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The use of recycled glass as a filter media for on-site wastewater treatment

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ABSTRACT

In situations where gravity-fed septic tanks are not suitable — high water table, shallow depth of subsoil to bedrock or poor subsoil percolation or overlying particularly vulnerable groundwater resources — alternative approaches are required to improve the quality of the effluent before discharge to ground. Such options include the use of a sand filter or a raised mound soil percolation area, either as a secondary treatment unit or as a polishing filter. Investigations have been made into the use of recycled glass as an alternative media to sand in such filters and as a soil conditioner for mound systems. The phosphate removal capacity of six different indigenous types of sand and 3 grades of recycled glass were studied to determine their respective adsorption isotherms, finding the highest adsorption in calcareous sand but almost nothing for the recycled glass. Filters set up in parallel in the laboratory (one with a typical sand, the other with recycled glass) and dosed with wastewater found that the glass filter performed similarly (with the exception of phosphate) to the sand filter across a range of hydraulic loading rates (42–85 L/m^2.d) attaining removal efficiencies of 72–83% COD, 10–26% total nitrogen and 3.7–4 log removal of faecal coliforms. Both filters also performed better if the wastewater was applied in smaller-volume, more frequent doses. Finally, the addition of recycled glass into the matrix of a clay subsoil promoted a significant improvement in both the rate and uniformity of percolation, as measured both in the laboratory and out in the field demonstrating its potential for use in raised mound treatment systems.

Keywords: Onsite wastewater treatment; Recycled glass; Sand filters; Raised mound systems

1. Introduction

In Ireland, wastewater from over one third of the population is treated in small-scale independent systems [1], the most common treatment application being the conventional septic tank system with percolation area. Groundwater resources provide over 25% of all water supplies [2] and hence protection from contamination by on-site domestic wastewater effluent is crucial. Due to the ever-increasing pressure on the planning authorities for development in more rural areas, a rigorous site assessment procedure is now being introduced according to guidelines from the Irish Environmental Protection Agency [3]. This determines the vulnerability of local groundwater resources which are especially at risk in areas where the bedrock or water table is close to the surface or where subsoil of high permeability underlie the site. In situations where a septic tank installation is not suitable, some form of secondary treatment system can be installed such as mechanically-aerated systems or filter systems to improve the quality of the effluent before discharge to the subsoil. One of the options promoted is the use of an intermittent stratified sand filter either as a secondary treatment unit or as a polishing filter in place of the percolation area. Field studies in Ireland have been carried out on stratified sand filters with

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the recommendation that a hydraulic loading rate of 30 L/m^2.d is used for sand filters as a secondary treatment process and 60 L/m^2.d if used for tertiary treatment application [4].

Various studies have shown that single stage intermittent sand filters, loaded organically and hydraulically at 5–20 g BOD/m^2 d and 40–100 L/m^2 d respectively, attain removal efficiencies of 90% COD, 95% BOD, 30% total nitrogen, 40% total phosphorous and 2–4 log removal of faecal coliforms [5–10]. The effluent from sand filters can be of high quality with typical concentrations of 5 mg/L or less of BOD and SS, as well as nitrification of 80% or more of the applied ammonia [8,11]. At higher loading rates denitrification can occur in anaerobic regions of the filter as a result of organic matter build-up promoting saturated conditions [10,12].

The aerobic conditions in sand filters are maintained through the intermittent application of the effluent and oxygen consumption is balanced by the renewal of the air phase with atmospheric air by the means of convective and diffusive exchanges through the surface and in general, studies have shown that slight improvements to treatment performance of filters can be gained by small-volume, short hydraulic flushes as opposed to less frequent, larger volume doses [7,13]. Dosing frequencies of between 4 and 24 times per day have been reported in the above studies, dependant also on the overall hydraulic loading rate.

Phosphorous removal in sand filters is primarily due to the mineral content of the sand used and is controlled mainly by adsorption and mineral precipitation reactions. The adsorption capacity of a sand is regulated by the occurrence of natural minerals such as iron, calcium and aluminium but also affected by the chemical characteristics of the effluent (Redox potential and pH) within the filter. Although several studies have shown sorption of phosphate onto calcareous sands [14], non-calcareous sands have been shown to be effective at phosphate removal in certain cases, for example in an aluminium enriched sand [15].

An alternative treatment system for situations where conventional gravity-fed septic tanks are not suitable, for example sites with a high water table, is the use of a raised mound soil percolation area. These systems have been shown to be effective if constructed using soil with appropriate percolation characteristics and ensuring that an even distribution of effluent is attained at the appropriate hydraulic loading rates [16]. However, in Ireland these raised mounds are normally made using the insitu soil which often has poor percolation characteristics (a contributive factor behind why the mound systems are required in many cases). Additionally, the *ad hoc* construction practises can detrimentally affect the percolation characteristics of the constructed mound. For example, over compaction of the soil can result in too slow, unsatisfactory percolation rates.

Currently, almost all of Ireland's recovered glass is exported to the UK whilst specialist silica required for sand filters is imported from the UK. The use of indigenous recycled glass as a filter media would thus reduce energy and transport costs addressing sustainability and compliments the EU Waste Management Directives [Framework Directive on Waste (91/156/EEC), Landfill of Waste (1999/31/EC) and Packaging and Packaging Waste (94/62/EC)]. Previous research has looked at using recycled glass as the media for both wastewater and water treatment filters being used at a large-scale wastewater treatment plant successfully in a recirculating filter [17]. Other trials using different grades of glass at a loading rate of 9.5 m^3/m^2.h for tertiary treatment [18] have reported slightly better suspended solids and COD removal compared to a parallel sand filter. Other research has indicated that sand filters are more effective than soil filters in terms of faecal coliform and total-N removal [19].

Hence, the aim of this study was to evaluate the use of recycled glass as a media for single pass filters used for on-site waetwater treatment in comparison to filters constructed from indigenous sand media. An initial objective was to compare several Irish sands and the glass specifically with respect to phosphorus removal. The overal treatment performance of two filters in parallel was then compared in terms of other wasetwater parameters (organics, nitrogen and faecal coliforms) at different hydrauclic loading rates. Finally, the use of glass as a conditioner to improve the permeability of slowly draining soil was investigated for the potential use in mound systems which are being used for on-site treatment in areas with high water tables — a common situation in Ireland.

2. Methodology

2.1. Evaluation of phosphorus adsorption

The phosphate adsorption capacity of several samples of different indigenous sands and recycled glass were compared by the determination of the Freundlich and Langmuir isotherms. The sand samples were a coarse beach sand from Sligo, granite sand from Carlow, silica sand from Chleford, limestone sand from Larne and sand from Aughrim derived from schist and greywacke. Three grades of recycled glass — coarse (2–5 mm), medium (0.7–2 mm) and fine (0.2–1 mm) — were obtained from Tullagower Quarries, Kilrush in County Clare. Adsorption isotherms were determined by preparing solutions of potassium ortho-phosphate and potassium nitrate to give concentrations of 320, 160, 80, 40, 20, 10, 5 and 2.5 mgP/L. Five grams of each sand/glass sample were put into 125 ml Nalprene bottles followed by 100 ml of the respective solution. The pH of the solution was measured and adjusted to the equilibrium pH using potassium hydroxide. The samples were then sealed and fixed to a slowly rotating wheel which kept the sample and solution continually mixed for a period of 20 h. The concentration of the solution was then analysed for ortho-phosphate before and afterwards using the ascorbic acid method and a Merck spectrophotometer to calculate the percentage adsorbed.

The phosphate removal efficiency of three different sands (Chelford silica, Larne limestone and Sligo beach) and the recycled glass were then determined under varying hydraulic loading rates using 100 mm deep vertical filtration columns in the laboratory. The influent solution of ortho-phosphate on the filters was kept constant at 20 mgP/L to be within the range of normal on-site effluent concentrations. High hydraulic loading rates were used, however, compared to normal on-site filter rates in order to promote a breakthrough of phosphate during the relatively short trial times of 2 weeks per filter, and thus provide a comparison between the different media types.

2.2. Comparison of sand and glass filter using synthetic wastewater

Initially, samples of the sand and recycled glass were analysed under a Hitachi S-4300 Field Emission Scanning Electron microscope down to resolution of 1.5 nm. The samples were then analysed for surface roughness using a Zygo New View 100 white light Interferometer and the surface area and pore size was measured using a Quantachrome Nova 4200e Surface Area and Pore Size Analyser (BET).

Two filters were then set up in parallel in the laboratory: one with a typical sand, the other with recycled glass which had been sieved to provide similar particle size distributions, as shown on Fig. 1. Each filter had a surface area of a 230 mm internal diameter pipe and 600 mm depth of media. The sand filter had 100 mm of Chelford silica sand on top of 100 mm limestone sand on top of 400 mm Chelford sand. Both filters were overlain with 100 mm of distribution gravel with the trial configuration shown in Fig. 2. Both filters were then dosed via accurate peristaltic pumps set to the identical flow rate with the same wastewater influent at different hydraulic and organic loading rates to compare their treatment performance. The wastewater was synthetic sewage comprised of peptone, meat extract, urea, NaCl, $CaCl_2$, $MgSO_4$ and K_2HPO_4. It was dosed on a timer to achieve the respective hydraulic loading rate and dosing periods. A new batch of synthetic sewage was made up at the start of each week which meant that the charac-

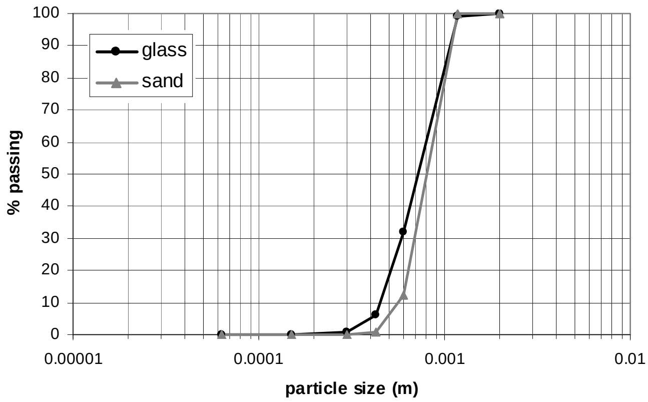

Fig. 1. Particle size ditribtuion of sand and glass media used in the filter trials.

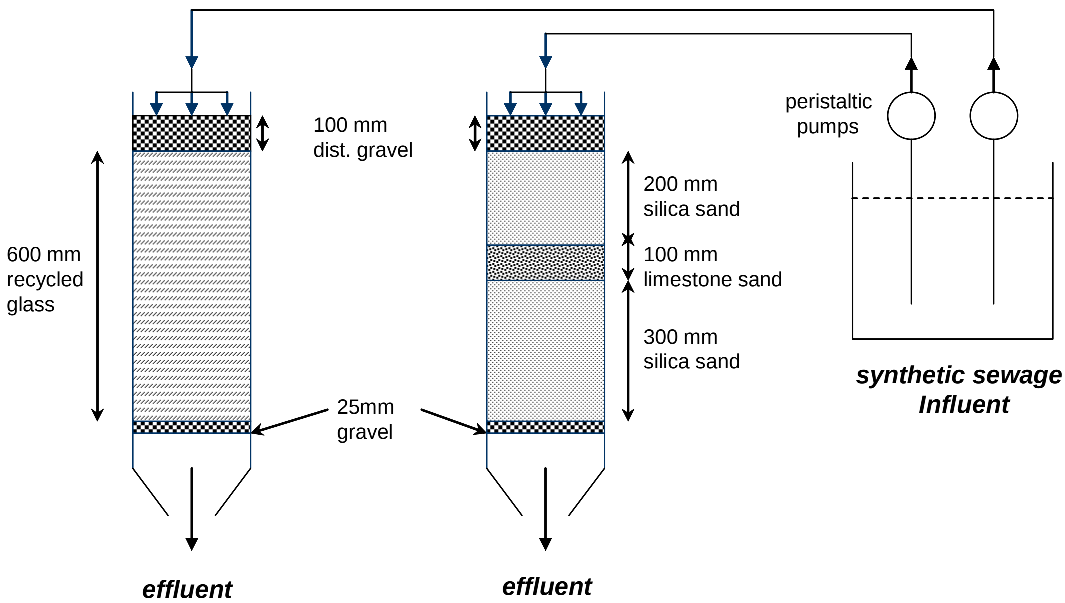

Fig. 2. Schematic diagram of the parallel filter trials.

teristics of the synthetic sewage did vary over the different trial periods as reported in the influent concentrations in the results section.

Trials were carried out a at range of hydraulic loading rates (42–84 L/m^2.d) with 3 doses per day. The hydraulic loading rate was then maintained at 42 L/m^2.d whilst the dosing frequency was increased to 4 and then 6 times per day to investigate the effect of this parameter on such a fixed film treatment process. Effluent from an activated sludge secondary treatment plant in Dublin was also dosed onto the filters to assess their microbiological removal performance efficiencies. Finally, the base of each filter was flooded by alteration of the outlet pipe level to promote a 200 mm depth anoxic zone in the bottom of each filter to see whether denitrification could also be achieved in the filters. Composite influent and effluent samples were taken every day for analysis for chemical parameters using the Spectroquant Nova 60® spectrophotometer and associated reagent kits for chemical oxygen demand (COD), ammonium (NH_4^+-N), nitrite (NO_2^--N), nitrate (NO_3^--N), Total nitrogen and ortho-phosphate (PO_4^{3-}-P). Samples were analysed for total coliforms and *E. coli* using the Colilert® analysis.

2.3. Percolation rate of soil amended with recycled glass

Finally, studies were carried out to investigate the concept of mixing recycled glass into a subsoil used for raised mound wastewater treatment in order to achieve greater certainty and uniformity to its percolation characteristics. Three different grades of recycled glass were investigated and mixed into a soil with relatively slow percolation characteristics. The soil was sourced from County Monaghan and was determined to be a SILT/CLAY according to the BS5930 classification [20]. The in-situ percolation rate of the soil was measured to be equivalent to a field saturated hydraulic conductivity of 0.14 m/d using a standard falling head percolation test (the so-called T-test) which involves timing three consecutive water drops from 300 mm to 200 mm in a 300× 300 mm plan hole [21,22]. In the laboratory, samples of the soils and varying quantities and combinations of recycled glass (graded coarse, medium and fine as described in Section 2.1) were prepared. The characteristics of the different mixes are shown in Table 1 and the respective particle size distributions of the soil and glass shown on Fig. 3. The coefficients of permeability for the different mixes were then determined using a standard falling head test [23] on 110 mm diameter cross-sections of the samples. For Mixes 13, 14 and 15 the permeability coefficients were determined using the constant head test [24] due to the high permeability rates for the glass-only samples.

A 1.2 m tall mound was finally constructed on the site in Co. Monaghan with one section using 100% native soil (as Mix 1) and the other side made from a soil amended with glass according to the proportions in Mix 12 (Table 1), both sides undergoing the same degree of compaction. The standard falling head percolation test (the T-test) [21] was then carried out from the top of the raised mound on the two different soil types to determine the percolation rate of the constructed mound system.

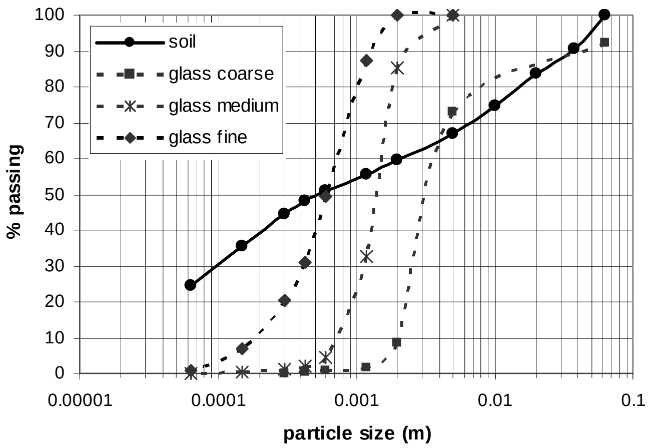

Fig. 3. Particle size ditribtuion of soil and glass media used in the different mixes.

Table 1
Characteristics of soil/glass mixes used for permeability tests

Mix no.	Soil	Recycled glass		
		Coarse	Medium	Fine
	(% by vol.)	(% by vol.)	(% by vol.)	(% by vol.)
1	100	—	—	—
2	80	20	—	—
3	65	35	—	—
4	50	50	—	—
5	80	—	20	—
6	65	—	35	—
7	50	—	50	—
8	80	—	—	20
9	65	—	—	35
10	50	—	—	50
11	50	30	—	20
12	50	25	12.5	12.5
13	—	100	—	—
14	—	—	100	—
15	—	—	—	100

3. Results and discussion

3.1. Phosphorus adsorption capacity of sands and glass

The results of the phosphate adsorption tests are presented in Table 2. The Freundlich parameters were de-

Table 2
Results of adsorption isotherm tests for phosphate for glass and sand samples

	Freundlich		Langmuir	
	K	$1/n$	q_m	K_{ads}
Glass (coarse)	0.00076	1.091	0.02837	0.0006
Glass (medium)	0.00032	1.303	–0.0324	–0.0042
Glass (fine)	0.00196	1.010	0.4040	0.0055
Limestone (Larne)	0.00846	1.006	0.6761	0.0195
Silica (Chelford)	0.00862	0.546	0.0762	0.1025
Granite (Carlow)	0.01271	0.510	–0.5828	–0.0103
Silica beach (Sligo)	0.00624	0.889	2.1308	0.0022
Schist (Aughrim)	0.00210	1.012	0.1221	0.0249

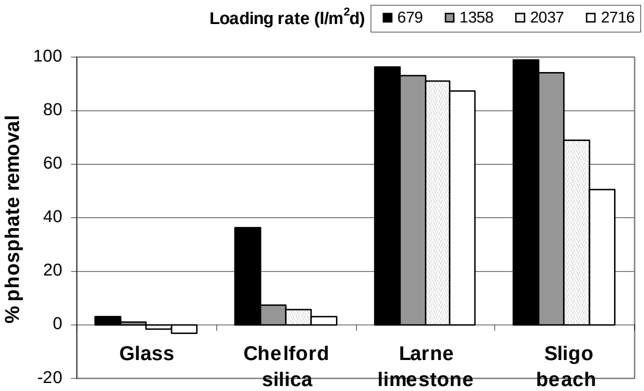

Fig. 4. Phopshate removal results for four different filter media at different hydraulic loading rates.

termined by plotting a best fit line on a graph of log (q) vs. C, whilst the Langmuir parameters were determined by plotting a best fit line on a graph of $1/q$ vs. $1/C$, where q is the sorbed concentration (mg/g) and C is the aqueous concentration of adsorbate (mg/l). A $1/n$ parameter slightly less than unity and a relatively high K value indicates a significant amount of adsorption will occur at low aqueous concentrations (typical of domestic wastewater). The results indicated that the glass has very little adsorption capacity or affinity for phosphate, as expected. The comparison of the sand samples shows that both the Sligo beach and Larne limestone sands do have a high affinity for phosphate compared to the Chelford silica which does not or the Aughrim sand. It should also be noted that the Freundlich isotherm provided a better fit to the data than Langmuir isotherm as found in previous studies [24] with mean R^2 regression coefficients across all the tests carried out of 0.925 compared to 0.834. This may be indicative that precipitation was also an important removal mechanism in some of the media (as well as adsorption), particularly for the Carlow granite and Chleford silica sands which exhibited much lower correlation coefficients using the Langmuir isotherm.

The results from the phosphate loading filter trials on the four different types of media are shown on Fig. 4 which confirms the conclusions from the adsorption isotherms. Dosed at high hydraulic loading rates the Larne limestone and Sligo beach sand continually demonstrated high phosphate removals across the 100 mm deep sample compared to the performance of the Chelford silica sand which dropped away markedly at higher hydraulic loading rates. The glass was shown to have almost no effect on the removal of phosphate. Samples of the Chelford silica sand were analysed using X-ray diffraction analysis (Phillips PW1720) to reveal the respective mineral composition. Apart from the expected predominance of quartz, some goethite (Fe_2O_3) was also found in the sand sample. Hence, the iron oxide would act as sites for cation exchange with the soluble phosphate but obviously has a limited effect as the sites are quickly filled at the higher loading rates. In comparison, calcium carbonate (the main mineral in the limestone sand) has been shown in several other studies to have a high sorption capacity for phosphorus.

3.2. Comparison of treatment performance of sand versus glass filter

The magnification of the surfaces of the Chelford silica sand compared to the medium recycled glass under the SEM are shown on Fig. 5, which clearly shows that the sand sample has a higher surface area to volume ratio and therefore might be expected to provide a more efficient media for wastewater treatment. This visual analysis was confirmed by the surface roughness and surface area analysis (Table 3) with the two sand samples displaying 4–5 times the surface area per unit weight and 5–10 times the roughness.

The results of the parallel filter tests (sand vs. glass) using synthetic sewage dosed three times per day at different hydraulic loading rates are shown in Table 4. The glass filter performed similarly to the sand filter for COD removal and both filters showed that partial nitrification has occurred. A comparison of the process performance of the two filters across the trial period in terms of COD loads removed is shown in Fig. 6 which indicates a slightly better performance (~16% enhancement) from the

Table 3
Results of surface roughness and surface area and pore size analyses

	Glass (coarse)	Sligo (coarse)	Chelford (coarse)
Surface roughness (μm)	0.330	3.032	1.469
Surface area per wt (m^2/g)	0.51	2.05	2.63

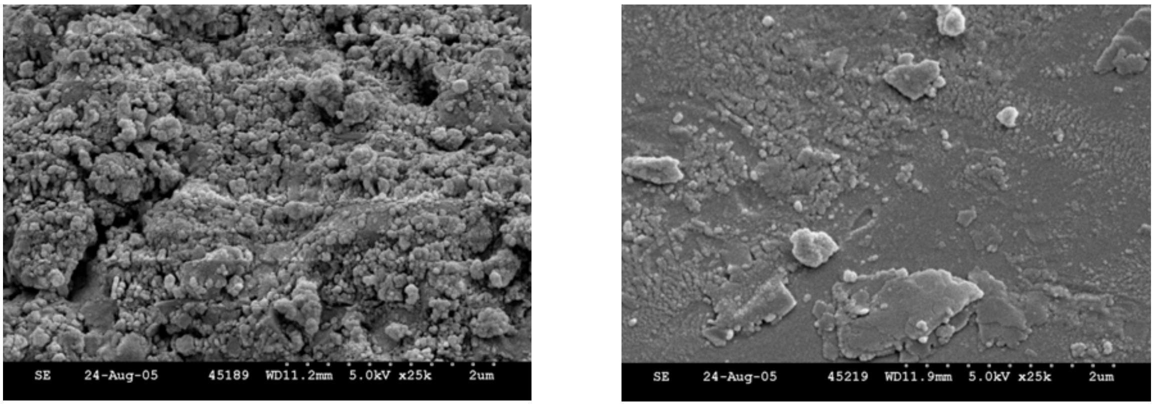

Fig. 5. SEM images of the Chelford silica sand (left) and recycled glass (right) surfaces.

Table 4
Results of filter trials of mean influent and effluent concentrations (mg/l) from the sand and glass media filters

Hydraulic load rate	42 L/m²d			63 L/m²d			84 L/m²d		
	Influent	Effluent (sand)	Effluent (glass)	Influent	Effluent (sand)	Effluent (glass)	Influent	Effluent (sand)	Effluent (glass)
COD	329	77	60	667	190	150	278	35	46
Total-N	33.3	25.1	24.5	39.0	35.1	33.8	44.4	38.5	37.1
NH_3-N	8.6	<0.5	<0.5	13.8	<0.5	<0.5	14.7	<0.5	0.9
NO_3-N	0.4	14.4	15.7	0.2	17.7	14.3	<0.1	10.9	2.2
Org-N	24.3	10.1	8.2	25.0	16.9	18.5	28.7	27.0	33.8
Ortho-PO_4	1.22	0.16	0.7	1.21	0.02	1.01	2.20	0.07	2.36

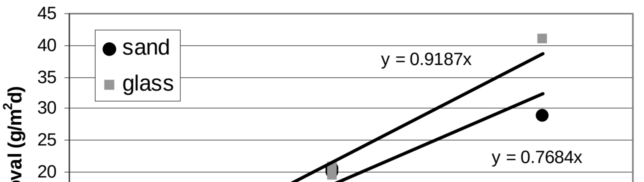

Fig. 6. Process performnace for COD removal in the sand and glass filters.

glass filter. At the highest hydraulic loading rate however, the glass filter did reveal a falling off in nitrification compared to the sand filter perhaps due to the lower surface area per unit volume. The COD load removal efficiencies across the range of hydraulic loadings fall in the range 72–83% which are slightly lower than previously reported studies [5–10] which can be attributed to the difference in media types and size distributions used between the studies and also the difference between using real wastewater and synthetic wastewater. The total nitrogen removal efficiencies of 10–26% were also low when compared to some of the previously reported studies, although some of the removal statistics were for recirculating filters which would improve total nitrogen removal. The removal rate compared similarly however, to other studies on single pass filters [26] although again the effect of scale, different media sizes and synthetic wasetwater will mean that direct comparisons can not be made too rigorously. The ortho-phosphate results clearly showed that the sand filter (with a 100 mm layer of 1imestone derived sand) very effectively removed the phosphate compared to the glass where the removal efficiency was poor especially at higher loading rates, as expected from the experiments outlined in previous sections. Following these trials the dosing frequency was changed from 3 doses per day to 4 doses to 6 doses per day with the hydraulic loading rate kept at 42 L/m²d. This revealed a slightly better performance for all parameters and also promoted almost full nitrification (i.e. full mineralisation and subsequent nitrification of organic and ammoniacal nitrogen) at the 6 dose per day regime. This shows the beneficial effect of smaller-doses but more frequent wetting for the secondary treatment of wastewater using such a fixed film process.

The microbiological treatment performance was also assessed by dosing effluent from a secondary treatment plant towards the end of the testing regime period. Total coliforms and *E. coli* (concentrations of 2.4×10^{6} and 2.0×10^{4} respectively) showed average reductions of 4.1 log and 5.0 log through the sand filter compared to 3.7 log and 3.2 log through the glass filter respectively. Hence, the sand filter provided a better treatment in terms of these bacterial indicators. A tracer study carried simultaneously indicated that the hydraulic detention time of both filters was similar at 20–24 h during these trials. Finally, the denitrification trial was carried out at the end experimental period whereby the bottom 200 mm of both filters were flooded to provide an anoxic zone and both filters loaded at 42 L/m^{2}.d and 6 doses per day. The results did indicate a slight enhancement in total-N removal (25% for the sand and 20% for the glass filter) but the anticipated improvement was not realised probably due to the low COD concentrations in the effluent by the time it reached the anoxic zone, as carbon is required as the energy source for the heterotrophic denitrifying bacteria.

3.3. Permeability of soil amended with glass

The addition of the glass into the matrix promoted a significant improvement in both the rate and uniformity of percolation as can be seen from the results of the permeability testing in the laboratory in Fig. 7. The permeability of the soil on its own was 1.1×10^{-8} cm/s, which is slow due to high clay content. The addition of 20% glass improved the permeability into the range of $3–4\times10^{-7}$ cm/s for all grades of glass. As the percentage of glass increased up to 50%, the permeability increased to a range of $1.6–5\times10^{-3}$ cm/s with the fine grade promoting the highest rates. An optimum blend of glass (Mix 12) was determined to give a permeability of 1×10^{-4} cm/s for use in the field trial. The trials using only the glass samples showed very high permeability results, ranging from 0.7 for the medium grade glass up to 2.4×10^{-2} cm/s for the more densely packed fine grade of glass.

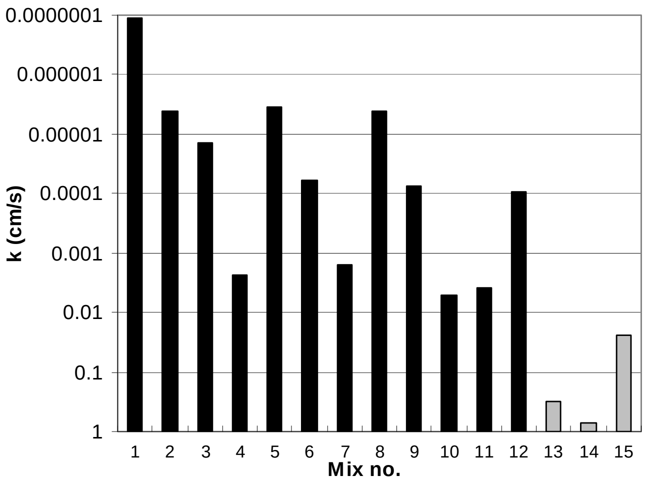

Fig. 7. Coefficient of permeabilities (k) across 100 mm cross-sections of different soil-glass mixes. (Mixes 13, 14 and 15 are glass only).

Finally, the comparison of the in-situ subsoil and glass amended subsoil used for a mound system on site gave percolation rates equivalent to a field saturated hydraulic conductivity of 0.02 m/d for the soil only (Mix 1) compared to 1.2 m/d for the glass amended soil (Mix 12). Hence, the disturbance of the native soil and compaction when constructing the mound can be seen to have drastically reduced the percolation rate of the soil when compared to the original in-situ field saturated hydraulic conductivity of 0.14 m/d (see Section 2.3), making it unsuitable for the effective treatment of on-site effluent. The soil amended with 50% glass however, retained good percolation characteristics under the same construction regime which would be suitable for on-site wastewater treatment. Hence, the addition of recycled glass to the soil has the potential to promote greater certainty and consistency to the percolation characteristics of raised mound systems.

4. Conclusions

Overall the laboratory trials and analyses have demonstrated the use of recycled glass as a media for a filter for on-site wastewater treatment has significant potential. With the exception of phosphate, the glass has been shown to remove the other pollutants at similar process efficiencies as the sand at the recommended hydraulic loading rates. The benefit of frequent wetting at smaller-doses has also been shown. The removal of phosphate is clearly a function of the mineralogy of the sand and it is recommended that any filter made from recycled glass in the future is augmented with a 100 mm depth of limestone derived sand to pick up the phosphate if necessary. Alternatively, other media could be used to target the phosphorus load, such as steel furnace slag which has shown good potential in full scale trials [27]. The overall treatment efficiencies in the laboratory trials of both the sand and glass filters are slightly lower than some of the previously reported full-scale trials due to the differences between synthetic and real wastewater and the effects of scale It is therefore concluded that full-scale trials of a filter made from recycled glass should now be started for the treatment of on-site wastewater effluent. The use of indigenous recycled glass as a filter media would have the overall benefit of reducing the energy and transport costs involved in the export of Ireland's recovered glass to the UK (whilst specialist silica required for sand filters is imported in reverse) thus addressing sustainability and complimenting the EU Waste Management Directives.

Finally, the concept of mixing recycled glass into a clay subsoil to be used for the construction of an on-site raised mound treatment system has also been shown to have potential for future development. The effect of the augmenting glass into the soil was to achieve greater certainty and uniformity of the percolation characteristics of the mound, leaving it less susceptible to the variabilities of local soil type and unregulated construction practices.

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