Developing and Characterizing Green Sorption Media for Nutrient Removal in an Innovative Septic Tank Underground Drainfield

Chang, N. B.*, Wanielista, M., Shah, T. B., Makkeasorn, A., and Xuan, Z.

Department of Civil, Environmental and Construction Engineering
University of Central Florida, Orlando, Florida, USA

ABSTRACT

Growing worldwide concerns of nitrates and phosphorus in ground water led to research efforts directed towards developing a sorption media for a septic tank drainfield. Extensive research has been conducted in the past few decades, in order to find suitable media for denitrification with high selectivity towards nitrogen and phosphorus simultaneously. To explore a new design of septic tank underground drainfield with cost-effective, reliable, and longer life expectancy features, material characterization, packed bed column experiments, batch isotherm identification and microcosm study were collectively conducted and presented together in this paper so as to illuminate the potential of a suite of new material mixes. After initial literature review and multi-criteria decision making process, one of the columns was packed with tire crumb, saw dust and sand while the other column was packed with tire crumb, paper and sand. Under the hydraulic retention time (HRT) of 24 hours, samples illustrated treatment efficiencies of greater than 90% for both the columns for all pollutants of concerns. The batch adsorption isotherm data was fitted in the Langmuir isotherm and Freundlich isotherm models, and adsorption capacity for phosphorus was found to be 34.4 mg g^{-1} Langmuir isotherm. A microcosm of the septic tank underground drainfield was built with one of the recipes applied in the column test as a continuous system dosed with synthetic wastewater. Under the HRT of 72 hours, samples from the microcosm physical model illustrated more than 80% of removal efficiency for nitrates and phosphorus. Additionally, with the aid of the isotherm tests, the life expectancy of the proposed sorption media in the microcosm physical model was estimated to be around 63 years for phosphorus sorption. Overall, the results indicate that the green sorption media investigated (i.e. "Black and Gold^{TM} Nugget Mix") has the potential for removal of nutrient flux and exhibit high potential of in full-scale field applications.

Keywords: Nutrient removal, Septic tank, Green sorption media, Sustainability Science

INTRODUCTION

Nitrate in drinking water system usually originates from fertilizers or from animal or human wastes. Nitrate concentrations in the natural water system tend to be highest in areas of intensive agriculture or where there are many septic systems. High nitrogen and phosphorus content in the water body has impeded water reuse potential and impacted ecosystem integrity and human health. Nitrate (NO_3^-) may be toxic and can cause human health problem such as methemoglobinemia, liver damage and possible cancers (WHO, 2006). Phosphorus (P) may trigger the eutrophication issues in fresh water bodies, which could result in toxic algae and endanger the source of drinking waters eventually (ESA, 2000). On the other hand, when urban regions gradually expand due to regional development, centralized sewage collection, treatment, and disposal is often unavailable for both geographic and economic reasons. Thus, decentralized or on-site wastewater treatment systems (OWTS) may be necessary to protect public health. Nation wide, wastewater effluent from OWTS can represent a large fraction of nutrient loads to groundwater aquifers, however.

In the modern era, OWTS also referred as septic system primarily includes a septic tank and soil adsorption field or drainfield also known as subsurface wastewater infiltration systems (SWIS). Drainfields are located in permeable, unsaturated natural soil or imported fill material so wastewater can infiltrate and percolate through the underlying soil to the ground water thereby treating itself through a variety of physical, chemical, and microbiological processes. However, the nitrate ion (NO_3^-) and soil are negatively charged, and so the NO_3^- ion is not bound to the soil. Therefore, nitrate ions move freely with the soil solution and are readily leachable. Nitrogen, particularly nitrates, easily moves from terrestrial ecosystems into surface and groundwater, including lakes, streams, rivers, and estuaries (Baker, 1992; Kahl et al., 1993;

Peterjohn et al., 1996). Two important processes that result in the transformation of nitrate are nitrification and denitrification. Nitrification is a process in which ammonium is oxidized and denitrification is a process in which nitrate is reduced back to nitrogen gas before escaping into the air. However, only denitrification that is a microbiologically mediated process occurring under anaerobic (oxygen depleted) conditions can result in the permanent removal of nitrate. Approximately, 55-85% of the nitrogen that enters the septic tank is available to ground water mainly in the form of nitrates (Stoltz and Reneau, 1998). Based on recent Florida research data, a family of four will discharge 11.36 Kg (25 pounds) of nitrogen (measured in the form of nitrates) per year into the drainfield of a conventional onsite sewage treatment and disposal system (Florida Department of Health, 2004).

Nitrates are the primary pollutants of concern in this research. The main risks are in "Blue baby" syndrome and suspected carcinogenic effect of nitrates on humans, and the nutrient enrichment of receiving waters. It has regulatory health limits in the US of maximum contamination level (MCL) of 10 mg-N L^{-1}. A septic tank with a conventional drainfield does not typically remove nitrogen in the form of nitrates since it is very soluble and does not sorb well to soil components during infiltration (Spalding and Kitchen, 1988). The use of different sorption media in septic tank drainfields turns out to be an appealing engineering approach in dealing with the increasing trend of higher nitrate concentrations that is expected to continue in the surface and groundwater systems. Besides, the use of the sorption media for denitrification rather than traditional gravel-filled drainfield for handling the effluents from the septic tank system would become a new focus in rural communities. Large-scale implementation with different sorption media to remove nutrients will be popular in the future (Mothersill et al., 2000; Birch et al., 2005).

It is believed that functionalized sorption media might have a better ion exchange capacity to support adsorption/desorption capacity. The aim of this paper is to screen sorption media via a thorough literature review, characterize the selected sorption media, and examine their sorption capacity for nutrient removal using column study, isotherm tests and microcosm assessment in support of the new underground drainfield design as an integral part of modern septic tank system. Pollutants of concern include nitrates, ammonia, total nitrogen, ortho-phosphorus, total phosphorus and BOD. Sorption media of interest include but are not limited to tire crumb, tree bark, wood chips, sawdust, paper (newspaper), alfalfa, mulch, cotton, wheat straw and sulfur/limestone. Two recipes with mixed sorption media were selected in the end of the initial literature study for columns study. At the end of the column study, the recipe including sand, tire crumb and sawdust was further used to estimate the sorption life of the media mix and also as a media mix for the design of microcosm physical model. The descriptions in the following sections start with investigating the material characterization then perform the column study, batch isotherm tests and end up with the assessment of microcosm physical model for further field implementation.

Literature review

Sorption Media Used for Nitrogen Species Removal

Many researchers had tried to remove nitrogen species by using sorption media. Kim et al., (2000) used different kinds of sorption media, such as alfalfa, mulch compost, newspaper, sawdust, wheat straw, wood chips for nitrate removal from storm water runoff. They found that alfalfa and newspaper had 100% nitrate removal efficiency but mulch compost had 60% nitrate removal efficiency. They also found that sawdust, wheat straw and wood chips had good removal efficiency (>95%), but wood chips showed consistently better performance in nitrate removal over sawdust. From their experiment, it could be concluded that all of these were electron donors and good carbon sources for promoting denitrification. They suggested that increasing the retention time may gain better removal efficiency. Kim et al. (2000) also found that soil could only remove 7% to 10% of nitrate due to its anionic form.

Güngör and Ünlü (2005) conducted nitrate and nitrite removal experiment by using only three types of soils, including sandy clay loam (SCL), loamy sand (LS) and sandy loam (SM). They found significant nitrate and nitrite removal (i.e., over 90%). Hsieh and Davis (2005) found that mulch was very effective in removing nitrate, unlike sand. But they had not gained good ammonia removal efficiency by using mulch. They concluded that soil with higher silt/clay and cation (Mg/Ca/K) contents might be very effective in nutrient removal. They concluded that course media might not be able to retain the nutrient in repetitive loading due to small surface area so that sand should not be used.

Darbi et al., (2002) used sulfur and limestone for nitrate removal from potable water. In their experiment, sulfur was used as an electron donor and limestone was used to maintain the pH. They found that the optimum mixing ratio of sulfur and limestone is 1:1 for nitrate removal (i.e., about 98% nitrate removal was observed). They also suggested that increasing the retention time may obtain higher nitrate removal efficiency. Lisi et al. (2004) tried to use granulated tire for the removal of nitrate. They found 48.000 g of tire crumb can remove 16.2 g of NO_3^--N. Sengupta and Ergas (2006) did an experiment to remove nitrate from wastewater by using marble chips, limestone and oyster shell. Their experiment gave some significant outcomes about using those solids as sorption media. They found that oyster shell (almost 98% $CaCO_3$) and limestone could remove 80% and 56% of nitrate, respectively. The pH and alkalinity were higher in testing using oyster shell rather than limestone and marble chips. Oyster shell was very much efficient to reduce nitrite accumulation and dissolved oxygen (DO) did not work as a denitrification inhibitor when oyster shell was used as a sorption media. From these findings, it can be concluded that oyster shell is much more effective than limestone or marble chips for removing nitrate. Oyster shell can also be a good candidate for controlling the pH that is sensitive for denitrification.

Savage and Tyrrel (2005) used wood mulch, compost, soil, broken brick and polystyrene packaging for removal of NH_3-N from compost leachate. They reached in a conclusion that wood mulch (75%) and compost (55%) had better removal efficiency for NH_3-N than other media and polystyrene was the least capable one to remove NH_3-N. Soil and broken brick could remove 38% and 35% of NH_3-N, respectively. All these media had the same capability to remove BOD_5 by microbial oxidation process. The research group found that compost and wood mulch had a tendency to increase the pH. They concluded that specific surface area, void space, permeability, and adsorption capacity might influence the removal efficiency.

Sorption Media Used for Phosphorus Species Removal

Phosphorus removal from storm water is both precipitation and adsorption processes due to chemical reaction. As phosphorus has enormous effect on aquatic ecosystem, researchers have been trying to discover an economically feasible removal procedure. Some functionalized sorption media that can be used for phosphorus removal are sand rich with Fe, Ca or Mg, gravel, limestone, shale, light weight aggregates (LWA), zeolite (natural mineral or artificially produced alumino silicates), pelleted clay (along or in combination with soils), opaka (a siliceous sedimentary rock), pumice (natural porous mineral), wollastonite (a calcium metasilicate), fly ash, blast furnace slag (BFGS – a porous non-metallic co-product in iron industry), alum, goethite (a hydrous ferric oxide), hematite (a mineral form of iron(III) oxide), dolomite and calcite (Korkusuz, 2007).

DeBusk et al. (1997) used sand (with quartz), fresh organic (peat) soil, crushed lime rock (2.5 cm nominal size) and wollastonite (a mine containing calcium metasilicate plus ferrous metasilicate) to remove phosphorus (P), nickel (Ni) and cadmium (Cd) from storm water. They found that wallastonite had very good removal efficiency for their targeted contaminants. Wallastonite could remove about 87.8% P, 97.7% Cd and 80.3% Ni. On the other hand, limerock, peat and sand could remove 41.4%, 44%, and 41.4% P respectively. It can be concluded that wallastonite is very effective in phosphorus removal because it contains calcium and ferrous ions. Calcium and ferrous ions can remove phosphorus by precipitation reaction or adsorption.

Hsieh and Davis (2005) found good total phosphorus (TP) removal (about 41% to 48%) by sand and concluded that it might happen due to simple adsorption or complex sorption/precipitation processes. They found that mulch was not a good candidate for TP removal. This research group concluded that TP removal was highly variable and it might be related to properties of sorption media used and flow pattern of nutrient laden water through the sorption media. Again, organic matter could also accelerate TP removal up to 93%.

Richman (1997) found that compost had good removal efficiency for 90% solids, 85% oil and greases and 90% heavy metals. Clark and Pitt (2001) tried to remove contaminants in aerobic and anaerobic conditions from storm water runoff by using activated carbon, peat moss, compost and sand. They found good phosphorus removal efficiency by all four media in both conditions. They also found no desorption condition in their system for phosphorus. But they observed that sorption was better and leaching was lesser in aerobic condition for compost. Forbes et al. (2005) used lightweight expanded shale and masonry sand for the removal of phosphorus. They summarized that sand is a poor candidate for retaining phosphorus and expanded shale has greater removal efficiency due to its larger surface area.

Tables 1-4 summarize all the sorption media used by different researchers to remove nutrient (both nitrogen and phosphorus species) from storm water and wastewater. For removing nitrogen and phosphorus from storm water or wastewater, these filtration media can be further classified based on the derivation from: 1) plants or processed from components of plants; 2) sand and clay; 3) minerals; and 4) waste materials that may be recycled from the society. The mixture with the water material in the particularly

Table 1: Sorption media derived from plants or processed from components of plants used to remove nutrients from storm water or wastewater

No.	Sorption media	Additional environmental benefits in terms of removal	Physical/Chemical Properties	References
1	Alfalfa	100% NO_3-N removal;	D<4mm	Kim et al.(2000)
2	Leaf mulch compost/ Hardwood mulch/Wood compost	Copper , Cadmium, Lead, Zinc, 1, 3 dichlorobenzene (DCB),	Silver maple, Norway maple, Red oak and Cherry mulch (Ash 10.90%, 44.12% C, 5.86% H, 0.63% N, 0.16% S, 38.33% O), size 4760 micron,	Ray et al. (2006)
		60% NO_3-N removal;	D<2mm	Kim et al.(2000)
		Oil & greases (85% removed), heavy metals (90% removed),	Maple & elm leaf compost	Richman (1997)
		Lead		Hsieh & Davis (2005)
3	Sawdust		30% sawdust Wall structure, Monterey pine (Pinus Radiata D. Don) sawdust,	Schipper et al. (2005)
			Medium density fiberboard sawdust, Density 950 to 990 kg/m^3, Particle size 150 to 850 micron,	Gan et al. (2004)
		95% NO_3-N removal;	D<2mm	Kim et al.(2000)
4	Wheat straw			Tshabalala (2002), Rocca et al. (2005)
		95% NO_3-N removal;	D<4mm	Kim et al.(2000)
5	Wood chips/Wood fibers		D = 4.0 mm	Seelsaen et al. (2006)
		95% NO_3-N removal;	D<2mm	Kim et al.(2000)
		Polynuclear Aromatic Hydrocarbons	Aspen wood fibers composed of 51% cellulose, 26% hemicellulose, 21% lignin, and 1% ash	Boving and Zhang (2002)

				Jokela et al. (2002), Savage and Tyrrel (2005)
6	Peat	Cu, Zn, Ni, PAHs (Polyaromatic hydrocarbons)		DeBusk et. al. (1997), Clark and Pitt (1999), Clark et al. (2001), Kietlińska and Renman (2005)

Table 2: Sorption media derived from sand and clay used to remove nutrients from storm water or wastewater

No.	Sorption media	Additional environmental benefits in terms of removal	Physical/Chemical Properties	References
1	Sandy clay loam (SCL)	NO_2-N removal is 94%; NO_3-N removal is 90%;	Sand (53.28%), Silt (24.0%), Clay (22.72%); Porosity 0.51	Güngör and Ünlü (2005)
2	Loamy sand (LS)	NO_2-N removal is 95%; NO_3-N removal is 93%;	Sand (78.28%), Silt (10.64%), Clay (11.08%); Porosity 0.33	Güngör and Ünlü (2005)
3	Sandy loam (SL)	NO_2-N removal is 96%; NO_3-N removal is 73%;	Sand (70.28%), Silt (14.64%), Clay (15.08%); Porosity 0.45	Güngör and Ünlü (2005)
4	Carbon sand, enretech sand or sand			Bell et al. (1995), DeBusk et al. (1997), Clark and Pitt (1999), Clark et al. (2001), Seelsaen et al. (2006)
5	Clay	Thiocyanates, Cadmium, Lead, Nickle		Harris et al. (1996), Gálvez et al. (2003), Lazaridis (2003)
6	Zeolite+ Clay			Gisvold et al. (2000)
7	Masonary sand		Bulk density of masonry sand is 1670 kg/m^3; Porosity of masonry sand is 0.304.	Forbes et al. (2005)
8	Waste foundry sand	TCE, Zn, Metolachlor, Alachlor,		Benson (2001)

Table 3: Sorption media derived from minerals used to remove nutrients from storm water or wastewater

No.	Sorption media	Additional environmental benefits	Physical/Chemical Properties	References
1	Zeolites	Benzene, Sulfate, Chromate		Clark and Pitt (1999), Li (2003), Seelsaen et al. (2006)
2	Perlite			Redco II (2007)
3	Opoka			Braun-Howland (2003)

4	Wollastonite			DeBusk et al. (1997), Hedström (2006)
5	Iron Sulfide			Tesoriero et al. (2000), Baeseman et al. (2006)
6	Limerock			DeBusk et al. (1997)
7	Allophane		Clay-sized mineral containing silica, alumina and water	AEC (2007)
8	Chitin		A natural polymer, technically known as polyacetylglucosamine	AEC (2007)
9	Pumice		A light, porous volcanic rock composed of iron (18.2 %), aluminum (13.7%), calcium (12.7%) and magnesium (7.3%) and other.	AEC (2007)
10	Bentonite		Montmorillonite mineral with about 4%-8% calcium carbonate,	AEC (2007)
11	Clinoptilolite			Hedström (2006)
			Density 55 lb/ft^3; Particle size 0.3 to 4.76 mm.	Smith et al. (2008)
12	Polonite	Zn, Ni, Co, Mn, Cu, Ba, Fe, Ti,	Manufactured from cretaceous rock Opoka (SiO2 39.4%, CaO 42%, Al2O3 4.3%, Fe2O3 2.0%)	Kietlińska and Renman (2005)
13	Expanded shale		Expanded shale (SiO_2 62.06%, Al_2O_3 15.86%, Fe_2O_3 5.80%, CaO 1.44%, MgO 1.68%); Bulk density of expanded shale is 728 kg/m^3; Porosity of expanded shale is 0.594;	Forbes et al. (2005)
14	Limestone		with sulfer, D= 2.38 to 4.76 mm	Zhang (2002)
			D =2.38 to 4.76 mm	Darbi et al. (2002), Sengupta and Ergas (2006)
			D= 0.6 to 1.18 mm	Kim et al. (2000)
			Large particles 2 to 2.36 mm and small particles 0.6 to 1.18 mm	Kim et al.(2000)
15	Sulfur		D =2.38 to 4.76 mm	Darbi et al. (2002)

Table 4: Sorption media derived from waste materials used to remove nutrients from storm water or wastewater

No.	Sorption media	Additional environmental benefits in terms of removal	Physical/Chemical Properties	References
1	Newspaper	100% NO_3-N removal;	D (average)<4mm	Kim et al.(2000)
			0.4 cm width ribbons, (25.49% extractives (protein, hemicellulose, labile carbon), 43.11% cellulose, 29.59% lignin, 2.59% ash)	Volokite et al. (1996)

			Powder form, 28% Calcium, Average particle size 200 micron, Surface area 237 m^2/g,	Namasivayam et al. (2005)
2	Oyster shell			Sengupta and Ergas (2006)
3	Marbel chips		$Mg(OH)_2$ and $CaCO_3$	Sengupta and Ergas (2006)
4	Activated carbon	Cu, Fe, Pb, Zn		Clark et al. (2001)
5	Tire crumb/Tire chips	2,4-dichlorophenol (DCP), 4-chlorophenol (CP)	20 to 40 mm,	Shin et al. (1999)
		VOC		Lisi et al. (2004),
6	Cotton waste			Rocca et. al. (2005)
7	Polyurethane porous media		Porous structure, Average diamerer 3-5 mm, External pore diameter 300 micron.	Han et al. (2001)
8	Blast furnace slage			Hedström (2006)
		Zn, Ni, Co, Cu, Ba,	SiO_2 36.2%, CaO 35%, MgO 13.4%, Al_2O_3 10.6%,	Kietlińska and Renman (2005)
9	Oversized pulverozed brick			Savage and Tyrrel (2005)
10	Polystyrene packing			Savage and Tyrrel (2005)
11	Glass		D= 4.0 mm	Seelsaen et al. (2006)
12	Lignocellulosic material		Basically pine bark chips,	Tshabalala (2002)

MATERIALS AND METHODS

Material Characterization

The research team screened the possible sorption media through the following five criteria: 1) the relevance of denitrification process, 2) the removal efficiency as evidenced in the literature with regard to adsorption, 3) the cost level, 4) the availability, 5) low maintenance and 6) additional environmental benefits. Four sorption media were eventually selected for final consideration according to a multi-criteria decision making (MCDM) process. They include sawdust/wood chip, paper/newspaper, tire crumb and astatula sand (citrus grove sand). The two media mixes selected for use in the column tests are denoted as recipe - 1 which consists of 68%

fine sand, 25% tire crumb, and 7% sawdust, and recipe - 2 which is composed of 69% fine sand, 25% tire crumb, and 6% paper/newspaper (by volume). The reason for using paper in recipe 2 to replace sawdust in recipe 1 is that the electron donor to triggering the denitrification process has to be present in the media by some way. At the end of the column tests, recipe 1 was further used for isotherm study and also as a media blend for microcosm system study.

The ASTM D-421-85 Standard Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants was used. The Multi-point BET specific surface area by nitrogen adsorption method with respect to each type of recipe independently were performed by Quantachrome Instruments, which generated the surface area for these two mixed recipes as an average in the end. ASTM C29/C29M-07 - was applied for measuring the bulk density ("unit weight") and voids in soil and mixed media. ASTM D-854-92 Standard Test Method for Specific Gravity of Soils was applied for the determination of the specific gravity of soils and media that pass the 4.75-mm (No. 4) sieve.

Column Study

A laboratory column test method is a physical model, which attempts to simulate, on a small scale, a portion of the real world subsurface environment under a controlled set of experimental conditions. Lab column tests were conducted using three (2) plexi-glass columns (0.29 m inner diameter; 1.5 m height) with recipe - 1 and recipe - 2 respectively. The columns were packed in 5 cm lifts by adding pre-weighed dry sample. The final column porosity for both the columns was approximately 40%. For sampling ports, the columns were drilled holes at 1.37 m (4.5 ft) from top of the media as shown in Figure 1. Ball valves were used at the sampling ports and they were water sealed. The composition of all the columns in terms of weight and volume were thus determined as shown in Table 5. The feed solution (raw wastewater) from a functioning septic tank in Orlando, Florida was stored and was used in the column study. Raw wastewater was pumped at the top of the columns as a continuous system. The columns were covered with a lid from top and bottom and the discharge ports were air tight so as to prevent direct contact of air thereby keeping the columns anoxic in condition. Sampling Method**:** Effluent samples were directly collected from the bottom of the columns at the sampling port. The sampling ports used were air tight ball valves**.** The ball valves were opened and effluent samples were extracted. The influent and effluent samples were collected in sterilized plastic bottles and were transported for water quality analysis to ERD lab.

Table 5: Composition of Columns in Terms of Weight and Volume

	Column STS		*Column STP*	
	wt %	*vol %*	*wt %*	*vol %*
Tire Crumb	10.9	25.0	10.7	25.0
Paper	-	-	4.0	6.2
Sawdust	4.0	7.1	-	-
Astatula Sand	85.1	67.9	85.3	68.8

* Note: STS is the acronym of Sand, Tire Crum and Sawdust; STP is the acronym of Sand, Tire Crum and Paper

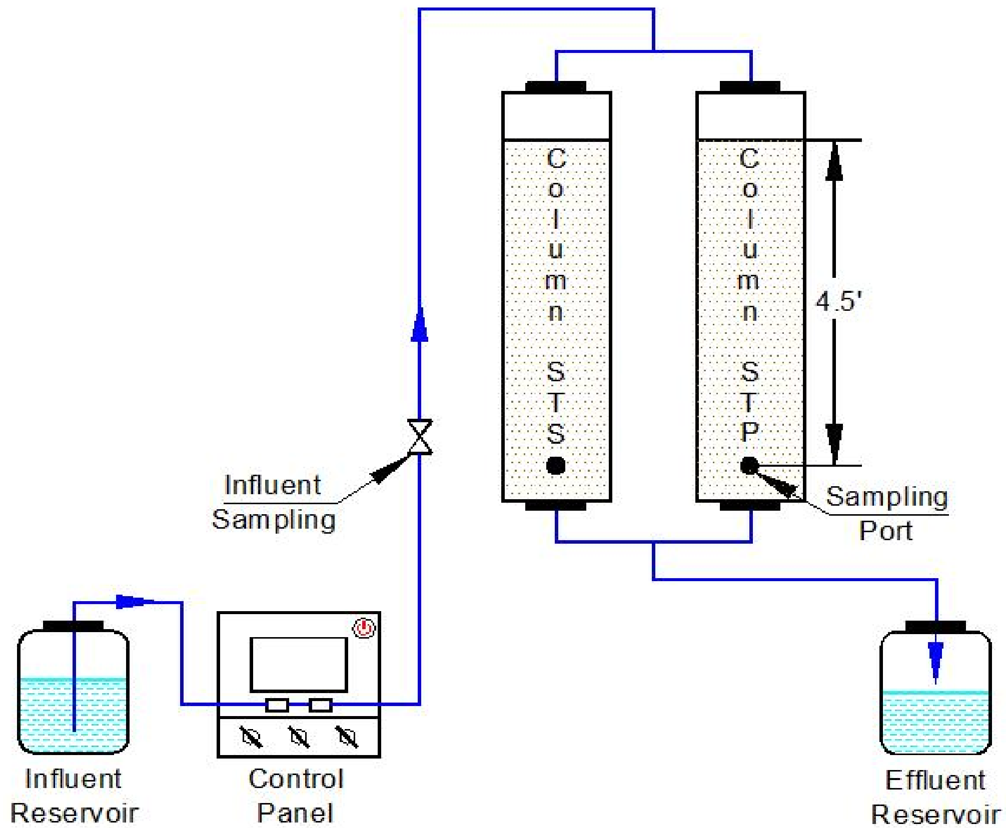


Figure 1: Schematic of Column Test

Batch Study

An Isotherm study as a batch process was carried out with recipe - 1 so as to study the sorption of ortho-phosphorus and nitrates. It is helpful in determining the sorption capacity and also the estimated life of the media for the sorption of nutrients. For isotherm study of nitrates, five flasks were prepared containing 100 gm of recipe - 1 and nitrate solution of 50 mL of 9.6, 8.4, 7.2, 6.0, 4.8 mg/L NO_3-N was added in different flasks. The media mix and the solution were mixed thoroughly and kept for a residence time of 24 hours. After 24 hours, nitrate solution was extracted from the media and analyzed. For isotherm study of ortho-phosphates, one flask was prepared containing 200 gm of recipe - 1 and phosphate solution of 100 mL of 4.12 mg/L PO_4-P. The media mix and the solution was mixed thoroughly and kept for a residence time of 24 hours. After 24 hours, phosphate solution was extracted from the media and analyzed. Using the same media mix in the flask 100 ml of fresh 4.12 mg/L PO_4-P was added to the flask and mixed thoroughly and resided for 24 hours. The previous step was repeated for 6 days using the same media mix and the extracted solutions from the media were analyzed.

Microcosm Study

A Microcosm model is a small, representative system having analogies to a larger system in constitution, configuration and development. A microcosm model was built with a rectangular plastic container (L = 56 cm; W = 34.5 cm; D = 15 cm). The model mainly consists of two zones, treatment zone to the length of 46 cm whereas collection zone of 10 cm. Figure 2 shows the schematic of this system.

The bottom 5cm of the treatment zone consists of recipe - 1 whereas the rest of the model is packed with astatula sand. Synthetic wastewater flows into the model through the perforated tubing (inner diameter 0.3 cm) which acts as header pipes and has a downward slope of around 1%. These tubes are engineered with holes and slots, allowing it to collect and disperse the wastewater as it passes over the corrugations in the tubes. As the wastewater is distributed throughout the tubes, it trickles down to the media allowing partial biological breakdown before reaching the media. The wastewater is retained in the media for a hydraulic retention time of 72 hrs so as to provide the desired denitrification. The wastewater is retained in the treatment zone with the help of pre-fabricated riser at around 46 cm length and 6.5 cm in height as shown in Figure 2. The model is run as a continuous system and effluent is collected from the collection zone. Additionally, the locations of sampling ports in the different compartments of the model are also depicted in Figure 2.

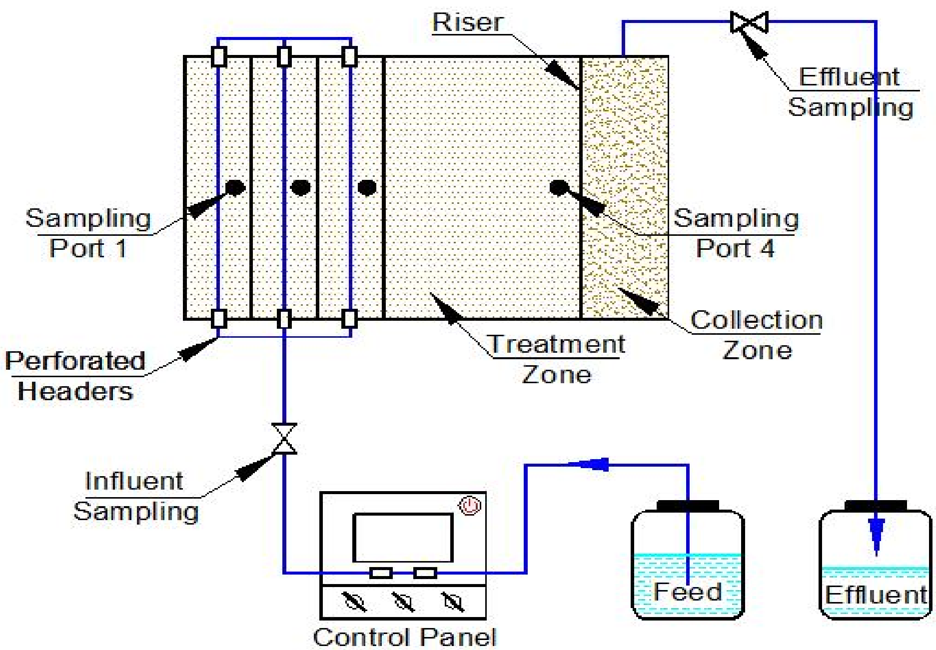


Figure 2: Experimental Design of Microcosm Model

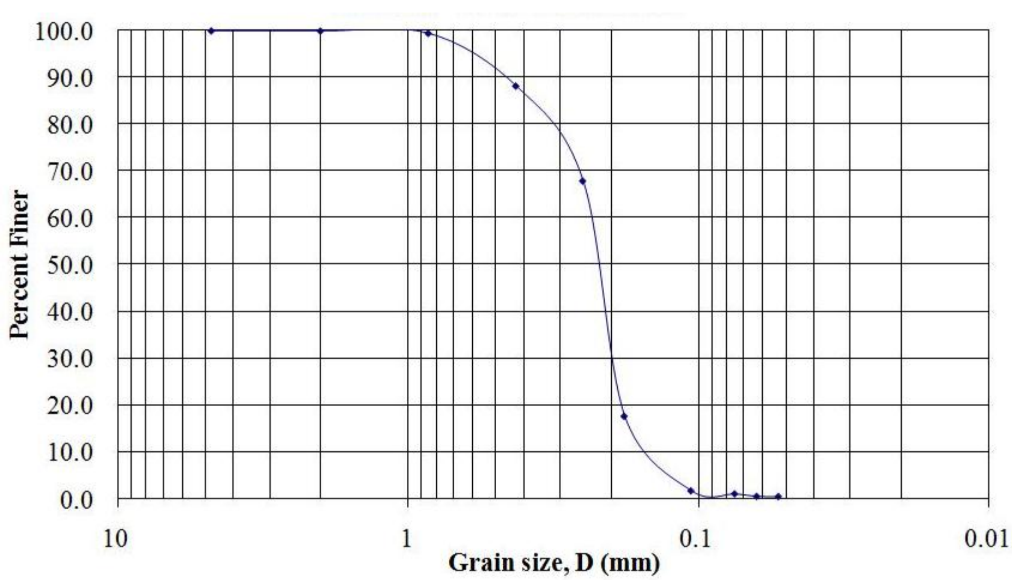
RESULTS & DISCUSSION

Material Characterization

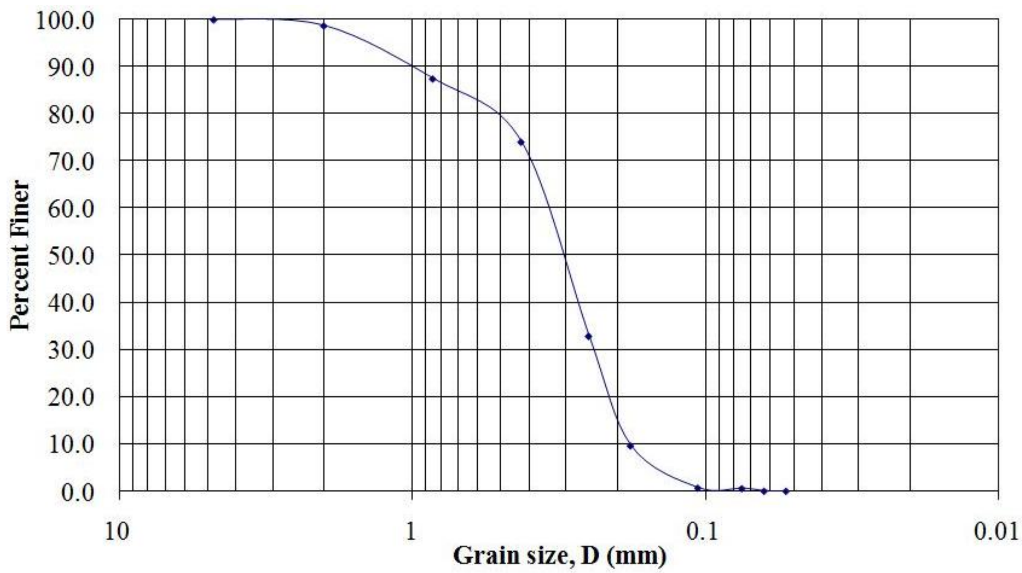
The permeability of the astatula sand was measured to be 55.0 cm/hr (21.6 in/hr). The permeability of recipe 1 and recipe 2 were measured to be 54.4 cm/hr (21.4 in/hr) and 59.4 cm/hr (23.4 in/hr), respectively. To determine the particle-size distribution a sieve analysis was performed. Table 6 lists the summary of material characterization of the astatula sand and the two recipes used for the column tests. Surface area of astatula sand, recipe – 1 and recipe – 2 are approximately 0.32 m^2 g^{-1}, 0.08 m^2 g^{-1} and 0.18 m^2 g^{-1} respectively. Surface areas were determined by a nitrogen sorption BET test (Quantachrome Instruments, Boynton Beach, FL). Figure 3(a), 3(b), and 3(c) present the gradation curve of Astatula sand and two mixes used in our recipes comparatively.

Table 6: Summary of Material Characterization

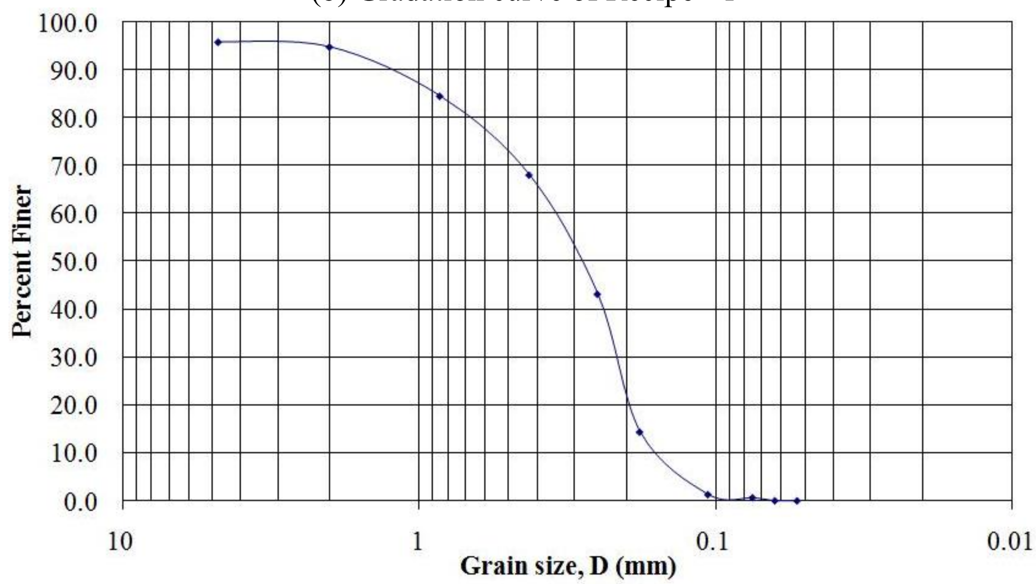
	Astatula Sand	*Recipe - 1*	*Recipe - 2*
Density (g cc^{-1})	1.53	1.24	1.28
Void Ratio (unit less)	0.73	0.69	0.62
Porosity (unit less)	0.42	0.41	0.38
Specific Gravity (Gs)	2.65	2.32	2.15
Surface Area (m2 g^{-1})	0.32	0.08	0.18
Permeability (cm hr^{-1})	55.0	54.4	59.4



(a) Gradation curve of Astatula Sand



(b) Gradation curve of Recipe - 1



(c) Gradation curve of Recipe - 2

Figure 3: Gradation curve of natural soil and sorption media

Column Study

The following Table 7 presents the results from the Column Study for Column STS and Column STP with Recipe 1 and Recipe 2 respectively. During the experimental period the columns did not show any signs of saturation with nutrients although the columns were loaded with high concentrations of nutrients with average total phosphorus concentration of 188 mg/L which is approximately thirteen fold than the average concentration of 14 mg/L for total phosphorus (USEPA, 2002) and average total nitrogen concentration of 415 mg/L which is approximately eight fold than the average concentration of 50 mg/L for total nitrogen (USEPA, 2002).

Table 7: Results from Column Study in 2006-2007 time period

	19-Oct	*26-Oct*	*10-Nov*	*17-Nov*	*30-Nov*	*2-Feb*	*26-Feb*	*7-Mar*	*Avg Conc [mg/L]*
Nitrates									
Influent	0.27	0.31	3.02	3.49	3.10	0.16	0.21	1.95	1.56
Recipe 1	0.04	0.06	0.08	0.02	0.15	0.01	0.01	0.02	0.05
Recipe 2	0.03	0.06	0.11	0.08	0.86	0.08	0.01	0.03	0.16
Average Percentage Removal (%); Recipe 1 = 97.0 & Recipe 2 = 90.1									
Ammonia									
Influent	4.9	27.8	1.5	119	112	10.7	72.9	-	49.7
Recipe 1	0.3	3.7	0.7	4.1	4.4	6.7	10.8	-	4.4
Recipe 2	0.1	0.2	0.0	0.1	0.8	0.9	11.0	-	1.9
Average Percentage Removal (%); Recipe 1 = 91.2 & Recipe 2 = 96.2									
Total Nitrogen									
Influent	96.4	35.6	1135	488	689	678	126	67.5	414
Recipe 1	6.2	6.4	5.3	4.2	5.2	6.9	12.1	10.3	7.1
Recipe 2	5.1	7.0	6.5	5.7	5.4	1.1	15.9	0.9	6.0
Average Percentage Removal (%); Recipe 1 = 98.3 & Recipe 2 = 98.6									
Ortho Phosphorus									
Influent	0.86	0.91	0.81	0.63	0.73	0.23	0.71	1.26	0.77
Recipe 1	0.01	0.00	0.02	0.04	0.00	0.00	0.00	0.00	0.01
Recipe 2	0.02	0.01	0.02	0.02	0.01	0.01	0.05	0.00	0.02
Average Percentage Removal (%); Recipe 1 = 98.8 & Recipe 2 = 97.8									
Total Phosphorus									
Influent	6.8	4.2	705	195	550	36.1	3.2	2.1	188
Recipe 1	0.15	0.06	0.23	0.09	0.18	0.09	0.08	0.14	0.13
Recipe 2	0.21	0.08	0.19	0.15	0.21	0.19	0.07	0.07	0.15
Average Percentage Removal (%); Recipe 1 = 99.9 & Recipe 2 = 99.9									
BOD									

Influent	-	-	2180	1475	7200	606	173	198	1972
Recipe 1	-	-	240	45.0	405	85.0	36.9	52.0	144
Recipe 2	-	-	751	750	833	342	2.00	48.0	454
Average Percentage Removal (%); Recipe 1 = 92.7 & Recipe 2 = 76.7									

In the previous study by Davis et al. (2003), paper and sawdust showed some excellent results in terms of nitrate removal and were accepted as one of the best electron donors. In this research, sawdust and paper (newspaper) showed similar results and were just not limited to nitrates but also to total nitrogen, total phosphorus, ammonia, ortho-phosphorus and BOD. At the end of the experimental period, the newspaper print in the columns was still visible and most of the newspaper in the media mix remained similar in appearance to the original material. These observations are consistent with other studies that indicate that newspaper is somewhat resistant to bacterial degradation under anoxic conditions (Cummings and Stewart, 1994; Volokita et al, 1996; Davis et al, 2003). This resistance seems to be the chemical composition of newspaper, in particular the relatively high lignin content. Tire crumb that was used for this research has carbon content of 85% and does not have any metal content. Though tire crumb was never used as an individual media for the septic tank drainfield, the results indicate that it has a strong potential for creating an environmentally safe and value-added option for scrap tire reuse.

Overall, the green sorption media showed significant potential for pollutant removal in a septic tank drainfield. Throughout the experimental period, both the columns showed almost equal and consistent removal of more than 90% for all the water quality parameters (i.e., ortho-phosphorus, total phosphorus, nitrates, total nitrogen, ammonia, BOD).

Batch Study

The results for the nitrate and ortho-phosphate isotherm results are presented in Table 8(a) and 4(b) respectively. It can be seen from Table 4(a) that there is very little or no removal of nitrates. It was concluded that the nitrates was not sorbed by the sorption media and biological activity could not initiate as the batch studies were performed in 24 hrs. However, substantial removal of phosphorus was observed from the batch tests. The sorption results for phosphorus were plotted for the linearized form of Langmuir and Freundlich Isotherm Model as shown in Figure 4(a) and 4(b) respectively. The linearized form of Langmuir and Freundlich isotherm models are as presented below:

Table 8: Isotherm Results

(a) Nitrate Isotherm Results

Sample	*Mass Loading [mg]*	*Mass Removed [mg]*
1	0.48	0.11
2	0.42	0.00
3	0.36	0.08
4	0.30	0.01
5	0.24	0.00

(b) Phosphate Isotherm Results

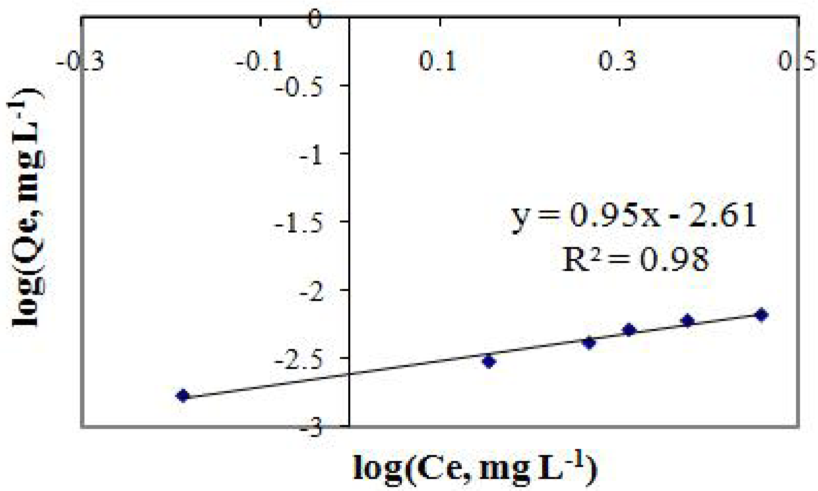
Sample	*Mass Loading [mg]*	*Mass Removed [mg]*
1	0.41	0.35
2	0.41	0.27
3	0.41	0.23
4	0.41	0.21
5	0.41	0.17
6	0.41	0.12

Langmuir isotherm equation: $(1/Q_e) = (1/(Q_{max}b)) \times (1/C_e) + (1/Q_{max})$ ……..(Eq. 1)

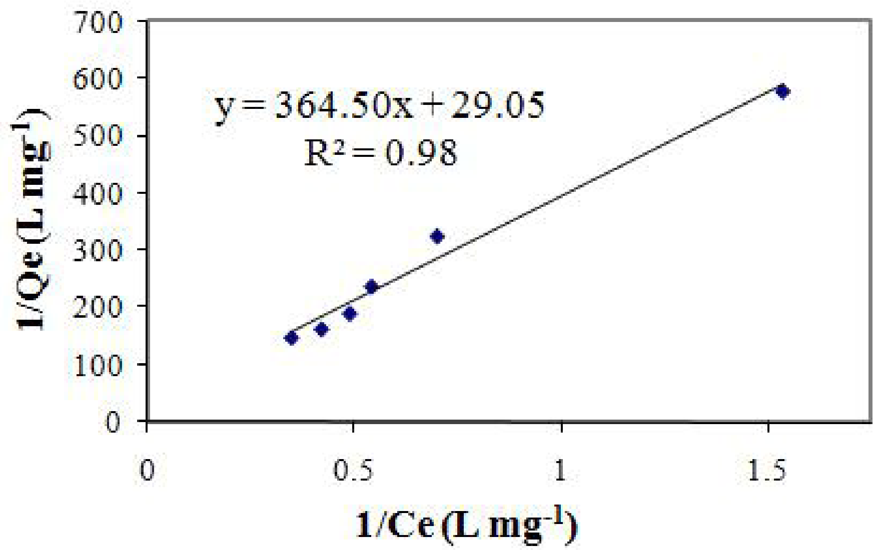
where: Q_e = Sorbed concentration [mass adsorbate/mass adsorbent]; Q_{max} = Maximum capacity of adsorbent for adsorbate [mass adsorbate/mass adsorbent]; b = Measure of affinity of adsorbate for adsorbent; C_e = Aqueous concentration of adsorbate [mass/volume].

Freundlich isotherm equation: $\log q_e = \log K + (1/n) \log C_e$ ....(Eq. 2)

where: q_e = Sorbed concentration [mass adsorbate/mass adsorbent]; K = Capacity adsorbent [mass adsorbate/mass adsorbent]; C_e = Aqueous concentration of adsorbate [mass/volume]; n = Measure of how affinity for the adsorbate changes with changes in adsorption density.



(a) Freundlich Plot



(b) Langmuir Plot

Figure 4: Isotherm Plots

Assume that monolayer coverage of phosphorus adsorbed to the media surface. From the graphical plots as shown in Figure 4(a) and 4(b), the adsorption capacity for phosphorus from the Langmuir and Freundlich isotherm models were calculated to be 34.4 mg g^{-1} and 0 mg g^{-1}

respectively. It can be concluded that the Langmuir Equation fits better for the sorption of phosphorus.

Microcosm Study

The results from the Microcosm model are as presented in Table 9. The samples illustrated around 80% removal efficiency for nitrates and ortho-phosphorus. Additionally, the results also include the concentration and removal efficiency from sampling ports located in the different compartment of the model. It appears that most of the denitrification reactions occur in the last compartment before riser in the microcosm in which a well fostered anoxic environment can be maintained throughout the operation. This observation is consistent with our design philosophy completely.

Table 9: Results from Microcosm Model

	Nitrates			*Ortho-Phosphorus*		
	Concentration [mg/L]	*% Removal*	*Cum % Removal*	*Concentration [mg/L]*	*% Removal*	*Cum % Removal*
Influent	2.38			1.28		
Sampling Port 1	2.33	1.87	1.87	1.15	10.17	10.17
Sampling Port 2	2.26	2.91	4.79	1.02	10.67	20.84
Sampling Port 3	1.72	22.68	27.47	0.76	20.33	41.17
Sampling Port 4	0.49	52.03	79.50	0.23	40.91	82.08
Effluent	0.47	0.62	80.12	0.20	2.16	84.24

To determine the life of the green sorption media, which is applied as a 5 cm (2 inch) layer in the microcosm model, only two factors need to be known. These factors are the mass of the pollution control media and the phosphate mass loading rate per year. Knowing that the density of the green sorption media is 1.37 g cc^{-1} (85.5 lbs ft^{-3}), the mass of media is 11,719 grams. Also knowing that the average concentration of phosphorus coming into the drainfield is around 14 mg L^{-1} (http://pubs.usgs.gov/sir/2004/5299: USEPA, 2002) and daily flow of wastewater to the model is 1.25 L, the mass loading of phosphate year is determined to be about 6,388 mg yr^{-1}. Additionally, the adsorption capacity from the batch isotherm tests for phosphorus was estimated to be around 34.4 mg g^{-1}. The life of the green sorption media is thereby calculated to be about 63 years.

CONCLUSION

The information generated in the present study is valuable for understanding the postulated development of green sorption media applied to solve the nutrient removal in an innovative septic tank underground drainfield. Under the hydraulic retention time (HRT) of 24 hours, samples illustrated treatment efficiencies of greater than 90% for both the columns for all pollutants of concerns. The batch adsorption isotherm data was fitted in the Langmuir isotherm and Freundlich isotherm models, and adsorption capacity for phosphorus was found to be 34.4 mg g^{-1} based on Langmuir isotherm. A microcosm of the septic tank underground drainfield was built with one of the recipes applied in the column test as a continuous system dosed with synthetic wastewater. Under the HRT of 72 hours, samples from the microcosm physical model illustrated more than 80% of removal efficiency for nitrates and phosphorus. Additionally, with the aid of the isotherm tests, the life expectancy of the proposed sorption media in the microcosm physical model was estimated to be around 63 years for phosphorus sorption. The significant removal efficiencies of the targeted contaminants suggest that the use of such green sorption media might be a suitable and powerful material for an *in-situ* remediation of nitrate and ortho-phosphate contaminated in groundwater. Overall, this research demonstrates the effectiveness of sawdust and paper as electron donors in a drainfield whereas tire crumb may have better adsorption capacity for nutrient removal. The field study in the future would be more appropriate to examine the long-term performance and determine the expected life of the media mix in terms of removal of nutrients. Economic analysis is also planned to be carried out so as to compare the new drainfield against the conventional standard drainfield.

REFERENCES

Analytical & Environmental Consultants (AEC), 2005. locally available adsorbing materials, sediment sealing, and flocculants for chemical remediation of lake and stream water, http://www.ebop.govt.nz/media/pdf/report/Chemicalremediationstudy.pdf, accessed in June, 2007.

Baeseman, J. L., Smith, R. L., and Silverstein, J., 2006. Denitrification potential in stream sediments impacted by acid mine drainage: effects of pH, various electron donors and iron, *Microbial Ecology*, 51(2), 232-241.

Baker, L. A., 1992. Introduction to nonpoint source pollution in the United States and prospects for wetland use. Ecological Engineering, 1, 1-26.

Boving, T. B. and Zhang, W., 2004. Removal of aqueous-phase polynuclear aromatic hydrocarbons using aspen wood fibers, *Chemosphere*, 54, 831-839.

Birch, G. F., Fazeli, M. S., and Matthai, C., 2005. Efficiency of an infiltration basin in removing contaminants from urban stormwater. Environmental Monitoring and Assessment, 101, 23–38.

Benson, C. H., 2001. Using waste foundry sands as reactive media in permeable reactive barriers, DNR project #147.

Bell, W., Stokes, L., Gavan, L. J., and Nguyen, T. N., 1995. Assessment of the pollutant removal efficiency of Delaware Sand filter BMPs, *City of Alexandria, Department of Transportation and Environmental Services*, Alexandria, VA.

Clark, S. and Pitt, R., 1999. Storm water treatment at critical areas: Evaluation of filter media, EPA 600/R-00/010, Washington D C, USA.

Clark, S., Pitt, R., and Brown, D., 2001. Effect of anaerobiosis on filter media pollutant retention, *Presented at the Engineering Foundation and the American Society of Civil Engineers Conference on Information & monitoring needs for evaluating the mitigation effects of BMPs*, Snowmass, CO.

Cummings, S. P.; Stewart, C. S. (1994) *Newspaper as a Substrate for Cellulolytic Landfill Bacteria.* J. AppL. Bacteriol., 76, 196.

DeBusk, T.A., Langston, M. A., Schwegler, B. R., and Davidson, S., 1997. An evaluation of filter media for treating storm water runoff, *Proceedings of the fifth Biennial Storm water Research Conference*, 82-89.

Davis, Hunho Kim, Eric A. Seagren, 2003. *Engineered bioretention for removal of nitrate from stormwater runoff*. Water Environ Res 75 no4.

Darbi, A., Viraraghavan, T., Butler, R., and Corkal, D., 2002. Batch studies on nitrate removal from potable water, *Water South Africa*, 28(3), 319-322.

Ecological Society of America (ESA), 2000. Nutrient Pollution of Coastal Rivers, Bays, and Seas. Issue in Ecology, Vol. 7, Fall, 2000.

Florida Department of Health. 2004. *Wekiva Basin Onsite Sewage Treatment and Disposal System study*. Department of Onsite sewage program. Copy available at the internet at: http://www.doh.state.fl.us/environment/////ostds/wekiva/wekivastudyrtp.pdf

Forbes, M.G., Dickson, K.L., Saleh, F., Doyle, R.D., Hudak, P., and Waller, W.T., 2005. Recovery and fractionation of phosphate retained by lightweight expanded shale and masonry sand used as media in subsurface flow treatment wetlands, *Environmental Science & Technology*, 39(12), 4621-4627.

Gan, Q., Allen, S. J., and Matthews, R., 2004. Activation of waste MDF sawdust charcoal and its reactive dye adsorption characteristics, *Waste Management*, 24, 841-848.

Güngör, K. and Ünlü, K., 2005. Nitrite and nitrate removal efficiencies of soil aquifer treatment columns, *Turkish J. Eng. Env. Sci*., 29, 159-170.

Gálvez, J. M., Gómez, M. A., Hontoria, E., and López, J. G., 2003. Influence of hydraulic loading and air flow rate on urban wastewater nitrogen removal with a submerged fixed-file reactor, *Journal of Hazardous Materials*, B101, 219-229.

Güngör, K. and Ünlü, K., 2005. Nitrite and nitrate removal efficiencies of soil aquifer treatment columns, *Turkish J. Eng. Env. Sci*., 29, 159-170.

Harris, W. G., Rhue, R. D., Kidder, G., Brown, R. B., and Littell, R., 1996. Phosphorus retention as related to morphology of sandy costal plain soil materials, *Soil Science Society of American Journal*, 60(5), 1513-1521.

Han, D. W., Yun, H. J., and Kim D. J. (2001). Autotrophic nitrification and denitrification characteristics of an up flow biological aerated filter, *Journal of Chemical Technology and Biotechnology*, 76, 1112-1116.

Hsieh, C. H. and Davis, A. P., 2003. Multiple-event study of bioretention for treatment of urban storm water runoff**,** Diffuse Pollution Conference Dublin, Ireland.

Hedström, A., 2006. Reactive filter materials for ammonium and phosphorus sorption in small scale wastewater treatment, Doctoral Dissertation, Luleå University of Technology, IAAN: 1402-1544.

Jokela, C. H. Y., Kettunen, R.H., Sormunen, K. M., and Rintala, J. A., 2002. Biological nitrogen removal from municipal landfill leachate: low-cost nitrification in biofilters and laboratory scale in-site denitrification, *Water Research*, 36, 4079-4087.

Kahl, J. S., Norton, S. A., Fernandez, I. J., Nadelhoffer, K. J., Driscoll, C. T., and Aber, J. D., 1993. Experimental inducement of nitrogen saturation at the watershed scale. Environmental Science and Technology, 27, 565-568.

Kim, H., Seagren, E. A., and Davis A. P., 2000. Engineering Bioretention for Removal of Nitrate from Storm water Runoff, in WEFTEC 2000 Conference Proceedings on CDROM Research Symposium, Nitrogen Removal, Session 19, Anaheim CA, Oct. 2000.

Kietlińska, A., and Renman G., 2005. An evaluation of reactive filter media for treating landfill leachate, *Chemosphere*, 61, 933-940.

Korkusuz, E. A., Beklioglu, M., and Demirer, G. N., 2007. Use of blast furnace granulated slag as a substrate in vertical flow reed beds: field application, *Bioresourse Technology*, 98, 2089-2101.

Kietlińska, A., and Renman G., 2005. An evaluation of reactive filter media for treating landfill leachate, *Chemosphere*, 61, 933-940.

Lazaridis, N. K., 2003. Sorption removal of anions and cations in single batch systems by uncalcined and calcined Mg-Al-Co_3 hydrocalcite, *Water, Air and Soil Pollution*, 146, 127-139.

Lisi, R. D., Park, J. K., and Stier, J. C., 2004. Mitigating Nutrient Leaching with a Sub-Surface Drainage Layer of Granulated Tires. Waste Management, 24(8), 831-839.

Mothersill, C. L., Anderson, B. C., Watt, W. E., and Marsalek, J., 2000. Biological filtration of stormwater: field operations and maintenance experiences. Water Quality Research Journal Canada, 35(3), 541-562.

Namasivayam, C., Sakoda, A., and Suzuki, M. (2005). Removal of phosphate by adsorption onto oyster shell powder-kinetic studies, *Journal of Chemical Technology and Biotechnology*, 80, 356-358.

Peterjohn, W. T., Adams, M. B. and Gilliam, F. S., 1996. Symptoms of nitrogen saturation in two central Appalachian hardwood forest ecosystems. Biogeochemistry 35, 507-522.

Richman, M., 1997. Compost media capture pollutants from storm water runoff, *Water Environment & Technology*, 9, 21-22.

Rocca, C. D., Belgiorno, V., and Meric, S., 2005. Cotton-supported heterotrophic denitrification of nitrate-rich drinking water with a sand filtration post-treatment, *Water South Africa*, 31(2), 229-236.

Ray, A. B., Selvakumar, A., and Tafuri, A. N., 2006. Removal of selected pollutants from aqueous media by hardwood mulch, *Journal of Hazardous Materials*, B136, 213-218.

Sawyer, McCarty, and Parkin, "*Chemistry for Environmental Engineering Science*", Fifth Edition, 2003.

Sengupta, S. and Ergas, S. J., 2006. Autotrophic biological denitrification with elemental sulfur or hydrogen for complete removal of nitrate-nitrogen from a septic system wastewater, *a report submitted to The NOAA/UNH cooperative institute for costal and estuarine environmental technology (CICEET).*

Savage A. J. and Tyrrel, S. F., 2005. Compost liquor bioremediation using waste materials as biofiltration media, *Bioresource Technology*, 96, 557-564.

Snoeyink, V. L., and Summers, S. R., "*Adsorption of Organic Compounds*", Water Quality and Treatment 5th Edition, McGraw-Hill, 1999.

Spalding, R. F. and Kitchen, L. A., 1988. Nitrate in the intermediate vadose zone beneath irrigation cropland. Groundwater Monitoring Review, 8(2), 89-95.

Stoltz and Reneau, Jr., R. B., 1998. *Potential for Contamination of Ground and Surface Waters from On-site Wastewater Disposal Systems.*

Schipper, L. A., Barkle, G. F. and Vukovic, M. V., 2005. Maximum rates of nitrate removal in a denitrification wall, *Journal of Environmental Quality*, 1270-1276.

Seelsaen, N., McLaughlan, R., Moore, S., Ball, J., and Stuetz, R., 2006. Pollutants removal efficiency of alternative filtration media in storm water treatment, *Water Science & Technology*, 54(6-7), 299-305.

Smith, D. P., Otis, R., and Flint, M., 2008. Florida passive nitrogen removal study (Final report), Florida Department of Health, Tallahassee, Florida.

Tshabalala, M. A. (2002). Use of Lignocelluloses materials as sorbents for pesticide and phosphate residues, *USDA Forest Division, Madison*, WI 53705-2398.

Tesoriero, A. J., Liebscher, H., and Cox, S. E., 2000. Mechanism and rate of denitrification in an agricultural watersheds: electron and mass balance along groundwater flow paths, *Water Resources Research*, 36(6), 1545-1559.

Tshabalala, M. A., 2002. Use of Lignocelluloses materials as sorbents for pesticide and phosphate residues, *USDA Forest Division, Madison*, WI 53705-2398.

U.S. Department of Health, Education, and Welfare. *Public Health Service Drinking Water Standards*; Publ. 956; U.S. Dep. Health, Educ., and Welfare: Washington, DC, 1962.

U.S. Environmental Protection Agency (USEPA). 2002. *Manual: Onsite Wastewater Treatment Systems*. EPA 625/R-00/008. U.S. Environmental Protection Agency.

Volokita, M., Belkin. S., Abeliovich, A., and Soares, M. I. M., 1996. *Biological Denitrification of Drinking Water Using Newspaper.* Water Res., 30, 965.

World Health Organization (WHO), 2006. *Guidelines for Drinking-water Quality*, 1st Addendum to the 3rd ed.,Volume 1: Recommendations, World Health Organization, Geneva.

Zhang, T. C., 2002. Nitrate removal in sulfur: limestone pond reactor, *Journal of Environmental Engineering, ASCE*, 128(1), 73-84.