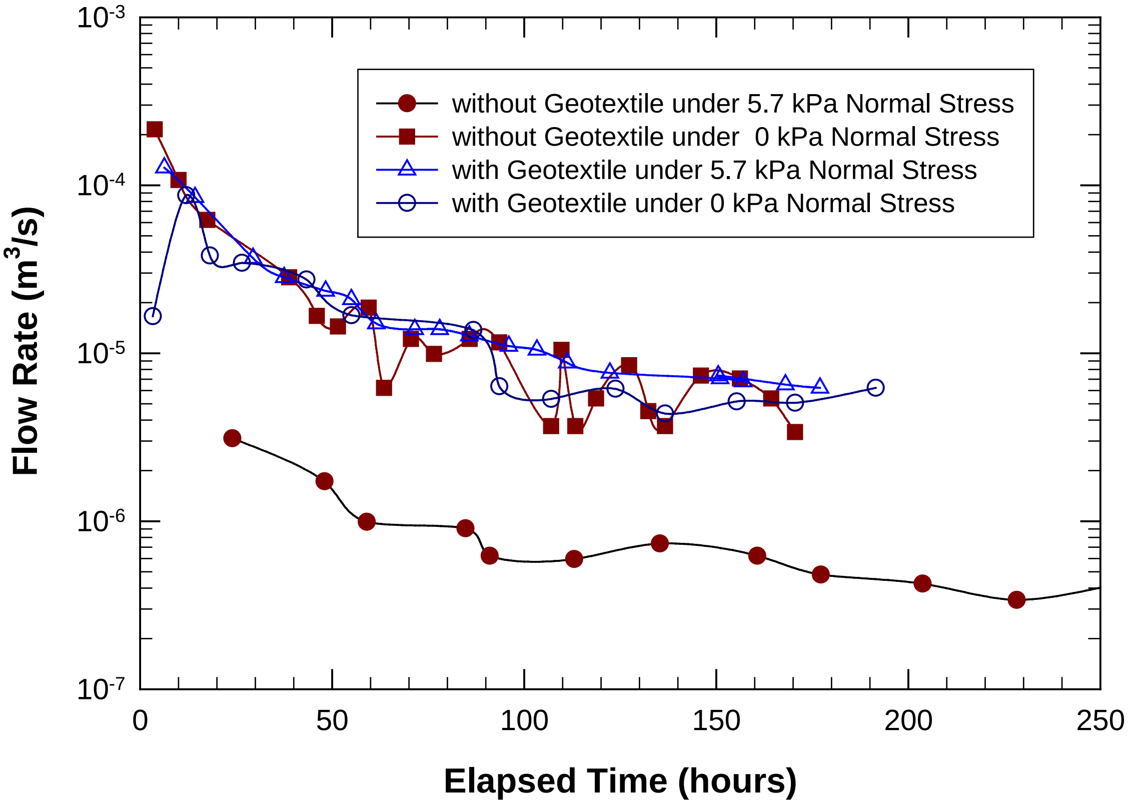

Figure 5. Clogging Test Series III with TS2 Tire Shreds and 15.2 cm-Cover Soil Layer