Determination of the suitable size of tire chips for landfill leachate treatment

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ABSTRACT
Five bio-filters were built in the laboratory. Four of which were packed with different sizes (mixed, large, medium and small) of tire chips and the remaining one was packed with tire crumbs to determine the suitable size of tire chips for landfill leachate treatment. The overall results demonstrated that highest removal of BOD (55-56%), COD (93-100%), NH_3-N (78-80%), TS (42-45%) and TSS (98-100%) were attained in small (10-20 mm) and medium (20-40 mm) size tire chips. The bio-film, 25 g/kg or 1.1 kg/m^2 surface area of tire chips, was equally attached onto both the medium and small sizes tire chips. Indeed, minimal clogging effect, which was observed in these two media did not considerably affect the hydraulic conductivity. Based on the findings, 10-40 mm size (defined as small and medium) tire chips can be used as packing media in bio-filter for secondary treatment of landfill leachate.

RÉSUMÉ
Cinq bio-filtres ont été construits dans des états de laboratoire. Quatre dont ont été emballés avec différentes tailles morceaux (mélangés, grands, moyens et petits) de pneu et autres ont été emballés avec des miettes de pneu pour déterminer les tailles appropriées des morceaux de pneu pour le traitement de lixiviat de remblai. Les résultats globaux ont démontré que le déplacement le plus élevé de la DBO (55-56%), la MORUE (93-100%), NH_3-N (78-80%), les SOLIDES TOTAUX (42-45%) et les SOLIDES SOLUBLES TOTAUX (98-100%) ont été atteints dans petit (10-20 millimètres) et les tailles du milieu (20-40 millimètres) fatiguent des morceaux. Le bio-film, la superficie 25 g/kg ou 1.1 kg/m^2 du pneu ébrèche, a été joint également à l'un ou l'autre milieu et les petites tailles fatiguent des morceaux. En outre, l'effet obstruant minimal était dans ces deux médias, qui n'ont pas affecté de manière significative la conductivité hydraulique. On le conclut que des morceaux de pneu de tailles de 15-40 millimètres (définies comme petites et moyennes) peuvent être employés comme médias d'emballage dans le bio-filtre pour le traitement secondaire du lixiviat de remblai.

1 INTRODCTION

In Canada, huge generation of undesirable scrap tires is a growing issue of health risk and harm to the environment because tire materials are not biodegradable. The scrap tire stockpiles provide the congenial breeding ground for mosquitoes, rodents, snakes, and west Nile viruses thereby become a potential source for health hazards (Mondal, 2006). Not only have that, incineration of scrap tires caused the hazardous pollution in air (BP-431E, 2002; Rowe et al., 2002; Robert and Christian, 2003; Warith *et al*, 2002). Furthermore, disposing of scrap tires in landfills takes much more space due to their uneven settlement and tendency to rise to the surface that will damage landfill covers. The toxic substances liberated from the predisposed tire materials can also cause serious environmental impacts (Rowe *et al*., 2005). The extended producer responsibility policy for tire stewardship program in Ontario supports the goal of "zero waste" approach philosophy through 3Rs-reduce, reuse and recycling programs (EPR, 2008). The recent "zero-waste" approach desperately advocates the reuse of discarded tires. As a result, finding more options than available for scrap tire reuse is more important than disposing these tires to landfills and incinerating them. An alternative use of scrap tires, Mondal and Warith (2008) and Rowe et al. (2005) tried to use the mixed tire chips of size 10-100 mm for landfill leachate treatment but the performance of mixed tire chips was not conducive to the landfill leachate treatment compared to crushed stones and sands. However, on the basis of their investigations, it may be concluded that relatively more homogeneous tire chips than existing tire chips may provide a better performance in the field.

In addition to the problems of using scrap tires, landfill leachate treatment becomes another challenging issue embedded with high cost technology and water pollution through leaching. To protect the groundwater environment from contamination, there is an urgent need for treating landfill leachate before final discharge to lagoon or wastewater treatment plants to reduce the cost burden. Recent studies have suggested that aerobic bio-filtration can be a proven low-cost technology for landfill leachate treatment through the use of suitable size of tire chips (Mondal and Warith, 2008). However, rapid clogging in the existing leachate treatment system is a major issue considering particularly its cost to be addressed to resolve in an economical way. Hence, the removal rate of contaminants and study of hydraulic conductivity of the tire chips pertaining to the pore-size distribution could provide the information for optimal sizes of tire chips.

Keeping the above views in mind, the purpose of this study is to design a cost effective bio-filter for secondary treatment of landfill leachate through the trials of different sizes of tire chips within acceptable remediation limits. The specific objectives of this research work are to (1) find out the suitable size of tire chips for effective filtration bed of a secondary bio-filter, and (2) assess the clogging effect of tire chips through measuring the reduction of hydraulic conductivity.

2 MATERIALS AND METHODS

2.1 Experimental design and grading of tire chips

The experiments were conducted as the second part of the research at two phases within the period of June to August 2008. Each phase of the study was observed for 21 days (phase 1 from July 21, 2008 and phase 2 from August 8, 2008). Five PVC upward flow bio-filters were constructed with diameter 0.30m and column height 1.2m. Each bio-filter was filled with tire materials up to 1.1m. Shredded tire chips and tire crumbs were collected from a shredding facility, Transept Automation Inc., City of St. Catharines, Ontario. The size of collected shredded tire materials (chips and crumbs) were graded into five categories such as Mixed tire chip (MI): 10-100 mm, Large tire chip (LA): 50-100 mm, Medium tire chip (ME): 20-40 mm, Small tire chip (SM): 10-20 mm, and tire crumbs (CR): 1.5-6.5 mm. Four columns were packed with four different sizes of tire chips (MI, LA, ME and SM) and the remaining one was packed with tire crumbs. The effective volume of each column was 0.31 m^3 tire crumbs. The effective volume of each column was 0.31 m^3, and a constant head of 17 cm was maintained to compare the flow rates. The variable displacement pumps were used to pump the leachate.

2.2 Procedure for Packing of Tire Materials

The tire materials were thoroughly washed with tap water and dried for an hour in an oven. Before packing the columns, the surface area, bulk density, particle density, porosity, volume, hydraulic conductivity and retention time of each category were determined. Table 1 represents the physical properties of tire materials. After completion of the procedure, the PVC columns were packed with tire chips and crumbs applying equal intensity of pressure by a 2 cm diameter steel rod.

2.3 Collection of Landfill Leachate

Leachate was collected from Keel Valley Landfill (KVL) near the City of Toronto. This landfill is about 22 to 25 years old and enriched with highly organic matters.

2.4 Preparation of Influent

Before starting the experiment, the media was acclimated with KVL leachate diluted with 75% of tap water. After acclimation of the media, raw KVL leachate was directly used for phase 1 immediately after collection. For phase 2, activated sludge was collected from Lesley water treatment plant and added to the preserved leachate that was used in phase 1 at the rate of 10 gm per liter to enhance the population of micro organisms. In addition, the preserved leachate was enriched with synthetic compounds to build up more organic loading. However, zinc sulphate and copper sulphate were not added to the leachate since these metallic compounds were available in the preserved leachate. The composition of synthetic leachate was basically the same as the composition used by Mondale and Warith (2007) that was adapted from Rowe *et al*. (2002).

2.5 Hydraulic and Organic Loading Rate

The hydraulic loading rate for the experiments were maintained between 1.0 $m^3\ m^{-2}\ d^{-1}$ and 4.0 $m^3\ m^{-2}\ d^{-1}$ to enhance better biodegradation. Mondal and Warith (2007) observed better biodegradation at this low flow rates. In phase 1, organic loading rate maintained at 0.38 to 0.77 kg $BOD_5\ m^{-3}\ d^{-1}$, which resembles organic loading rate for a low-rate submerse or trickling filters. For phase 2, organic loading rate was increased in the range of 0.66 to 0.77 kg $BOD_5\ m^{-3}\ d^{-1}$ that is near to the high rate of organic loading of 0.32 to 1.0 kg $BOD_5\ m^{-3}\ d^{-1}$ (Metcalf and Eddy, 2002).

2.6 Air Supply System

A continuous air supply into bio-filters was made available using air blowers to maintain dissolved oxygen (DO) between 3.5 mg/L and 5.0 mg/L during the experimental periods. The pH was stabilized between 7.5 and 8.5. Knox (1985) maintained the DO level in leachate approximately 2 mg/L. Air flow into leachate was used 1 $m^3\ m^{-1}\ min^{-1}$ as Mondal and Warith (2007).

2.7 Biomass Attachment Monitoring

During the 21 day experimental periods, tire chips and tire crumbs were left undisturbed to grow colony of microorganism onto its surfaces. Biomass attachment onto the surface of the tire chips, tire crumbs and sloughing of biomass were quantitatively monitored throughout the experiment.

2.8 Equipments Used for Testing and Analysis

Raw leachate samples at three repetitions were grabbed from a common holding tank to analyze the initial levels of BOD, COD, NH_3-N, TSS, and TS. During the experimental period, the leachate samples were collected at every three days intervals for the same observations. Standard methods (Laboratory Manual, 2006) were followed to analyze the test parameters. For BOD_5 test, the DO levels in distilled water was maintained at 8.0 ± 0.5 mg/L using an aerator. Horiba

Table 1. Physical properties of different sizes tire materials used as packing media of bio-filters.

Tire materials	Surface area (cm^2/chip)	Bulk density (g/cm^3)	Particle density (g/cm^3)	Porosity (%)	Hydraulic conductivity (cm/S)	Retention time (hr)
Mixed (MI)	33.6	0.575	1.24	0.54	0.1705	3.23
Marge (LA)	67.8	0.446	1.27	0.55	0.0870	3.30
Medium (ME)	23.3	0.542	1.23	0.54	0.1744	3.23
Small (SM)	11.1	0.546	1.20	0.52	0.1767	3.12
Crumbs (CR)	--	0.491	1.03	0.48	0.0304	2.88

DO Meter OM-51, Japan was used to measure the DO level for BOD analysis. A Lambda 20 spectrophotometer manufactured by Thermo Electronic Co. was used for determining the COD concentrations in leachate. The available NH_3-N concentration in leachate was measured by using Horiba pH/ION Meter, D-53, Japan. A pH meter-OAKTON pH 6 Acorn Series was used to measure pH and temperature of the samples. Analytical methods were applied to measure the TS and TSS concentrations in leachate samples (Laboratory Manual, 2006).

3 RESULTS AND DISCUSSION

3.1 Typical Composition of Leachate

The initial compositions of leachate collected from Keele Valley Landfill were as follows: total solid (TS) 10850~15250 mg/L, total suspended solid (TSS) 300~1000 mg/L, BOD 400~1500 mg/L, COD 2375~4500 mg/L, NH_3-N 376~1750 mg/L, turbidity 22000~52000, pH 6.5~8.5. While in Ontario, the acceptable limits of contaminants in leachate are TS 300~400 mg/L TSS 5~30 mg/L, BOD 5~30 mg/L, COD 100~200 mg/L, NH_3-N 5 mg/L, Turbidity 2~5 NTU, and pH>6.5. These results indicate the KVL leachate is very strong and needs treatment before leaving to drainage systems or lagoon or municipal water treatment facilities.

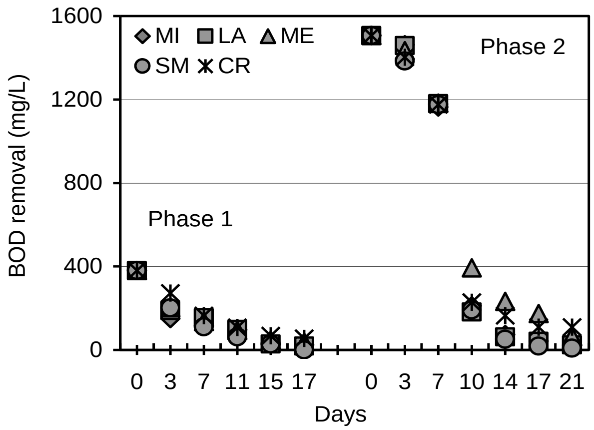

Figure 1. Removal of biological oxygen demand (BOD) by different tire materials.

3.2 Performance of Bio-filters

3.2.1 Removal Efficiency of BOD

The BOD removal efficiency of all tire materials was above 90%, which is a positive signal of reliability of using tire material for landfill leachate treatment. Initially, the removal efficiency of BOD was very rapid during the first 10 to 14 days by all tire materials (Figure 1). After 21 days, 100% removal of BOD was achieved at the bio-filter packed with small size tire chips compared to other packing media (Table 2). This can be attributed from the better aggregates, porosity and air passages through the small size tire chips that might initiated the growth of microorganisms for faster organic adsorption. Similar characteristics of tire chips were reported by Modal and Warith (2008). Although, the BOD removal efficiency of other three sizes of tire chips (MI, LA, ME) was above 90%, but the deviation among the phases were remarkably higher (Table 2). While the performance of tire crumbs for BOD removal recorded fewer than 90%. Although the average BOD removals shown in Table 2 have no big difference among the tire chips, the small size tire chips might be more reliable for using as packing media of bio-filter for leachate treatment. In small size tire chips, adequate growths of bacteria might have potential influence for 100% biodegrading the solids available in leachate.

3.2.2 Removal efficiency of COD

Initially, the removal rate of chemical oxygen demand (COD) was rapid during the first 10 days of the experiment under all tire chips except tire crumbs (Figure 2); this might be accelerated by high density of bacterial growth. Similar trends in COD removal were reported by Mondal (2007) and Memon (2006). The color of leachate changed along with the COD removal rate. At the beginning of the phase I and phase II experiments, the concentrations of COD were high 2275 mg/L and 4465mg/L respectively. It was noticed that the color of leachate changed with removal rate of COD. At 0 day, 10 days and 21 days of experiments, the leachate color observed were blue, bluish green and light yellow respectively.

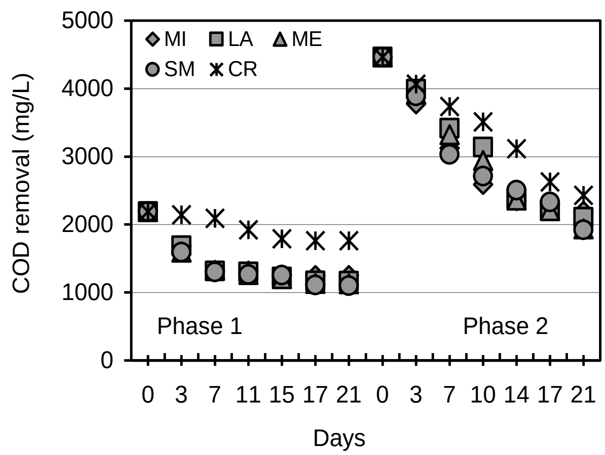

Figure 2. Performance of tire materials for removing the chemical oxygen demand (COD).

The bio-filter packed with medium sizes tire chips attained the highest removal efficiency of COD (54-58%) followed by small sizes tire chips (53-57%) (Table 2). Thus, 18% higher COD removal was observed at medium and small sizes tire chips over mixed tire chips used by Mondal and Warith (2007) in their studies. Also a non-linear regression curve fitted with COD removal by medium and small sizes tires chips was found to be highly significant (R^2 = 0.85**). This analysis recommends that medium and/ or small size tire chips can be used in bio-filter for landfill leachate treatment.

3.2.3 Impact of BOD:COD Ratio on Leachate Treatment

Table 2. Reduction of contaminants and hydraulic conductivity during the experimental period.

Measured parameters	Days (/phase)	Phase	Removal efficiency of contaminants by different sizes tire materials (%)				
			Mixed (MI) (%)	Large (LA) (%)	Medium (ME) (%)	Small (SM) (%)	Crumbs (CR) (%)
BOD	21	1	94	95	90	100	86
		2	99	98	96	99	93
COD	21	1	45	49	54	54	29
		2	49	51	58	57	36
NH_3-N	21	1	59	66	70	74	18
		2	87	85	80	90	66
TS	21	1	36	40	45	42	24
		2	15	17	19	16	14
TSS	21	1	77	73	80	90	73
		2	96	96	95	96	93

The BOD:COD ratio is widely used as conventional index of biodegradability of leachate or wastewater. Higher ratio of BOD:COD indicates better the biodegradability and lower ratio indicates lower biodegradability. It has been demonstrated by Samudro and Mangkoedihardjo (2010) that BOD:COD>1.0 represent the toxic limit and the ranges 0.1 to 1.0 (low, moderate, and high) is biodegradable. The BOD:COD ratio exhibited the similar trend in both phases (Figure 3). The higher values in BOD:COD ratios of 0.29 observed at Phase 1 and 0.39 at Phase 2 at 3rd and 7th day, which implies the high biodegradation that means high rate of solids were eaten by bacteria within 7-10 days. This result recognized the findings of Kaornaros and Lyberatos (2006).

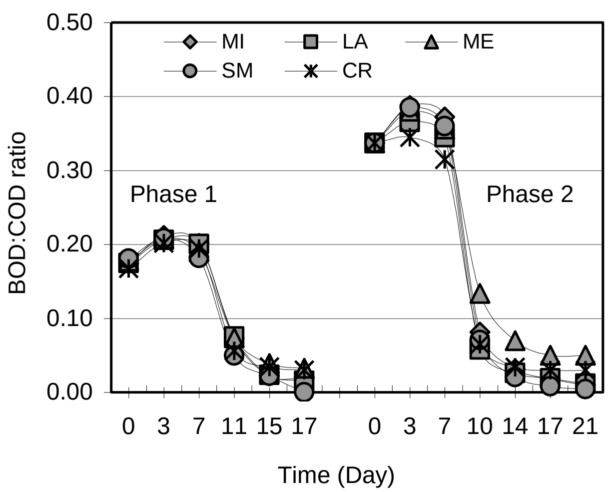

Figure 3. The BOD:COD ratio of different tire materials.

Also clear discrimination in BOD:COD ratio among different sizes of tire materials indicated the variation in the percentage of biodegradable compounds in leachate (Figure 1 and Figure 2). The BOD:COD ratio below 0.18 in all bio-filters throughout the experiment is less biodegradable leachate and greater than 0.25 is highly biodegradable leachate (Warith et al., 2002; Jin, 2005; Mondal, 2006). In phase 2, the BOD:COD ratio was well below 0.10 in all bio-filters when COD was stabilized and BOD continued to be removed. It is also evident that better biodegradability of leachate obtained in medium and small size tire chips compared to other tire materials. Based on the analytical results, it can be proposed either medium or small size tire chips or its combination could be used for secondary treatment of leachate.

3.2.4 Removal of Ammonia-Nitrogen

The trend of ammonia-nitrogen removal rate was very similar to that of BOD and COD removal. Figure 4 showed that the removal rate of NH_3-N was linear with time for each bio-filter except the bio-filter packed with tire crumbs. Poor performance of nitrogen removal (42%) was served at tire crumbs; this might be due to less acclimation

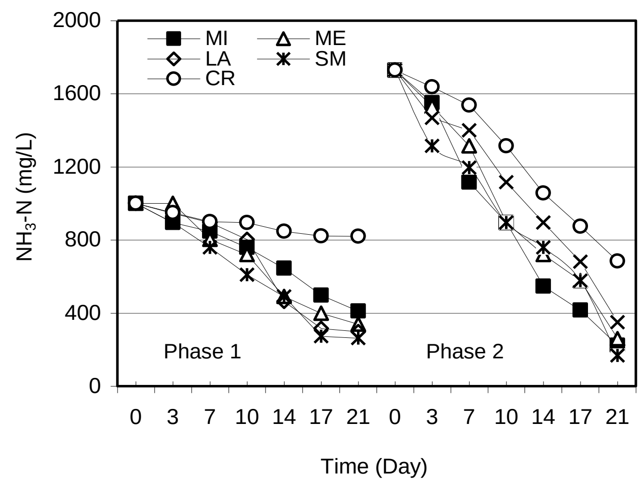

Figure 4. Removal of ammonia nitrogen by tire materials.

of nitrifying microorganisms in tire crumbs affected from clogging effect. Although, as summarized in Table 2, the bio-filters packed with four different sizes of tire chips did not significantly reduce ammonia, the bio-filter packed with small size tire chips had the highest removal efficiency (84%), and mixed, large, and medium tire chips achieved 73%, 79%, and 79% respectively. Mondal and Warith (2006) reported NH_3-N removal for mixed tire chips and tire crumbs of 67-68% and 58-67% respectively. It is suggested that the small size tire chips could be used as packing media of bio-filter for landfill leachate treatment to remove NH_3-N.

3.2.5 Removal of Total Solids and Total Suspended Solids

The removal rate of TS and TSS are presented in Figure 5, Figure 6 and Table 2. It is evident from both phases of studies that TS removal was limited and some removal was achieved, with medium size tire chips performing the best (45% and 19%), followed by small size tire chips (42% and 16%), medium sizes tire chips (40% and 19%), and other two media (MI and CR) (Figure 5).

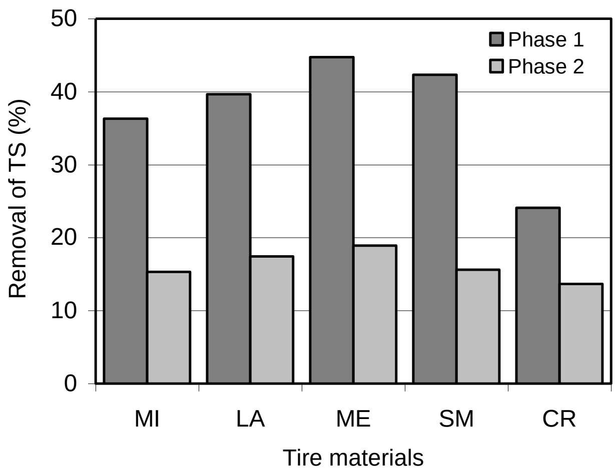

Figure 5. Removal efficiency of total solids by tire materials.

As TSS was relatively low (Figure 6), the majority of the TS removed were total dissolved solids, this is reflected as the reduction of conductivity (Table 2). All five bio-filters achieved complete or almost complete removal of TSS after 21 days study period; however, within 7 to 10 days a significant amount of TSS was removed by small and medium sizes tire chips (Table 2, Phase1). This result indicated that the medium and small sizes tire chips are suitable for the removal of TS and TSS from leachate.

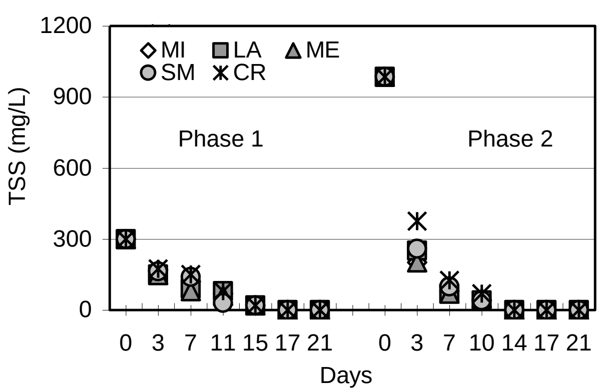

Figure 6. Removal of total suspended solids from leachate by tire materials.

3.2.6 Analysis of Hydraulic Conductivity

Hydraulic conductivity (HC) is an important parameter to identify the clogging effects in bio-film reactors. The reduction rate of HC in respect to time was monitored for each bio-filter to assess how long it would take for clogging in order to reduce the HC. The decrease in HC was significant and affected by different size tire materials (Figure 7). It is evident from Figure 7 that HC were severely affected by bio-filter packed with tire crumbs and within 7 days it reached nearly zero. However, due to better physiological properties such as pore space, medium size tire chips followed by small size attained the highest HC

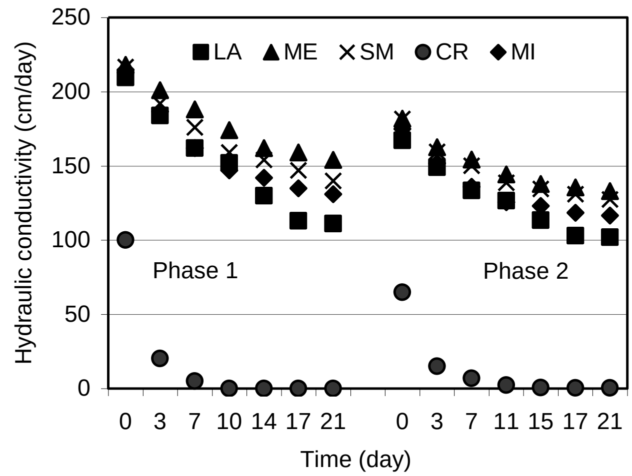

Figure 7. Daily reduction rate of hydraulic conductivity affected by different tire materials.

compared to other three tire materials. In a column study, Kerry *et al*., (2006) observed similar behavior at 15 mm size packing media than 4-6 mm sizes packing materials. In addition, the lowest decrease in HC (24%) recorded at medium size tire materials followed by small and large size tire materials (31%). On the other hand, the highest decrease (98%) in HC observed at tire crumbs due to its severe clogging effect. Furthermore, it is concluded that

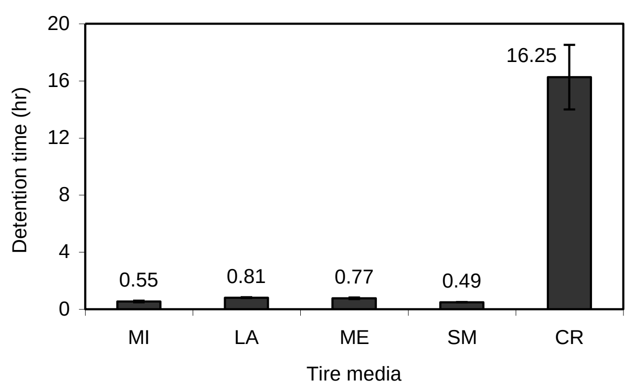

Figure 8. Detention time affected by different tire materials.

bio-clogging has decreased the HC through reducing the pore volume for long-term use. Therefore, medium size tire chips can be proposed for landfill leachate treatment.

Figure 8 exhibits the detention time measured at the end of experiment to evaluate the clogging effect of different tire materials. Low detention time (0.49 hr) was measured at the biofilter packed with small size tire chips that is an indication of the least clogging effect accelerated by void spaces.

High detention time (15.7 hrs) was measured at biofilter packed with tire crumbs that was affected by severe clogging effect (Figure 8). Most of the researchers agreed that bio-film morphology, BOD, suspended solids and bacteria are primarily responsible for clogging (Clabaugh, 2001; Kerry et al., 2005). Deposition of clogging materials onto the surface is an important parameter to see the suitability of tire materials for landfill leachate treatment. Figure 9 (a and b) depicted the deposition of organic slime that causes the clogging effect of the packing materials. High amount of clogging materials (24.1-24.8 g/kg) were deposited onto the surface of medium and small size tire chips (Figure 9a). In addition, Figure 9(b) showed the deposition of clogging materials onto unit surface area of tire materials. The highest quantity of clogging materials (1.10 kg/m^2) was deposited onto unit surface area of small size tire chips followed by the medium size tire chips (0.40 kg/m^2). The results confirmed the reliability of using 10-40 mm size tire chips (20-40 mm was defined as medium size and 10-20 mm as small size) as low cost alternative biofiter for landfill leachate treatment instead of tire crumbs and mixed or large size tire chips.

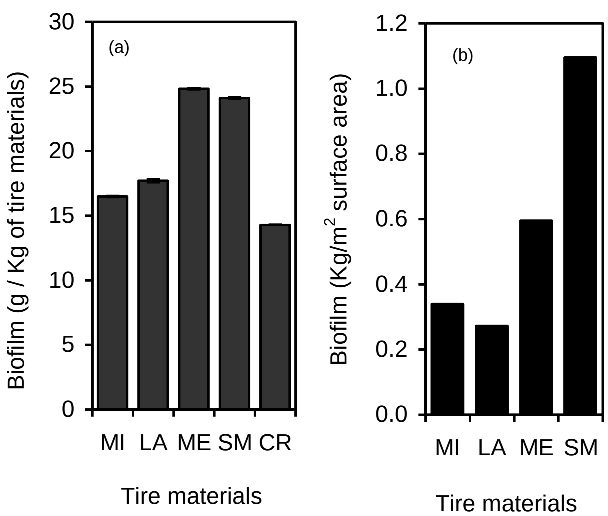

Figure 9. Deposits of clogging materials (biofilm) onto tire chips and crumbs (a) g/kg of tire materials, (b) kg/m^2 surface area.

3.2.7 Analysis of Clogging Effect

The rate and extent of clogging development is dependent on several factors, such as bio-film morphology - pore space, surface area, wastewater composition (or strength), loading rate, application method and continuation of experimental time (Dermou and Vayenas, 2007; Clabaugh, 2001; Kerry et al., 2005).

CONCLUSIONS

At the end of the studies, some deposition was observed at the bottom of each bio-filter along with bio-film attachment onto the surface of tire chips which indicated that most of the treatment occurred in suspended condition. At these circumstances, the packing media performed as a physical filter to clean the leachate. The treatment behavior of different sizes of tire chips was notable and the performances were very similar between phase 1 and phase 2. The overall results and discussion of the experiment leaded to conclude the followings:

1. The BOD, NH_3-N, TSS removal was 93-100%, 78-80% and 98-100%, respectively. The highest achievement that was observed at medium and small size tire chips which satisfied the Ontario wastewater disposal limits and regulations.
2. No back washing was needed within 21 day study period as less reduction in hydraulic conductivity (24-31%) observed at medium and small size tire chips that adhered by minimum clogging effect at these two sizes of tire chips.
3. The results revealed that secondary bio-filters could be designed as low cost alternative for landfill leachate treatment using 10-40 mm size tire chips instead of using the proven mixed size tire chips (Mondal and Warith, 2008).
4. This technology is suggested to be used by Municipality Landfill Inc., Municipal Solid Waste Management, Waste Diversion Ontario through reuse of scrap tire, Industry, Agricultural Farm, and other waste management authorities for landfill leachate or wastewater treatment.

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