

THE PERFORMANCE OF RECYCLED ORGANIC AND MINERAL MATERIALS AS REACTIVE FILTER MEDIA

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ABSTRACT. The Reactive Filter Media (RFM) sourced from recycled organic and mineral material offers a low cost and effective means of treating urban stormwater. Using recycled materials rather than from an increasingly scarce source of virgin materials ensures a sustainable long term economy. This paper presents results from the laboratory analysis and mathematical modeling to highlight the performance of recycled organic and mineral material in removing nutrients and metals from stormwater. Column leaching experiments were undertaken on several “Design Mix Configurations” to determine pollutant removal rates under constant-head and falling-head conditions. Design Mix Configurations included various combinations of recycled organic and mineral materials. Results indicate that high nutrient and metal removal rates can be achieved over a range of hydraulic conductivities and RFM mix designs. The next step is to test bed the performance of these RFM mixes in actual field trials selected from different rainfall regimes in various states.

Keywords: *Reactive filter media, Recycled organic material, Nutrient/metal removal.*

Introduction

In a world where natural resources are limited it is important to recycle organic and mineral waste materials for alternative uses. In stormwater management, sandy loam soils are typically used as the treatment substrate in bioretention devices and roadside swales due to their nutrient retention properties. However, these soils are often excavated from river banks and consequently not sustainable. Alternatively agricultural soils around the world are rapidly being lost due to land clearing and agricultural practices with estimates that that we have lost over 38 % of our food-production land since 1950 [1]. Therefore it is paramount that “new generation” sustainable substrates are found. Recycled organic and mineral waste materials have the potential to provide a sustainable solution with local economic benefits.

This paper presents results column tests and laboratory analysis that highlight the performance of recycled organic and mineral material in removing nutrients and metals from a polluted water. The aims of the study were to evaluate a range of raw recycled organic and mineral materials as potential Reactive Filter Media (RFM), and; gain preliminary data to assist future model development and creation of performance-based design specifications.

Column tests were undertaken on several “Design Mix Configurations” (DMC’s) to determine pollutant removal rates under constant-head and falling-head conditions. DMC’s included various combinations of recycled organic and mineral materials. Results indicate that significant nutrient and metal removal rates can be achieved over a range of hydraulic conductivities and RFM mix designs.

Materials and Methods

Column tests

The column tests were designed as a single-pass experiment under different hydraulic heads (constant and falling) to investigate the likely *in-situ* performance of the RFM DMC’s. For example, the column tests are an open system test that is more indicative of a how an RFM would behave under high flow conditions (saturated, low residence time) and low flow conditions (un-saturated, high residence time).

Packing of the columns was based on volume. For each DMC, a column (50 mm diameter) was packed with a known volume of DMC and the height in the column was measured. Each column was gently tapped and shaken to promote settling but no compaction was applied. Column depth ranged between 260 mm and 290 mm for all the DMC's. STE was again used as the solution for eluting through the columns.

On the unfiltered eluted sample from the column, pH and electrical conductivity (EC, $\mu\text{S}/\text{cm}$) were undertaken using a calibrated Horiba pH/EC meter. Nutrient analysis included Total Kjeldahl Nitrogen (TKN), Total Oxidisable Nitrogen (TON), Total Phosphorous (TP), Total Nitrogen (calculated as TKN + TON). Metals analysis comprised Ca, Na, Mg, K, Cu, Pb, Zn and Cd.

For constant-head conditions, a 1L volumetric flask containing STE was slowly poured into the top of the column. There is a point where the top of the column contains a "head" and at this time the volumetric flask is quickly inverted and the spout submerged in the STE above the DMC in the column. The volumetric flask is clamped in place and the STE moves through the column under gravity.

The time taken for the STE to be eluted through the column reflected the saturated hydraulic conductivity (K_{sat}) of the DMC and was determined by calculation (volume/time). The 1L of STE applied under constant-head conditions was approximately equivalent to a 420 mm rainfall event. For example, $1\text{L}/\text{m}^2 = 1\text{ mm}$ rainfall depth and since the area of the column and applied STE volume is known an equivalent rainfall depth can be calculated. The area of the 55 mm (ID) column is 0.00238 m^2 ($A = \pi r^2$) meaning $1\text{L} / 0.00238\text{ m}^2 = 420\text{ mm}$ of STE was applied. If the 1L takes 1 hour to move through the column then the K_{sat} would be 420 mm/hr.

After elution, any losses from the 1 L of STE were deemed to reflect the moisture holding capacity (MHC) of the RFM and was calculated using mass by difference. For example, if 1L of STE goes into the column and 0.8L is eluted out of the column (when freely drained) then the MHC equals 20 %.

A single DMC was selected for the falling-head column test (DMC3) because of the similarity in pH and EC to the sandy loam (control). In this instance, a 1L reservoir with a small tap was fitted with slow-release valve that allowed the STE to drip into the column rather than flow freely under constant-head conditions. The reason for the falling-head column test was to mimic low and/or intermittent rainfall conditions and increase residence time between the STE and DMC3.

Results & Discussion

The DMC's were designed based on discussions with Star Water Solutions about mixes that would satisfy general requirements such as hydraulic conductivity and pollutant removal performance.

Column tests: Constant-head

Results from the column tests are shown in Table 1. Values highlighted in green indicate the parameter was removed from solution. The initial parameter values for the STE are shown in red. Sandy loam was used as a 'control' comparison as it is typical of what is currently being used as filtration media in the stormwater industry.

The bulk density of all mixes ranged from $770\text{ kg}/\text{m}^3$ (DMC3) to $1179\text{ kg}/\text{m}^3$ (sandy loam). Hydraulic conductivity for all mixes ranged from approximately 200 mm/hr (DMC4) to 1050 mm/hr (DMC1 and sandy loam). DMC4 became problematic due to the fine particle sizes of the mix and the moisture holding capacity (MHC) of coir peat and was not included for metals analysis. DMC4A was created by adding 50% fine sand to DMC4 in order to improve the hydraulic conductivity (which it did). Moisture holding capacity (MHC) ranged from 19.5 % (DMC 4A) to 35.5 % (DMC4) and pH increased for all DMC's except sandy loam and DMC3.

Apart from DMC4, all other DMC's and the sandy loam showed reductions in TN (-4 to -47 %). These results highlight the dynamic transformations of N in the absence of TON uptake by plants but in an open system. Greater removal rates of N would be expected in the presence of vegetation. Apart from DMC4 (29 % increase in TP), all other DMC's and the sandy loam showed considerable reductions in TP (-8 to -85 %). Na and K appear to be generally flushed from all mixes tested. DMC1 adsorbed Na however higher K was leached from the column.

Table 1: Constant-head column test results

Mix	kg/m ³	mm/hr	%	uS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
	BD	Ksat	MHC	pH	EC	TKN	TON	TN	TP	Na	Mg	Ca	K	Cu	Zn	Cd	Pb
Sandy loam	1179	1052	22.2	7.4	720	2.8	6.3	9.1	3.7	1037	86.1	142	222	0.183	0.702	0.002	0.019
DMC1	922	1052	20.2	8.3	860	2.2	6.5	8.7	0.74	804	22.4	31.9	1227	0.119	0.66	0.002	0.049
DMC2	963	361	24.1	8.5	830	3.1	6.3	9.4	3.3	1143	14.7	25.9	620	0.366	0.626	0.003	0.052
DMC3	768	561	20.1	7.6	710	2.2	5.5	7.7	3.7	909	96.1	147.8	261	0.121	0.724	0.003	0.037
DMC4	813	202	35.5	8.3	840	9	4.8	13.8	6.3	ND	ND	ND	ND	ND	ND	ND	ND
DMC4A	1130	842	19.5	8.2	780	1.7	7.2	8.9	4.5	1614	20.3	12.6	400	0.274	0.84	0.003	0.059
DMC5	949	421	19.9	8.0	810	5.6	5.1	10.7	4.5	1044	86.2	122.3	710	0.138	0.866	0.002	0.035
STE	elution solution			7.2	750	8.1	6.3	14.4	4.9	893	83.2	146	206	0.078	0.71	0.004	0.035

Differences compared to STE

Mix	BD	Ksat	MHC	pH	uS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
					EC	TKN	TON	TN	TP	Na	Mg	Ca	K	Cu	Zn	Cd	Pb
Sandy loam				0.2	-30	-5.3	0	-5.3	-1.2	144	2.92	-4	16	0.105	-0.008	-0.002	-0.016
DMC1				1.1	110	-5.9	0.2	-5.7	-4.16	-89	-60.8	-114.1	1021	0.041	-0.05	-0.002	0.014
DMC2				1.3	80	-5	0	-5	-1.6	250	-68.5	-120.1	414	0.288	-0.084	-0.001	0.017
DMC3				0.4	-40	-5.9	-0.8	-6.7	-1.2	16	12.9	1.8	55	0.043	0.014	-0.001	0.002
DMC4				1.0	90	0.9	-1.5	-0.6	1.4	ND	ND	ND	ND	ND	ND	ND	ND
DMC4A				1.0	30	-6.4	0.9	-5.5	-0.4	721	-62.91	-133.4	194	0.196	0.13	-0.001	0.024
DMC5				0.7	60	-2.5	-1.2	-3.7	-0.4	151	2.95	-23.7	504	0.06	0.156	-0.002	0.000

Differences compared to STE (% change)

Mix	BD	Ksat	MHC	pH	%	%	%	%	%	%	%	%	%	%	%	%	%
					EC	TKN	TON	TN	TP	Na	Mg	Ca	K	Cu	Zn	Cd	Pb
Sandy loam				3	-4	-65	0	-37	-24	16	4	-3	8	135	-1	-50	-46
DMC1				15	15	-73	3	-40	-85	-10	-73	-78	496	53	-7	-50	40
DMC2				17	11	-62	0	-35	-33	28	-82	-82	201	369	-12	-25	49
DMC3				5	-5	-73	-13	-47	-24	2	16	1	27	55	2	-25	6
DMC4				14	12	11	-24	-4	29	ND	ND	ND	ND	ND	ND	ND	ND
DMC4A				14	4	-79	14	-38	-8	81	-76	-91	94	251	18	-25	69
DMC5				10	8	-31	-19	-26	-8	17	4	-16	245	77	22	-50	0

ND = No data

DMC4 was too difficult to filter with existing equipment resulting in low sample volume for metals analysis

Removed from solution

DMC1, DMC2 and DMC4A showed considerable removal rates for Ca and Mg. The cation exchange processes operating are likely to be complex and further research is warranted. The cation exchange dynamics between Ca, Mg, Na and K generally determine the available exchange sites for metals and, if they are dominantly occupied by Ca and Mg, then there is less opportunity for metals under saturated conditions. There was limited removal across the DMC's of Zn and Pb. Zn was removed from the STE by sandy loam, DMC1 and DMC2 (-1 to -12 %). Pb was removed by sandy loam only (-46 %).

Further interpretation cannot be made without detailed knowledge on the actual processes operating within the DMC's and further investigations are intended. The single-pass constant-head conditions provided relatively low residence time (short contact time between the RFM and the STE). Due to this, a falling-head column test was undertaken to increase residence time and to observe pollutant removal characteristics.

Column test: Falling-head

DMC3 was selected for the falling-head test because it was the only mix with similar pH and EC to the sandy loam (control) and both showed a decrease in EC indicating a similar exchange capacity and comparatively low salt leachability. Table 2 summarises pre and post column test results for DMC3.

The 1 L of STE took approximately 12 hours to permeate through the column (35 mm/hr). The pH both pre and post column remained relatively unchanged throughout the test. Post column EC rose by 41 % and this is likely to be reflective of greater contact time and saturation of particles and pores within the column that remove highly soluble cations such as Na and K.

TKN decreased by -70 % but the TON only by -5 %. TN was reduced by -35 %. These results again highlight the dynamic transformations of N in the absence of TON uptake by plants but in an open system and with longer residence time. For example, TN removal is generally higher in the column tests because

volatile N can escape to the atmosphere. Greater removal rates of N would be expected in the presence of vegetation.

Table 2: Column test results on DMC3

			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
	pH	EC	TKN	TON	TN	TP	Na	Mg	K	Ca	Cu	Zn	Pb
PRE	8.19	930	5.6	6.3	11.9	6.1	88.2	8.6	20.5	23.5	0.032	0.085	0.006
POST	8.16	1310	1.7	6	7.7	3.1	97.3	4.5	202	8.1	0.025	0.079	0.004
	%	%	%	%	%	%	%	%	%	%	%	%	%
Removal by DMC3	0	41	-70	-5	-35	-49	10	-48	885	-66	-21	-7	-33
(negative number indicates removal of pollutants from the STE by DMC3)													
Pollutants removed by DMC3													

TP was reduced by -49 %. DMC3 showed considerable removal rates for Ca (-66 %) and Mg (-48 %). The un-saturated conditions in the falling-head test and longer residence time resulted in removal of all measured metals (Cu, -21 %; Zn, -7 % and Pb, -33 %). Improved Cu, Zn, and Pb removal is likely to be a function of leached K and improved availability of sites for metals under un-saturated falling-head conditions.

Conclusion and future research

This study has demonstrated that a range of recycled organic and mineral materials have considerable potential as “new generation” Reactive Filter Media (RFM). The data collected is likely to provide satisfactory preliminary data for further studies including life span performance and subsequently to develop models for demonstrating performance characteristics of new generation RFM. The performance of recycled organic and mineral material (in Design Mix Configurations) in removing nutrients and metals from STE was considerable in the column tests which were a function of closed/open systems, residence time and available exchange sites. The results in this study highlight the importance of hydraulic conductivity (saturated and un-saturated) and residence time and these are vital parameters for designing RFM specifications for a certain use. Design specifications for new generation RFM need to cover a range of objectives based on water quality/quantity, catchment attributes (slope, % impervious, etc) and climate patterns.

References

[1] L.R. Oldeman (1994) *The Global Extent of Soil Degradation*; in Soil Resilience and Sustainable Land Use, CAB International, Oxon, U.K., p115