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Comparison of Shredded Tire Chips and Tire Crumbs as Packing Media in Trickling Filters

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A five stage study was conducted using two trickling filters, one with shredded tire chips (12 to 50 mm) and the other with tire crumbs (1.5 to 6.5 mm) as packing media, and both landfill leachate and synthetically prepared leachate, to evaluate treatment performance. Due to increased surface area and sorption capacity, compared with other materials, a thick layer of biomass developed over the surface of tire chips and crumbs and sloughed off after approximately 21 days. Biochemical oxygen demand, chemical oxygen demand, and ammonia nitrogen removal were in the range of 81 to 96%, 76 to 90%, and 15 to 68%, respectively, under stable conditions. Organic removal and total dissolved solids reduction from the leachate were well correlated, with the exception of when biomass sloughing caused an increase in the organic content. The trickling filter with tire crumb media exhibited a more consistent organic removal throughout the experimental program. Tire chips, being readily available, could be a better alternative to crushed stone or gravel as a packing media in trickling filters. Tire crumbs appeared to be promising for small scale treatment systems.

***Key words*: tire chips, tire crumbs, surface area, organic content**

Introduction

Scrap tire generation is a growing concern in Canada and the United States. Scrap tire stockpiles are potential health hazards, so finding options for scrap tire use is important. The product of shredded tires is usually referred to as "tire chips" which are typically between 12 and 50 mm in size and have most of the steel belting removed. The term tire shred or rough shred is used to describe larger tire particles, generally ranging in size between 50 and 305 mm (Lee et al. 1999). There are some practical concerns for the use of tire shreds, including health and safety issues related to handling when steel belt fragments and steel rims in the tires are present (Warith et al. 2004). When tire chips are granulated to crumbs in size ranges between 1.5 to 6.5 mm, the advantage is that loose steel and fibres can be completely removed. Tire crumbs have been used in construction and in recycled rubber production (Depository Services Program) (Government of Canada 2002).

The suitability of shredded rubber tires as an alternative to crushed stone in the leachate collection drainage layer of a municipal solid waste landfill site has been investigated (Warith et al. 2004). Certain important characteristics of tire chips, such as hydraulic conductivity, surface area, sorption capacity, compressibility, and environmental factors like pH and temperature will influence landfill leachate treatment. Thicker biofilm and a surprising level of supported invertebrates on the tire chips, compared with stone aggregates used in trenches, have been noticed in North Carolina and South Carolina (Grimes et al. 1999). Several micro- and macro-organisms including grazers, saprophytic feeders, and filter feeders were found in the South Carolina tire chip trenches. This complex and diverse group of organisms signalled the potential for wastewater treatment using tire chip aggregates (Grimes et al. 1999).

Recent applications of tire shreds in treatment systems such as drain-fields, septic tanks, and constructed wetlands indicate potential opportunities for recycling scrap tires. Besides compressibility and permeability, other factors like sorption capacity, surface area, and thermal conductivity must be studied further to better understand the processes and to evaluate any additional benefit.

The objective of this research program was to quantitatively compare the performance of shredded tire chips and tire crumbs for removal of biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), ammonia nitrogen (NH_3-N), and suspended solids from leachate using trickling filters. Landfill leachate and synthetically prepared leachate were used in this evaluation to investigate the use of scrap-tire-based attached growth media for the treatment of wastewater and leachate.

Materials and Methods

Packing Materials

Shredded tire chips and tire crumbs ranging in size between 12 to 50 mm and 1.5 to 6.5 mm, respectively, were obtained from Trensept Automation Inc. from St. Catharines, Ontario. The tire chips and crumbs were

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thoroughly washed with distilled water and dried at 105°C for 1 hour prior to use. Commercial gravel with diameters ranging between 12 and 20 mm was used as a drainage layer in the bottom of the two trickling filters employed for this experimental program.

Leachate

Landfill leachate was collected from the Keele Valley Landfill (KVL) (Toronto, Ontario). This landfill has been active for between 20 and 25 years, and the leachate is considered to be stable and organically enriched. Leachate samples were collected periodically throughout the experiments.

Synthetic leachate was prepared using a modified method from Rowe et al. (2002) (Tables 1 and 2). For the purposes of this work, the majority of the inorganic constituents in the trace metal solution were not used. Only zinc sulphate (99 to 103%) and copper sulphate (98 to 102%) were used in the trace metal solution preparation.

TABLE 1. Composition of synthetic leachate [a]

Component	*Purity (%)*	*Amount Added (/L)*
Acetic acid	99.7	7 ml
Propionic Acid	99	5 ml
n-Butyric acid	99	1 ml
K_2HPO_4	99.9	30 mg
$KHCO_3$	99.7–100.5	312 mg
K_2CO_3	99	324 mg
NaCl	99	1,440 mg
$NaNO_3$	99	50 mg
$NaHCO_3$	99–100.5	3,012 mg
$CaCl_2$	98.7	2,882 mg
$MgCl_2.6H_2O$	99	3,114 mg
$MgSO_4$	98	156 mg
NH_4HCO_3	21.3–21.73	2,439 mg
$CO(NH_2)_2$	99–100.5	695 mg
NaOH	97	To titrate to pH 7.0
Trace metal solution	(See Table 2)	1 mL
Tap water	—	To make 1 litre

[a] Modified from Rowe et al. (2002).

TABLE 2. Composition of Trace Metal Solution [a]

Solution components	*Purity (%)*	*Amount Added (/L)*
$ZnSO_4.7H_2O$	99–103	50 mg
$CuSO_4.5H_2O$	98–102	40 mg
H_2SO_4	96	1 mL
Distilled Water		To make 1 litre

[a] Modified from Rowe et al. (2002).

Preparation of Influent

Raw KVL leachate was diluted with tap water in a 50:50 ratio and used as influent during acclimation and stage one. Once the packing media was acclimatized with leachate, synthetic leachate was mixed with diluted leachate in 50:50 ratios and passed through the trickling filters during stage two. Slowly, the proportion of real leachate was reduced. KVL leachate was mixed with synthetic leachate in a 25:75 ratio during stage three. When the system was stable with leachate-friendly microorganisms, synthetic leachate only was used during stages four and five.

Trickling Filter Set-Up and Operation

Two 1.28 m-tall polyvinyl chloride tanks of 0.6-m diameter each were used as the two trickling filters and identified as TF1 and TF2 (Fig. 1). A 0.91-m tire chip/tire crumb packing and a 0.1-m gravel base were placed in each filter unit. A fixed distributor arm was placed within the available 0.25-m space at the top of the packing media. A single centrifugal feed pump, with a header line, was used to distribute and disperse leachate into the two trickling filters through the individual distribution arm in each filter unit. The entire system was operated for 10 hours every day during the acclimation and stage two, and continuously during stages three to five. One common treated effluent tank was provided for both TF1 and TF2 during acclimation. Two separate treated effluent tanks were provided during stages one to five in order to assess performance individually and to allow comparison of the two types of tire media treating landfill leachate. The trickling filters were operated as recirculating batch reactors. Maintenance work was carried out between stages two and three. Residence times for a single cycle through TF1 and TF2 were 60 and 70 seconds respectively. Stage durations, as indicated in Tables 3 and 4, were the overall batch reaction times.

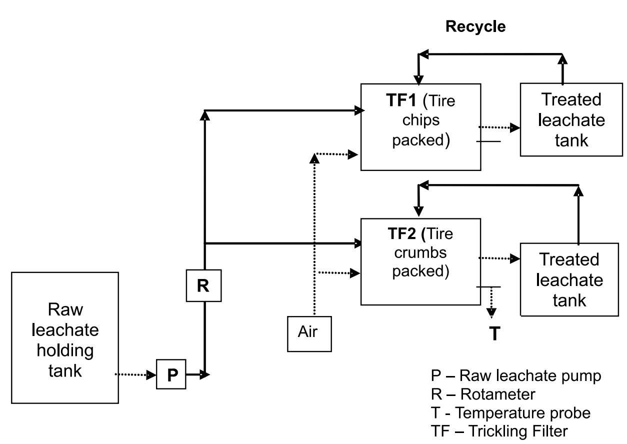

Fig. 1. Schematic diagram of trickling filter pilot plant.

TABLE 3. Operating conditions of trickling filter experiment

Stage / duration [a]	*Cumulative days*	*Influent*	*Filter operation*	*Flow rate (L/min)*	*Hydraulic loading rate ($m^3/m^2/d$)*	*Organic loading rate (kg $BOD_5/m^3/d$)*
Acclimation / 21	21	Diluted KVL leachate	Intermittent [b]	0.9–1.60	2.25–4.0	0.28–0.50
1 / 14	35	Treated leachate from Stage one	Intermittent	0.9–1.60	2.25–4.0	0.35–0.61
2 / 27	62	Diluted KVL leachate and synthetic leachate (50:50)	Intermittent	0.6–0.9	1.47–2.25	0.49–0.75
3 / 10	80* [c]	Synthetic and KVL (75:25)	Continuous	0.6–0.9	2.93–4.50	0.73–1.12
4 / 8	88	Synthetic leachate	Continuous	0.6 (TF1) 0.9 (TF2)	2.93 (TF1) 4.50 (TF2)	0.73 (TF1) 1.12 (TF2)
5 / 7	95	Synthetic leachate	Continuous	0.9 (TF1) 0.6 (TF2)	4.50 (TF1) 2.93 (TF2)	1.12 (TF1) 0.73 (TF2)

[a] Duration is expressed in days.
[b] Intermittent = 10 h/day.
[c] Asterisk (*) indicates that 8 days of maintenance are included in cumulative days and stage 3 was finished by the 80th day

TABLE 4. Removal efficiency of BOD_5, COD and NH_3-N by stage

Stage / days	*Cumulative days*	*Tire chips*			*Tire crumbs*		
		BOD_5 (%)	*COD (%)*	*NH_3-N (%)*	*BOD_5 (%)*	*COD (%)*	*NH_3-N (%)*
Acclimation / 21	21	81	75.5	15 [a]	81	75.5	15 [a]
1 / 14	35	33	69	67	47	69	67
2 / 27	62	96	89.5	68	92 [b]	89.5	63 [b]
3 / 10	80	33	16	negligible [c]	69	16	negligible [c]
4 / 8	88	39	13 [d]	45	56	13 [d]	50.5
5 / 7	95	58	16.5 [e]	35	46	16.5 [e]	58

[a] In 7 days.
[b] In 26 days.
[c] "Negligible" means that the percent removal for the concerned parameter was so small as to be insignificant.
[d] In 2 days.
[e] In 4 days.

Hydraulic Loading

Recommended hydraulic loading for low or standard rate trickling filters is 1 to 4 $m^3/m^2/d$ (Metcalf and Eddy 1991). Organic removal and NH_3-N removal from landfill leachate was observed to be possibly improved at low hydraulic loading rates (Cooke et al. 2001). Factors such as shear velocity and sloughing depend on filter hydraulic loading rate (Metcalf and Eddy 1991). Since overall treatment of landfill leachate, including NH_3-N removal, was planned to be evaluated in this study, low hydraulic loading rates between 1.47 and 3.91 $m^3/m^2/d$ were preferred. Considering all these factors, a hydraulic loading rate in the range of 2.25 to 4.50 $m^3/m^2/d$ was selected for this experimental study.

Organic Loading

Initially, the organic loading rate was maintained between 0.28 and 0.61 kg of $BOD_5/m^3/d$ during the first two stages. This resembles the organic loading rate for a low-rate trickling filter. When landfill leachate was mixed with synthetic leachate, the organic loading rate was increased automatically from 0.49 to 0.75 kg $BOD_5/m^3/d$. When the synthetic leachate proportion was again increased in stage three, organic loading reached its highest level, ranging from 0.73 to 1.12 kg $BOD_5/m^3/d$, which is very similar to organic loading rates for high rate trickling filters (Metcalf and Eddy 1991).

Temperature and pH

A temperature meter (VWR, Canada) and an accumet basic pH meter (Fisher Scientific, Canada) were used to regularly measure the temperature and pH of the influent and effluent.

The pH was generally between 8.30 and 8.60 for the tire chips, and between 7.90 and 8.30 for the crumbs. The temperature for both of the filters was between 15°C and 22°C. It was noted that the temperature for the tire-crumb-packed filter was slightly higher than the tire-chip-packed filter. Less void space in the tire crumb packing media hindered air passage through the crumbs. Consequently, temperatures inside the filter media increased. Although pH decreased due to synthetic leachate addition and increased during pH correction, it was stable in the range of 8.00 to 8.50.

Air Supply System

The rate of air flow was to be a minimum 0.30 $m^3/m^2/min$ for covered filters and dissolved oxygen should be maintained at 0.2 mg/L (Knox 1985). Initially, an air compressor was provided for supplying air to the filter towers. It did not function properly during stage one and a small ventilation fan with a timer was installed. The timer was set for half hour intervals of air supply. Also, air supply valves were throttled to maintain the required air supply to the system for stage two and later stages.

Dissolved Oxygen

The Orion 3 Star dissolved oxygen (DO) Benchtop (Thermo Electron Corporation, U.S.A.) was used to measure dissolved oxygen in the influent and effluent. As observed, except for a few days during stage three and the change-over from stage to stage, DO was maintained above 2 mg/L throughout the experimental program. DO concentrations were below 2 mg/L during stage one due to the lack of aeration. An increased DO level (8 to 9 mg/L) was observed during each change-over between the various experimental stages. This could be attributed to the fresh leachate and fresh water used for preparation of the synthetic leachate. Stable DO levels, between 2.5 to 5 mg/L, were observed during filtration.

Testing and Analysis

Grab samples of the influent and effluent were collected periodically. Those samples were analyzed for BOD_5 at 20°C, COD, NH_3-N, total suspended solids (TSS), and total solids (TS) in accordance with the analysis procedures in Standard Methods (APHA et al. 2005).

A Lambda 20 spectrophotometer at the Ryerson University Analytical Centre was used for determining the COD and NH_3-N concentrations in the liquid samples. The Colorimetric Method (Closed Reflux) and the Phenate Method, as per item no. 5220 D. and 4500-NH_3 F. in Standard Methods (APHA et al. 2005) respectively, were followed for the COD and NH_3-N tests. Total ammonia nitrogen, which includes un-ionized and ionized ammonia, was measured by the Phenate Method.

Biomass Attachment Monitoring

Initially, the tire chips and crumbs were left in the filter towers with leachate trickling through them continuously for a 3 week period to allow a colony of microorganisms to grow. The microorganism growth period took about 2 to 3 weeks, based on observations of biomass formation achieved in 2 weeks on tire chips (Shin et al. 1999). Biomass attachment to the tire chips and crumbs, and sloughing of biomass from them, were quantitatively monitored in this experiment. The thickness of the biomass on the tire chips was observed to be 1 to 2 mm.

Results and Discussion

An acclimation stage was chosen as the first step of this experiment. Since reasonable biomass growth was noticed in 14 days time and biomass sloughing by 21 days, the experimental study was initially planned for batch runs with a duration of 21 days each. However, the duration of the batches was increased or decreased depending on the experimental conditions.

The initial values of pH, BOD_5, and COD of the leachate at the collection point at KVL were between 7.6 and 8.0, 2,004 mg/L, and 19,950 mg/L, respectively. It was decided to start with diluted KVL leachate in order to have moderate organic loading. After the adaptation period, the experimental program was conducted in five stages of different durations. During this experiment, flow rate was maintained in the range of 0.6 to 1.60 L/min, and the hydraulic loading rate ranged from 1.47 to 4.50 $m^3/m^2/d$ for both trickling filter units. These loading rates resemble a low-rate trickling filter system.

Performance Evaluation

Acclimation stage (day 1 to day 21). Treated effluent was collected from TF1 and TF2 in one tank during this stage. The BOD_5 removal rate was noted to be rapid at the beginning of this stage. The highest BOD_5 removal efficiency was noted to be 60%. COD removal efficiency was also rapid. The greatest COD removal efficiency was determined to be 75%. These removal rates can be attributed to the organic content adsorption onto the tire materials, and to the activity of microorganisms consuming the organic contents of landfill leachate as substrate for their growth. Therefore, the biomass was well acclimated on the chips and crumbs within the trickling filters.

Stage one (day 21 to day 35). During this stage, treated effluent from TF1 and TF2 was collected in two separate tanks. Overall, BOD_5 removal using the tire crumbs was 47%. BOD_5 removal efficiency was significantly affected during this stage due to the lack of aeration. TF1 had 65% COD removal within the first 7 days, while TF2 exhibited a COD removal of only 30%. This observation may be attributed to better air passage through void spaces in the tire chips media, even when there was a lack of aeration, which may have allowed the utilization of available oxygen by the biomass. This phenomena was not possible within the tire crumb packing due to less void space and the corresponding higher density of the packing media.

TF1 and TF2 each exhibited approximately 67% NH_3-N removal during this stage of treatment. This observation can be attributed to better acclimation of the nitrifying microorganisms after 21 days. Lack of aeration might have reduced dissolved oxygen in the system, but pH and temperature were still favourable. Solids removal accelerated after the acclimation stage. Moderate temperature, stable pH, and minimum required DO concentrations may have contributed to a better environment, resulting in increased solids removal.

Stage two (day 35 to day 62). The greatest BOD_5 removal was achieved during this stage. TF1 exhibited 45% BOD_5 removal within the first 7 days. Although there was a spike in BOD_5 remaining within the next 7 days, 88% of BOD_5 was eventually removed by the end of the stage. A similar BOD_5 removal efficiency pattern was noticed for TF2 (Fig. 2).

Similar to BOD_5 removal, the highest COD removal was achieved in stage two (Fig. 3). A 68% COD removal efficiency by TF1 was noted within the first 7 days of treatment. The COD remaining in the effluent then started to increase over the next 7 days. This observation can be attributed to biomass sloughing. COD removal by TF2 was 80% within the first 7 days of the stage, followed by a gradual increase in COD remaining, similar to the trend noted in TF1.

After stage two, an improved aeration system was installed and organic removal was significantly increased. However, a decline in the rate of organic removal, due to biomass sloughing, resulted in the spikes in BOD_5 and COD in the treated effluent.

The rate of ammonia removal from TF1 was 63% during stage two. TSS increased from 350 mg/L to 1,250 mg/L in the treated effluent collected from TF1, and from 160 to 725 mg/L in treated effluent from TF2 over the next 14 days of treatment during this stage. As explained in the case of organic removal, this can be attributed to sloughing of biofilm attached to the tire chips and crumbs. Both filters started to exhibit an improved solids removal rate after day 56 of operation. Finally, TSS removal rates from TF1 and TF2 were 98 and 59%, respectively. This high TSS removal may have occurred due to quick adsorption of suspended solids onto the tire chips and crumbs after biomass sloughing.

Stage three (day 69 to day 79). The BOD_5 removal efficiency from TF1 and TF2 was noted to be 33 and 69% respectively, after 10 days of operation in stage three (Fig. 2). TF1 started to clog, due to the deposition of iron slag, but this did not affect the packing media's performance significantly.

COD removal started to decrease slowly in this stage. No significant COD removal was observed from TF1. However, TF2 exhibited better performance (up to 32% COD removal on day 77 of treatment). In general, the tire crumbs performed better than the chips in stage three. This may be due to better aeration in the tire crumb system. Considering the greater surface area of the tire crumbs than the tire chips, it can be hypothesized

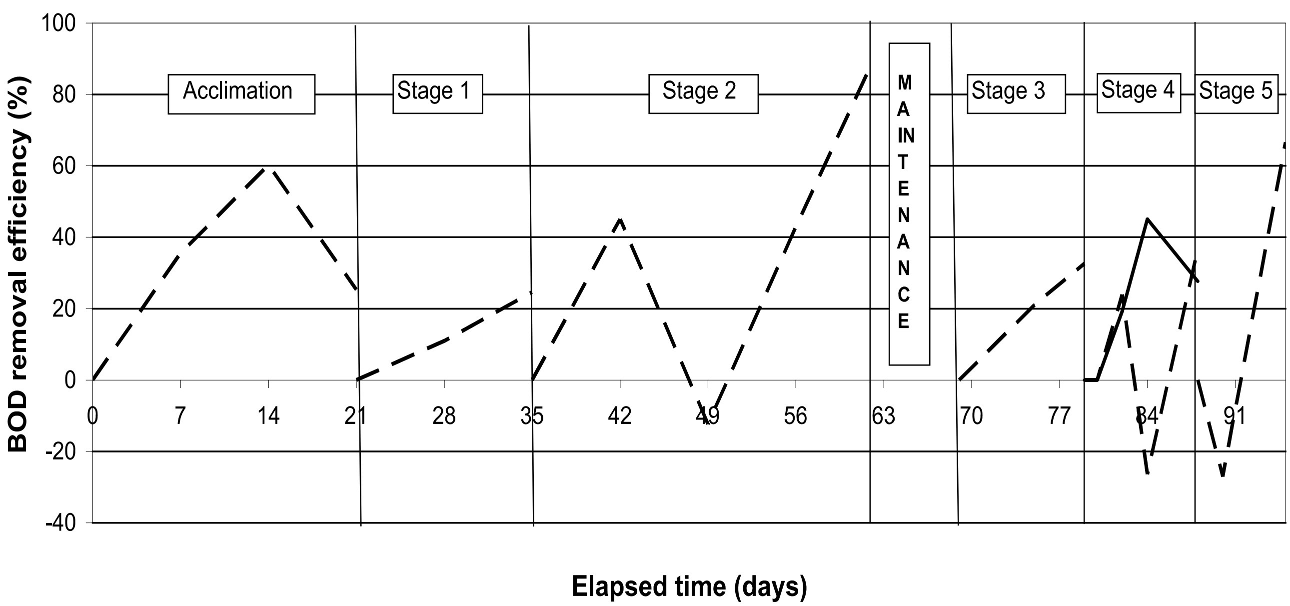

Fig. 2. Variation in BOD_5 removal efficiency from acclimation to stage 5. Chips, dashed line; crumbs, solid line.

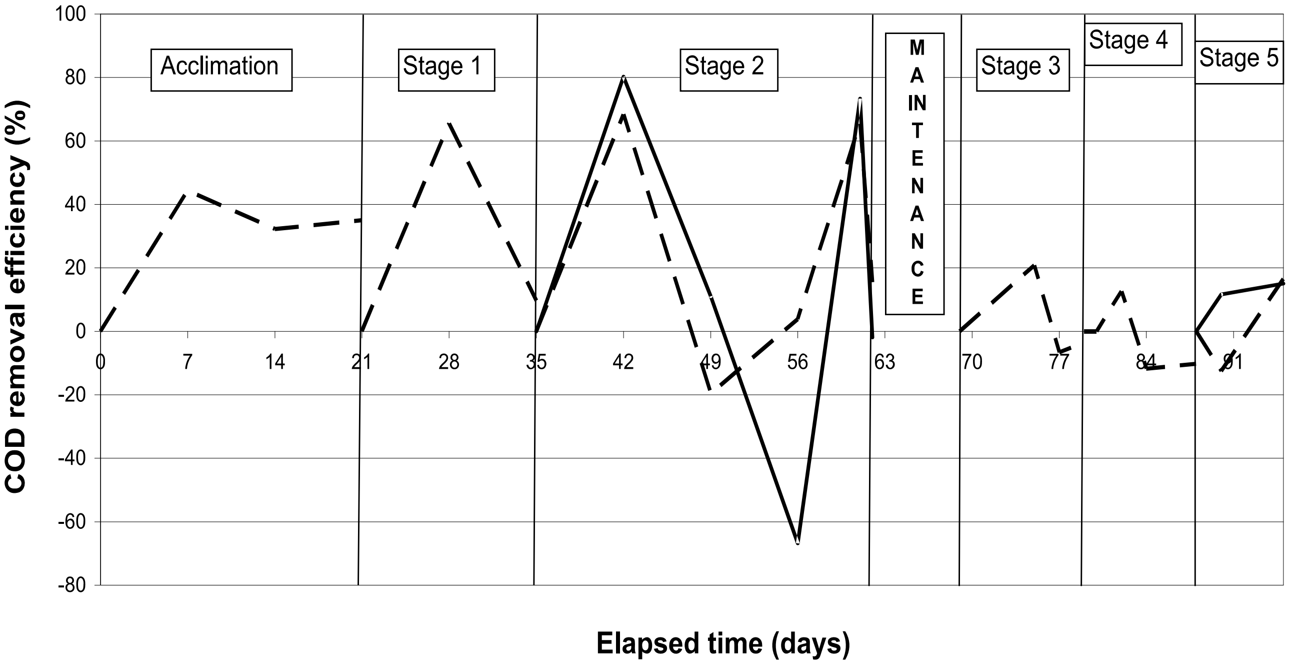

Fig. 3. Variation in COD removal efficiency from acclimation to stage 5. Chips, dashed line; crumbs, solid line.

that the tire crumbs probably had more biomass on them than the tire chips. This may be the major reason for the comparatively better and more consistent organic removal from the crumbs.

There was no significant NH_3-N removal from TF1 and TF2 during this stage of the experimental study. TSS in the treated effluent from TF1 started to increase significantly up to day 77 of the experiment. Only 22% TSS removal was achieved in TF1 during stage three. TF2 exhibited better performance in this regard.

Stage four (day 79 to day 88). Organic removal was quite inconsistent during this stage. It was observed that 24% of the BOD_5 was removed by TF1 in the first 2 days of this fourth stage, but a 26% increase in BOD_5 remaining was noticed after a further 2 days. This may be attributed to severe clogging. However, once the TF1 unit was backwashed, BOD_5 removal was revived to 36% after another 4 days (Fig. 2). Similarly 56% BOD_5 removal was achieved from TF2 after 4 days of operation. The BOD_5 removal in TF2 then declined to 28% over the next 4 days. Similarly, this can be attributed to clogging.

Initially in stage four, the COD removal was poor due to clogging in TF1. However, after the filter was backwashed, improved COD removal was observed. COD removal by TF2 was comparatively better. COD removal of 81% was observed by the end of stage four. Surprisingly, NH_3-N removal from TF1 was satisfactory. NH_3-N removals of 36 and 46% were obtained from TF1 and TF2, respectively. This can be attributed to the better performance of nitrifying bacteria after backwashing, after which TSS removal also improved. Eventually, 38% TSS removal was achieved in TF1. A similar TSS removal pattern occurred in TF2.

Stage five (day 88 to day 95). TF1 was heavily clogged in this stage. The effluent BOD_5 concentration increased to 27% of the original influent BOD_5. After backwashing, 67% of the BOD_5 was removed. This can be attributed to lower hydraulic and organic loading of TF1 in this stage. Conditions in TF2 were comparatively better. Although the rate of removal declined, BOD_5 reduced steadily and 27% removal was obtained after 7 days during this final stage of the experimental study. COD removal efficiency was affected for both filters, potentially due to severe clogging in this stage (Fig. 3).

NH_3-N removal from TF1 was similar to the removal efficiency observed in the previous four stages. A maximum NH_3-N removal of 27% was achieved from filter TF1. TF2 exhibited comparatively better performance. As both the filters were backwashed during the previous stage, TSS removal improved to some extent in stage five. Approximately 67% TSS removal was observed from the treated effluent from both trickling filters.

Clogging affected the packing media's performance, and organic removal was reduced significantly; hence, stage five was chosen to be the last batch run for this experiment. It was observed that biomass on the tire chips and the crumbs had some bacteria, aquatic microorganisms, and the remains of filter feeders. Further study is required for proper identification of the microorganisms. A comparative assessment of the performance of the tire chips and crumbs as packing media in trickling filters is presented in Table 5.

Effect of Biomass Growth and Sloughing

The greatest efficiency in BOD_5 and COD removal was achieved at approximately day 14 in the 21 day batches.

TABLE 5. Comparative assessment of performance of tire chips and tire crumbs media[a]

Stage	*Tire Chips*	*Tire Crumbs*
1	Significant removal of organics, NH_3-N and total suspended solids (TSS)	Significant removal of organics, NH_3-N and total suspended solids
2	Higher organic removal in totality, and a higher rate of NH_3-N removal at the initial stage	Higher organic removal efficiency, and higher NH_3-N removal in total
3	Reduced organic removal efficiency, TSS-increase in effluent due to biomass sloughing, and higher TSS removal after sloughing in the filter	Reduced organic removal, and TSS removal after sloughing in the filter
4	Faster clogging, reduced NH_3-N removal due to clogging, and significant TSS removal after backwashing	Slow clogging, higher NH_3-N removal, and reduced TSS removal after backwashing
5	Higher organic removal, insignificant NH_3-N removal, and significant TSS removal after backwashing	Reduced organic removal, significant NH_3-N removal, and reduced TSS removal after backwashing

[a]The word "significant" indicates removal in the range of 50 – 70%.

This is consistent with the findings of other researchers regarding biofilm development using tire chips. Thus, a reasonable solids retention time was determined to be 21 days. Because the trickling filter media were not being backwashed initially, biomass sloughing might have affected organic removal efficiency. When the biofilm materials sloughed off and mixed with effluent, there was an impact on the effluent characteristics. Consistency in organic removal was noticed in the first two weeks of each batch throughout the experiment. It is worthwhile noting that the 14 and 21 day scenario for biofilm growth and sloughing was maintained.

It is important to note that clogging affected the leachate treatment efficiency for both packing media. It was observed that TF1 clogged faster during the second half of stage four. In the last two days in stage four, TF2 also gradually clogged. It also became less effective during stage five.

Conclusions

Overall, BOD_5 and COD removal by the trickling filters was approximately 81 and 75%, respectively during the acclimation period. Initially, fresh chips and crumbs performed well due to good adsorption of the leachate's organic components. Organic removal from both trickling filters was reduced as a result of a lack of aeration during stage one. It is believed that the aerobic zone (in the biofilm attached to the tire chips and the tire crumbs) was reduced and, consequently, organic removal was influenced. This indicates that proper aeration is a basic requirement for making the biofilm's aerobic zone function properly. This will also help maintain dissolved oxygen and pH in the required ranges.

Installing a new aeration system just before the commencement of stage two enhanced the performance of both the tire chip and the tire crumb packed trickling filters. The greatest BOD_5 and COD removal was observed in stage two of this experimental, study. The advantage of having an established biofilm and a more stable media during this stage improved the filters performance. Lower hydraulic and organic loading might also have enhanced treatment efficiency in stage two compared with other stages.

Better consistency in BOD_5, NH_3-N, and TSS removal from the tire crumb packed trickling filter was noticed throughout the experiment. The lack of consistency in the tire chip packed filter can be attributed to faster clogging. Clogging during stage three deteriorated the performance. Therefore, the need for a filter backwash was determined. It was noted that the tire-chip-packed filter clogged faster than the tire-crumb-packed filter. This was due partially to iron slags from wires associated with the tire chips. Since biomass sloughing was noted every 21 days, it would be appropriate to backwash the filters at approximately 21 day intervals.

Most suspended solids removed from the filters were retained as bottom sediment in the treated effluent tanks. These were drained after each cycle of 21 days because of the biofilm sloughing. Treated effluent samples were collected from the top of the treated effluent tanks after allowing solids to settle to the bottom for at least an hour. This indicated that a proper settling arrangement, in addition to the trickling filtration system, can improve the solids removal.

Comparing the advantages (including better performance) of using shredded tire materials with other available biological treatment systems, a trickling filter system packed with tire chips or crumbs can be considered a successful biological treatment system for landfill leachate.

Shredded tire chips are suitable for large scale operations due to ease of handling and availability. Use of wireless tire chips is preferred as a packing media to reduce clogging in the filter unit and to enhance organic removal efficiency.

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