Characteristics of Shredded Tires as Landfill Filter media

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ABSTRACT: The generation of solid waste has become an increasingly important global issue over the last decade due to the escalating growth in world population and large increase in waste production. Landfill disposal is the most commonly waste management method worldwide. Leachate recirculation system is one of the techniques that can be used to enhance solid waste biodegradation. Drainage filters, which are mostly gravel and crushed stones, is required in landfill structure. In present study, tire chips have been introduced and used as landfill drainage layer. In this investigation the effects of using shredded tires as a landfill filtration media on solid waste biodegradation process and landfill's leachate were studied.

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3 1.0 INTRODUCTION

The generation of solid waste has become an increasingly important global issue over the last decade due to the escalating growth in world population and large increase in waste production. This increase in solid waste generation poses numerous questions concerning the adequacy of conventional waste management systems and their environmental effects. Landfill disposal is the most commonly waste management method worldwide. Landfills have served as ultimate waste receptors for municipal refuse, industrial residues, recycle discards and wastewater sludge. Biological processes are known to reduce the fraction of solid waste. Leachate recirculation system is one of the techniques that can be used to enhance solid waste biodegradation. Landfill's leachate may contain high concentration of organic and inorganic materials including toxic compounds and heavy metals. The recirculation of landfill's leachate accelerates the rate in which the waste is broken down, thus decreasing the time required to stabilize the landfill's site. This is important because the longer a landfill remains unstabilized, the longer it remains as a source for potential environmental problems (i.e. groundwater contamination, methane gas migration). Drainage filter, which is mostly gravel and crushed stones, is required in landfill structure. In this study, tire chips have been introduced and used as landfill drainage layer. Scrap tires represents approximately 1.2% of all solid waste generated in North America. Currently, three main options exist for the disposal of scrap tires: (1) landfilling; (2) recycling and reuse and (3) incineration. The most common method used in North America is landfilling. Shredded tires are being used for landfill application as drainage layer. Tire chips work as filters to neutralize the leachate before its ejection to the environment and prevent leachate clogging.

2. Scope

The aim of this study is to examine the effects of using shredded tires as a landfill filtration media on solid waste biodegradation process and landfill's leachate. The recirculation technique requires a drainage system (shredded tires) to separate and store the leachate from the waste. Tire chips have number of qualities that make them well suited to use as filters such as: high permeability, low pressure, light weight, high durability, low cost and good thermal insulators. Also, to study the characteristics of shredded tires as landfill filter media. The leachate is been collected from three bioreactor cells and tested for pH, BOD, and COD. The hydraulic conductivity of the shredded tires is been determined to measure the permeability of shredded tires.

3. Landfill Drainage Media

Landfill drainage layer plays an important role in modern landfill management. In traditional landfill site, the drainage layer controls the leachate level within the waste. In a modern landfill site that operates as a wet bioreactor, the drainage system provides the means of controlling leachate collection and recalculation between different part of the waste body (Townsend et al, 1998). The drainage layer consists of a high permeability natural material such as gravel and crush stones. The drainage media provide a uniform and continuos connection between the waste and the leachate collection system in which the liquid collected on the liner transmitted to the collector drainpipes. The drainage layer should be at least 30 cm thick with minimum hydraulic conductivity of 0.001 cm/sec.

The development of environmentally acceptable methods of used tire disposal is one of the greatest challenges that waste management experts face today. Over 280 million scrap tires are generated annually in North America (Jesionek et al, 1998). When scrap tires are not properly disposed, the health of the individual and the community is put at risk. Stockpiled tires provide an ideal breeding ground for mosquitoes and other disease-carrying vermin. In addition, vast tire mountains can trap a sufficient amount of oxygen to cause a fire. A melted automobile tire will yield two-third of a gallon of oil which is contaminated with various tire chemicals. These toxic substances can create a serious environmental hazard when they seep into the surrounding soil and groundwater (Gonzales et al, 1995). Potential municipal solid waste landfill applications have been found for scrap tires. These applications include: landfill daily cover, foundation layer of final cover system, landfill gas collection material, landfill leachate drainage material, and operations layer.

4. TIRES CHARACTERISTICS AND PERFORMANCE CRITERIA

Using shredded tires as landfill drainage materials is an emerging technology for municipal solid waste management system. The average weight of scrap automobile tires is approximately 10 kg (Gonzales et al, 1995). A scrap tire is a tire that can no longer be used for its original purpose due to wear damage. A typical tire is composed of 83 percent carbon, 7 percent hydrogen, 6 percent ash, and 1.2 percent sulfur. The primary constituents of tires include polymers, carbon black, and softeners. The softeners are mostly composed of hydrocarbon oils which in combination with the polymers give the tire very high heating value (Lund, 1993). Shredded tires are pieces of scrap tires that have a geometrical shape between 50 mm and 300 mm in size. A mechanical device called a shredder commonly accomplishes the reduction in tire size. Tires retain their basic chemical properties and physical shape even when shredded into smaller pieces (Benda, 1995). Shredded tires are generally combustible at temperature above 322 ºC. Combustion can be caused by the self-heating of the shredded tires fills. This is, however, not to be a limiting factor for the subject application because the typical leachate drainage layer thickness is on the order of 300 to 450 mm whereas the self-heating fire usually occurs at relatively tick shredded tires fills of height greater than 6 m (Humphery, 1996). Shredded tires properties are not affected by the adverse weather conditions after installation, including hot or freezing temperature. Performance criteria for the use of shredded tires as landfill drainage layer were developed to evaluate the general stability for this application. Assessment of the performance criteria has indicated that shredded tires are compatible with municipal solid waste, landfill leachate, and can to be used as leachate drainage layer. Also ,ordinarily, shredded tires will provide protection to public health, when used as landfill drainage layer, by not containing leachate toxic materials, pathogens, and being odorless. Shredded tires provide adequate durability when they used as drainage material because they are not susceptible to puncture or tearing and are resistant to freeze-thaw cycles. Shredded tires, when used as landfill drainage layer, will provide protection to the environment by not contributing to leachate generation and not contributing significant organics or inorganics to leachate or surface run off (Geosyntec, 1998).

5. Cost Analysis

Using shredded tires as leachate drainage layer is generally cost effective with comparison to granular materials, despite the additional labor costs to shred the scrap tires. The cost saving may result from collecting tipping fees for the scrap tires, saving airspace by using tires shreds as an landfill drainage material, and reducing costs associated with importing or purchasing granular material. However, cost effectiveness should be evaluated based on the local availability of the scrap tires and the cost of conventional leachate materials varies. The costs of shredded tires ranges form $3 to $10 per ton (Gonzales et al,1995).

6. Engineering Properties of Shredded Tires

The engineering properties of shredded tires have been determined to analyze the adequacy of using shredded tires as landfill drainage layer. The physical characteristics of shredded tires are dependent upon the shred size, uniformity, and exposed wire content. The following properties are required to determine the efficiency of shredded tires as drainage material: (1) clogging potential; (2) compacted density; (3) compressibility; (4) gradation; (5) hydraulic conductivity; (6) physical compatibility considerations, (7) shear strength; (8) specific gravity; and (9) water absorption.

6.1 Clogging Potential

Shredded tires, compared with gravels and crushed stones, have large bulk and uniform gradation. This may increase shredded tires susceptibility of clogging due to infiltration of fine particles from overlaying operations layer or waste, mineral precipitations, and biofilm growing under the ambient anaerobic conditions below the landfill waste (Townsend et al, 1998). Clogging is often occurred during the acidogenic-phase when organic substrates and precipitating metals such as calcium, magnesium, iron, and manganese are highly concentrated in the leachate. The high substrate concentration stimulates biological growth and the development of biofilms which become encrusted with inorganic precipitates. Therefore, it is recommended to place a geotextile separator over the shredded tires to prevent the clogging behavior of leachate collection drains at municipal landfill sites. In addition, the recirculation of landfill leachate will reduce the potential for clogging since leachate recirculation promotes a shorter acidogenic-phase and enhances metal removal in the waste mass.

6.2 Compacted Density

The dry density of dumped shredded tires is range from 3.3 to 4.8 KN/m^3 whereas the dry density for compacted shredded tires is between 5.9 and 6.7 KN/ m^3 (Humphrey, 1997). The evaluation of shredded tires compaction characteristic are useful in determining the compactive effort required to achieve a workable material density. Previous investigations have shown that compactive energy has only a small effort on the resulting dry density or unit weight. Thus, the maximum dry density can be achieved with an average amount of compactive energy. The compacted dry density of soils is between 15.6 and 19.5 KN/ m^3 (Terzaghi et al, 1967). This indicates that the dry density of compacted shredded tires is approximately 60% less than the dry density of compacted soils. The dry density of a mixture of shredded tires and soils indicates that the more soil in the mixture, the higher the unit weight. The typical thickness of leachate drainage layer is between 300 to 450 mm and that can be achieved by placing the shredded tires in 1 to 2 lifts and compacted. The purpose of compaction is to rearrange the shredded tires to create a stable leachate drainage layer as a working surface.

6.3 Compressibility

Shredded tires have a compressibility that is several orders of magnitudes greater than materials typically used as landfill filters such as gravel or crushed stones (Geosyntec, 1998). The overburden pressure and resulting compression of shredded tires could be significant since the leachate drainage material is usually located at the base of the waste mass. The compressibility of the shredded tires should be accounted for specifying the minimum thickness of leachate drainage layer. Vertical strains of approximately 25% may occur in the shredded tires, 75 mm in size, under low vertical stresses of 48 Kpa. However, vertical strains of approximately 50% may occur under high vertical stresses of 483 Kpa (Nickels, 1995). The compressibility of the shredded tires should not have any effect on the densification of overlying wastes or reduction in achievable density of the waste above the drainage layer since the typical thickness of the shredded tires is between 300 to 450 mm.

6.4 Gradation

Sieve analysis test was performed twice at University of Illinois in Chicago in accordance with ASTM D422 (ASTM, 1994) to determine the particle size distribution of the shredded tires. Two testes were performed, using two samples of shredded tires, in order to verify the effects of compaction on the gradation of shredded tires. The first test performed without compaction whereas the second done after compaction in a modified Procter mold. The sieve analysis results indicated that the gradation of shredded tires is not significantly affected by compaction. Also, shredded tires can be classified as uniformly graded, meaning the particles are mostly the same size. The acceptable size of shredded tires that can be used as leachate drainage layer is ranges form 50 to 300 mm.

6.5 Hydraulic Conductivity

The evaluation of the hydraulic conductivity of the shredded tires is necessary to determine their performance as landfill drainage layer. The ideal drainage material should possess high hydraulic conductivity to allow free drainage and prevent the build up hydrostatic pressures. A constant head permeability test was performed at University of Illinois in Chicago and indicated that the hydraulic conductivity value of shredded tires is approximately 0.034 cm/s (Gonzales et al, 1995).

The high value hydraulic conductivity indicates that shredded tires will allow free drainage of water, which makes shredded tires a desirable landfill drainage material.

6.6 Physical Compatibility Considerations

Bead metal wires, 3 mm in diameter, protruding from shredded tires may scratch or puncture the geosyntheic materials used in the underlying barrier layer of the containment system. In contrast, thinner belt wires are more flexible and do not puncture the geomembrane layer (Geosyntec, 1998). There are two options to oppose the bead wire restriction. The first option is to place a minimum of 150 mm thick soil layer between the shredded tires and the geosyntheic barrier material. The second is to remove the bead wire completely prior to the shredding of the scrap tires. If one of these options accomplished, the shredded tires can be placed in direct contact with the geosyntheic barrier layer.

6.7 Shear Strength

The use of shredded tires as landfill drainage layer should not considerably impact the engineering performance of the landfill. Available published data on shear strength of shredded tires indicated that shredded tires have shear strengths at least comparable to typical values of municipal solid waste (Duffy, 1995). Generally, liner systems have critical layer interfaces, which are weaker than municipal solid waste. Therefore, the use of shredded tires as leachate drainage material should not have a detrimental effect on landfill stability.

6.8 Specific Gravity

The apparent specific gravity of the shredded tires depends on the amount of glass belting or steel wire in the tire. The specific gravity of shredded tires is between 1.02 to 1.27 meanings that tire shreds are heavier than water and will sink in the water (Humphrey, 1997). In contrast, the specific gravity for soil typically ranges from 2.6 to 2.8, which is more than twice that of tire shreds.

6.9 Water Absorption

Absorption capacity is the amount of water absorbed onto the surface of the shredded tires. It is usually expressed as percent water based on the dry weight of the shredded tires (Humphrey, 1997). The absorption capacity of the shredded tires typically ranges from 2% to 4%.

7. Experimental work

In this study, an experiment was designed to simulate a landfill environment to observe the effect of using shredded tires as a landfill drainage layer on landfill's leachate and solid waste biodegradation process. Three solid waste cells were built and used as a landfill bioreactor models. Leachate samples were collected from each bioreactor cells on weekly basis and analyzed for pH, BOD, and COD tests.

7.1 Bioreactor Design

The bioreactor cells were designed and constructed in accordance with W. Zekry (1998) experimental method.

7.2 Bioreactor Construction

7.2.1 Drain Pipe Installation

Each bioreactor cell had a hole drilled in the bottom to match the diameter of the drain spout (Zekry, 1998). PVC pipes were used to connect the bioreactor cells with leachate collection tanks and the contacted areas were sealed by silicon to prevent leachate and gas migration to the surface.

7.2.2 Leachate Recirculation Tank

10-liter plastic gas containers were used to collect the leachate generated in each bioreactor cell. The containers were turned 90º on their side and had a 5 cm diameter hole drilled to fit the drain spout protruding from the base of the containers. The vents of the containers were fitted with a brass screw type adapter to allow the connection of flexible tubing.

Three water pumps were used to recirculate the leachate collected in the 10 L tanks to the bioreactor cells. A flexible rubber tube was used to connect each pump inlet to the corresponding leachate tank. The outlet of each pump was connected to approximately 80 cm of tubing that extended vertically and was attached to a plastic hub that divided the flow into 10 cm pieces of aquarium airline tubing. The four equal streams were inserted into the bioreactor lid.

The gas collection system consists of well and collection device. A 13 mm PVC tube was used as a collection well. A length of 75 cm was cut and perforated to allow for gas migration. The tube was wrapped with # 200 nylon mesh to prevent fine particles from clogging the well. A flexible rubber tube was attached to the brass connector to transmit the gas generated in the bioreactor cell. The tube was then placed into graduated cylinder that was submerged into plastic cylinder. The graduated cylinder was filled with water and the initial water level was recorded. The generated gas will migrate through the well and transmitted be the rubber tube into the graduated cylinder. The amount of gas generated will be equivalent to the amount of water displaced in the graduated cylinder.

A plastic cover was used to enclose the bioreactor cell. The cover was sealed by silicon to prevent the migration of generated bioreactor gases to the surface. Also, to prevent air from entering and exiting the bioreactor cell. A brass connector was attached to the cover to connect the PVC gas well with the rubber tube. Four holes were drilled into the cell cover to allow the recirculated leachate to enter the system and distribute evenly through the waste particles.

7.3 Bioreactor Loading

The solid waste used in this experiment was collected from the curbsides of the city of Toronto in order to achieve a representative solid waste sample that normally goes to the landfill. Visual inspection of the refuse showed presence of a variety of food wastes, papers, packaging materials, yard wastes, glass containers, and tin cans. The waste was collected for a period of 2 weeks, chopped down into smaller portions, and thoroughly mixed. A sample splitter was used to divide the wastes into three equal portions. For each bioreactor, the following loading was done:

- 10 cm of shredded tires was used as drainage layer for the first bioreactor, gravel and crushed stones were used for the second and third bioreactor respectively.
- 35 cm of reprehensive solid waste layer was placed on top of each bioreactor's filter.
- A small layer of shredded tires, gravel and crushed stones was placed at the top of solid waste respectively for the first, second and third bioreactor. The purpose of this layer is to provide an even distribution of the recirculated leachate.
- 7 liters of tab water was added to each bioreactor.
- The bioreactor covers were sealed using silicon.

The leachate of each bioreactor was recirculated once a week at rate of 10 liter/week. 200 ml leachate samples were taken from each bioreactor once a week and analyzed for BOD5, COD, and pH tests. The Hydraulic Conductivity test of the shredded tires was performed in the Geotechnical lab at Ryerson University to measure the permeability of the drainage layer.

8. EXPERIMENTAL RESULTS

8.1 pH versus time

Figure 1 pH vs. Time

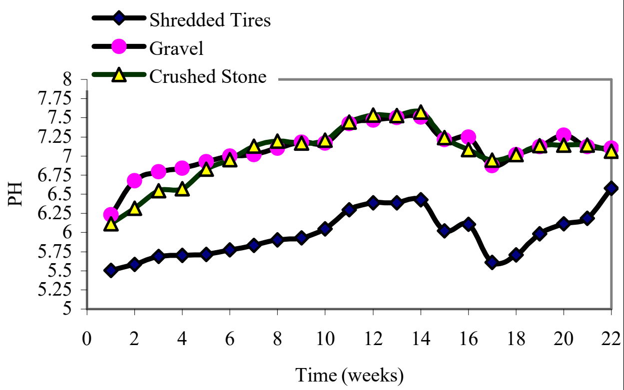

Figure 1 Change of PH with time

The variations in leachate pH during its recirculation in the bioreactor cells are illustrated in Figure 1. The pH measurements were done immediately after the leachate samples were obtained. pH measurements can be used as an indicator for stage of solid waste decomposition. Figure 1 shows that all the drainage materials, especially shredded tires, started at low pH and gradually increased until week 14. The pH values then dropped between weeks 14 to 17. The three curves moved up after week 17, hitting towards the neutral pH. The pH values that range between 4.7 to 7.7 indicate that waste decomposition have reached the Acid Formation Phase (Townsend et al, 1998).

8.2 BOD vs. Time

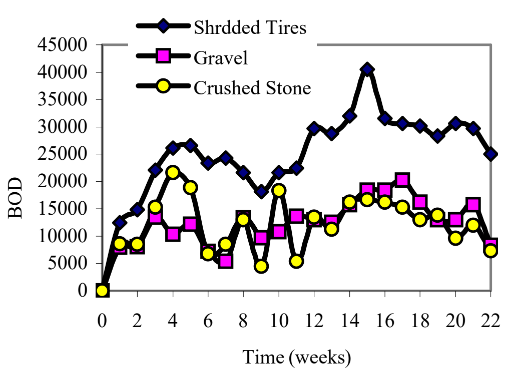

Figure 2 Variation of BOD/Cod ratio over the course of the experimental study

The analysis of biochemical oxygen demand (BOD) parameter was conducted over a period of 22-weeks and the results are shown in Figure 2. BOD test represents the amount of oxygen consumed by bacteria and other microorganisms while they decompose the organic matter. The BOD tests were done 24-hours after the leachate samples were defrosted. Figure 2 shows that the BOD values of shredded tires are higher than BOD values for gravel and crushed stones. The concentration of BOD reached a peak value of about 40,500 mg/L in the leachate from shredded tires cell. BOD values from week 2 to 14 were unstable for gravel and crushed stones bioreactor cells. After week 14, BOD values became more stable and around week 19, all the curves start to move downwards.

8.3 COD versus Time

Figure 3 COD versus Time

The determination of chemical oxygen demand (COD) was used to measure the overall level of organic contamination in the leachate. The contamination level is determined by measuring the equivalent amount of oxygen required to oxidize organic matter in the leachate sample. The peak COD concentration of about 55,480 mg/L was detected in the leachate sample from shredded tires cell. Figure 3 shows that shredded tires leachate have COD values greater than gravel and crushed stones leachate.

8.4 BOD/COD vs Time

Figure 4 BOD/COD versus time

The BOD/COD ratio was computed for the three cells in order to investigate the proportion of the biodegradable organic matters in bioreactor leachate. Figure 4 shows that shredded tires curve has higher BOD/COD ratio compared to gravel and crushed stones curves. The BOD/COD curve for shredded tires lies approximately between (0.4 to 0.8). A ratio of 0.4-0.8 implies a highly biodegradable leachate (Townsend, 1998). The high BOD/COD ratio in shredded tires cells may result from the high level of the organic contents in the shredded tires cell.

8.5 Hydraulic Conductivity

Figure 5 Falling Head Test

The falling-head test was performed to measure the hydraulic conductivity of the shredded tires. Figure 5 shows the apparatus set up for this test. The test measured the water flow through landfill drainage material (shredded tires). The test was performed four times for accuracy. The required hydraulic conductivity for landfill drainage layer is 0.001 cm/sec (Mcbean et al, 1995). The average calculated hydraulic conductivity of shredded tires was found to be 0.00115 cm/sec. This value indicates that shredded tires will allow free drainage of water and prevent any build up hydrostatic pressure, which makes shredded tires a desirable landfill drainage material.

Conclusions:

Based on present study, the following conclusions can be made:

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