Post-Filtration Compressibility Characteristics of Peat Used as Greywater Filter Media

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Abstract: Greywater produced daily in households is generally discharged to public waterways without prior treatment. As the health risks posed by the water are considered low, its disposal and possible negative impact on natural water bodies are not regulated. In a typical Malaysian household, used water from the laundry, bathroom and kitchen contribute to the total greywater discharge. The paper describes a laboratory-based examination of peat as a potentially cheap and effective filter media for household greywater. The greywater was prepared with controlled measures of common contaminants to represent the types of household greywater commonly produced. The filtered water quality was monitored over a month to gauge the effectiveness of the peat filter media. The peat, upon filtration of the different greywater after 28 days, was subjected to the oedometer test to examine its 1-dimensional compressibility characteristics in relation with the filtration process. The findings indicated that the peat media could be beneficial in the removal of suspended solids and lowering of BOD (Biological Oxygen Demand) and COD (Chemical Oxygen Demand) of the greywater, though laundry greywater showed some worrying signs of excessive residual chemicals left in the discharge. The compressibility test data showed bahaviour commonly observed in soft materials like peat, with an apparent reduction of settlement post-filtration of the greywater. The reduction of void ratio (e) and water content (w), pre- and post-tests was found to be following a linear pattern, while the bulk density (ρ) showed less compatibility, especially of the mixed greywater water sample. The compression and swelling indices (C_c and C_s) were shown to be related with a power law equation. Overall, the compressibility of peat improved post-filtration with lower void ratio and water content. It is postulated that the impurities and chemicals entrapped in the peat media contributed to the enhanced stiffness.

Key words: Peat · Greywater · Filter · Compressibility · Oedometer

INTRODUCTION

In this era of heightened awareness for water and natural resources conservation, the recycling and reuse of materials are popular approaches. The untreated discharge of greywater from households into natural waterways, for instance, is no longer considered an acceptable practice. While raw water is being treated in plants prior to distribution for common usage, contaminants from these point sources remain largely in the natural water bodies. This indiscriminate disposal of greywater has led to inadvertent pollution of streams and rivers [1]. It was reported by Loh and Coghlan [2] that household greywater derived from taps, bathrooms and laundry sources accounts for over 30% of water usage in a single household, with another 54% contributed by lawns and gardens. Considering that these waters contain low levels of contaminants compared to wastewater, untreated discharge does not only result in undesirable elements in the natural waterways and increase the load of water treatment plants, but also raise the question of wastage as greywater could be effectively cleansed for non-potable reuse. The cleansing methods include the simple to the sophisticated, such as filtration with various materials, namely sand, soil and membrane, as well as artificial wetland [3].

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Peat, on the other hand, presents another form of problem, especially in terms of its low strength, high compressibility and limited load-bearing capacities. The high organic matter content in peat soils is often attributed as the cause of the inferior qualities [4]. They are commonly found in places with surplus rainfall and poorly drained grounds, where the combined condition of high water content and incomplete aeration helps preserve disintegrated plant remains [5]. Climatic and ecosystem factors also affect the accumulation of organic materials forming the peat [6]. These soils are often found to be good agricultural material for their high nutrient contents, but are unfavourable for construction purposes due to the poor engineering properties mentioned earlier. As such, peat deposits are either replaced when encountered as a foundation soil, or require special improvement techniques for enhancing the originally poor engineering qualities. These techniques generally involve additions of various filler materials and binding agents to overcome the acidic soil while strengthening the bonds of the solids to form a stiffened soil matrix [7-9].

The present study examines the potential of using a locally available peat soil as the filter media for treating household greywater. To cater for the uncertainties in contaminant types and levels in actual greywater discharges, the water samples were synthesized in the laboratory using measured, known constituents, i.e. laundry greywater from powder and liquid detergents, bathroom greywater, kitchen greywater and a mixture of all. Interaction between the greywater and the peat could serve 2 purposes: (a) removal of impurities in the water and (b) improvement of the stiffness of the highly compressible peat. The cleansing effectiveness of the peat filter is reported in terms of the water quality parameters monitored. More importantly, the post-filtration effect on the compressibility characteristics of the peat was examined via standard oedometer tests. These results form a basic understanding of the greywater-peat interaction mechanism, particularly in the development of a large scale wetland type treatment system, where an improved peat soil bed (by filtration of the greywater) could be further reused as firm foundation grounds for light load-bearing purposes.

MATERIALS AND METHODS

Peat Soil: The peat soil used as filter media in this study was collected in bulks from a local oil palm plantation. The sampling depth was approximately 30 cm below the ground surface, to ensure retrieval of the material in its

Table 1: Physical properties of peat sample.

Parameters	Results
Natural moisture content (%)	371
Specific Gravity (Gs)	1.25
Acidity (pH)	2.94
Organic content (%)	49.72
Sieve analysis	60% 'medium sand', 20% 'fine sand'
Ash content (%)	50.3
Liquid Limit (%)	83

Table 2: Chemical properties of peat sample.

Chemical Composition	(%)
Ferum	42.4
Silica	24.8
Aluminium	9.4
Calsium	6.1
Sulphides	5.4
Zinc	4.5
Potassium	4.2
Chlorides	0.9
Phosphorus	0.7
Magnesium	0.6
Titanium	0.4
Bromine	0.2
Mangan	0.1
Carbonate	0.1

natural, undisturbed form. The physical and chemical properties are summarized in Tables 1 and 2. Note that the sieve analysis indicated a large portion of medium-sand size particles, which were essentially disintegrated plant remains constituting the major solid phase of the peat sample. The natural water content was relatively high, but not uncommon among peat soils, while the high organic content actually resulted in a significantly lower Gs value compared to normal mineral soils.

Greywater: 4 categories of 5 greywater samples were prepared and tested, i.e. laundry greywater from powder and liquid detergent, bathroom greywater from a common body cleansing agent, kitchen greywater from poultry, fish and vegetable processing, as well as a measured mixture of all. All the greywater samples were prepared using distilled water to avoid inherent contaminants. Details of each greywater sample are given below:

Laundry Greywater:

- Both powder and liquid detergent were of the same manufacturer.
- They were added according to the manufacturer's recommendations, as printed on the back labels on the bottles.

- A piece of soiled clothing (similarly prepared) was washed in each water-detergent mixture.

Bathroom Greywater:

- 2.5 g of shower foam (normal single usage) was diluted in 1000 mL of water.
- The soap water was used in a single washing of a specific body part (i.e. the knee-down leg portion) to maintain consistency of the greywater prepared.

Kitchen Greywater:

- 1 L of water was used to process and wash chicken meat, fish and vegetable of 300 g each.
- The materials were chosen as common food consumed daily in an average Malaysian household.

Mixed Greywater:

- This greywater sample was prepared with contributions from the above mixtures.
- The mixing ratio was 40% laundry, 40% bathroom and 20% kitchen for 1 L of water.
- The relatively low portion of kitchen greywater was in accordance with findings by Gross *et al*. [10] that raw kitchen effluent from a normal household is sufficiently small to make marked effect on the greywater's chemical contents.

Greywater Filter Setup: The greywater filter system is shown in Figure 1. The reactor was modified from an off-the-shelf plastic water can of approximately 35 cm in height and 50 cm in diameter. The peat soil was lightly compacted to form a 15 cm height layer, underlain by a plastic netting reinforced with wire mesh. The base functioned both as a support to the peat layer, as well as to prevent loosening and loss of the peat material during tests. Approximately 20×10^3 cm^3 of greywater sample was placed over the peat layer at the beginning of the test, corresponding to 10 cm height over the peat layer. Filtered water samples were collected at intervals of 1, 7, 14 and 28 days for water quality check. Upon completion of the test after 4 weeks, the peat media was carefully retrieved using the oedometer ring for compressibility test.
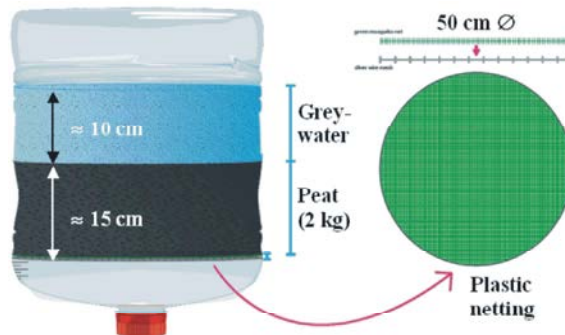

Fig. 1: Test setup of the greywater filtration system.

Water Quality Check: The water quality parameters examined were the Turbidity (T), Total Suspended Solids (S), pH (P), Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). Brief definitions of each parameter are given in the following:

Turbidity (T): A measure of cloudiness of water, i.e. higher turbidity indicates greater murkiness, which is a result of the presence of suspended solids in the water; could potentially shield microbes and increase treatment loading.

Total Suspended Solids (S): Any particles / substances that are neither dissolved nor settled in the water; relates to Turbidity.

pH (P): Measured on a scale of 0-14, with the lower values indicating high hydrogen ion activity (more acidic) and vice versa.

Biological Oxygen Demand (BOD): Measures the strength of polluted water based on the amount of oxygen required to stabilize the organic material present; defined as the oxygen demand for a mixed population of microbes in aerobic oxidation at 20°C in the water.

Chemical Oxygen Demand (COD): An indicator of the presence of organic waste in the water; defined as the oxygen demand to oxidize reactive chemical in the water.

Oedometer Test: The standard oedometer test is conventionally conducted to measure the 1-dimensional compressibility of soil samples, as prescribed in BS1377 [11]. The sample is confined in a metal ring of 75 mm in diameter and 20 mm in height, hence restricting the deformation under load in the vertical direction only (i.e. 1-dimensional). The ring containing the sample is

submerged in water in the oedometer cell to ensure full saturation of the sample throughout the test. This is crucial as the fundamental consolidation theory makes the assumption that the settlements recorded against loading in the test are manifestations of water expulsion from the soil's voids, i.e. a fully saturated soil sample with the voids filled with water alone.

Referring to the Standards, the test was performed by applying a certain load on the soil sample, which is maintained for 24 hours in general, to allow for completion of the primary consolidation with onset of the secondary compression. Loads or stresses were applied in the multiples of 2, i.e. 12.5 kPa, 25 kPa, 50 kPa, 100 kPa, etc. Unloading was performed upon the maximum stress applied, in reversed order of the loading sequence, i.e. 400 kPa, 200 kPa, 100 kPa, etc. The gradual unloading procedure was to avoid sudden load removal which could cause swelling of the soil sample due to drastic pressure difference within the soil and the atmospheric pressure acting on the water bath.

A recording of the settlement (or corresponding void ratio) at the end of each loading stage was next plotted against the applied stress in a compression curve, where the compression index (C_c), swelling index (C_s) were derived. The initial and final void ratios, water contents as well as the bulk and dry densities were also recorded and analysed.

RESULTS AND DISCUSSIONS

Compressibility of Peat Media
Compression-Unloading Curves: The compression-unloading curves of all the post-filtration peat specimens are shown in Figure 2. It can be readily observed that the plot of the original soil lies above all the others, indicating

the reduced initial void ratio after 28 days in the filtration system. This could be attributed to the entrapment of impurities within the porous structure of the peat media and also possible formation of slime coating the solids of the material, resulting in reduction of the initial voids.

A closer inspection of the loading portion of the compression curves reveals a distinct curvature, which demarks the overly and normally consolidated range of stresses for the particular soil sample (see inset figure). Settlement upon loading in the overly consolidated range is small compared to the compressibility in the normally consolidated range, where the pre-consolidation pressure (intersection of the tangential lines to the 2 portions of the curve) is defined as the maximum pressure previously sustained by the soil, hence the small settlement as long as the pressure is not exceeded. It can also be described as the pressure at which the soil yields by demonstrating dramatic compressibility.

An interesting observation noted in Figure 2 is the unloading path of the specimens, from 400 kPa to 25 kPa. The unloading paths are relatively linear on a log-scale and they are almost parallel to one another, regardless of the greywater which passed through it. Note that this is ignoring the slight discrepancy for specimen 'Kitchen' at 400 to 200 kPa, where the 200-25 kPa rebound path is apparently parallel to the rest. Indeed, the parallel unloading paths are not unlike that of the original peat sample too, strongly suggesting retention of the inherent rebound characteristics despite exposure to the respective greywater samples. Nonetheless the plastic strain difference upon unloading varied between 2.1-12.3% (corresponding to rebound path of 400 to 25 kPa), with the 'Kitchen' sample recording the highest difference. This can be traced to the sharp rebound from 400 to 200 kPa in the plot.
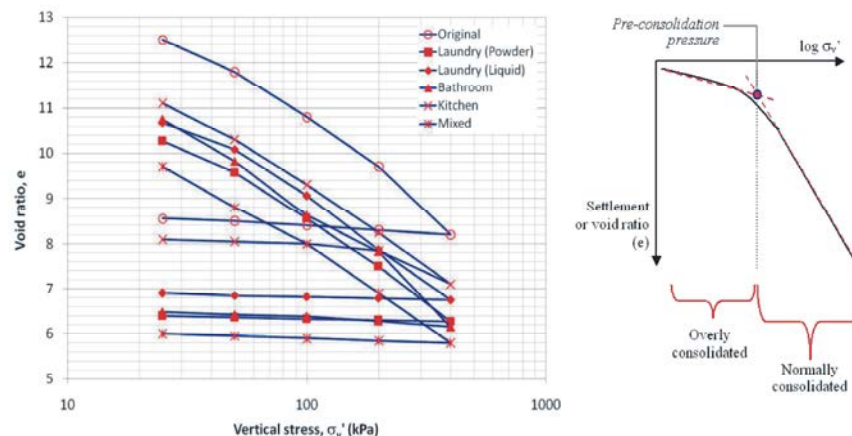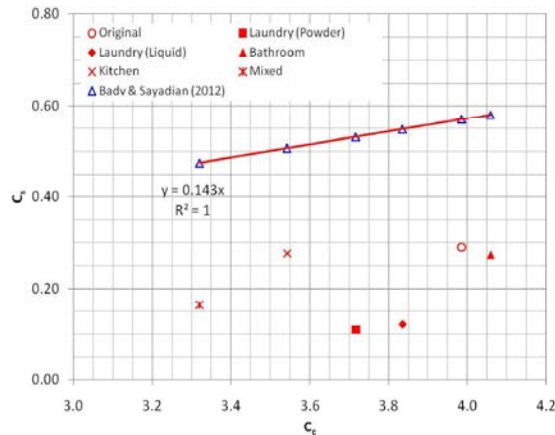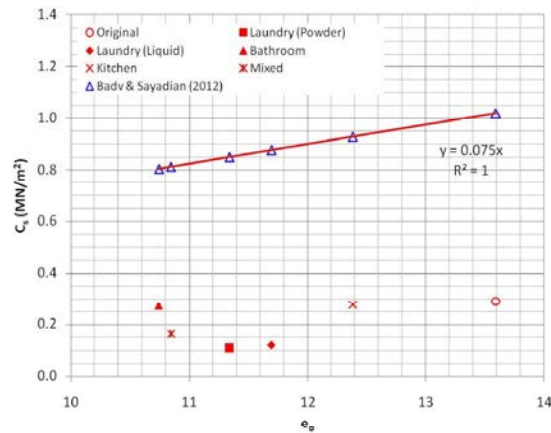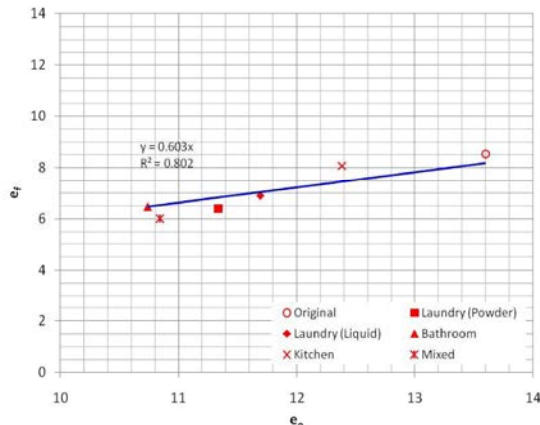

Fig. 2: Compression curves of peat specimens (post-filtration)

Fig. 3: C_s - C_c plots.

Fig. 4: C_s - e_o plots.

Fig. 5: e_f - e_o plots.

Compression (C_c) and Swelling (C_s) Indices: Figure 3 shows C_s plotted against C_c with a power law regression line fitted through the data. The indices are essentially the gradients of the compression and unloading or swelling plots respectively, computed with σ_v' taken on a log scale basis. The scatter is admittedly appreciable, owing to the
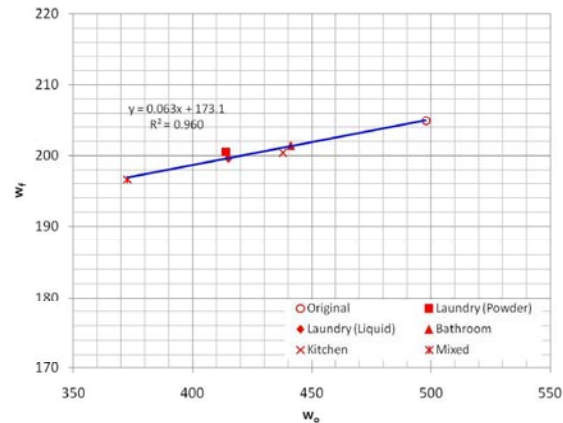
Fig. 6: w_f - w_o plots

scarce data available. However the range of C_c and C_s indices fall within those commonly reported in the literature for peat soils [12-14].

Also included in Figure 3 are the present data points derived using the C_s-C_c correlation from Badv and Sayadian [12]. The authors reported on the Urmia peat in Iran, which has similar organic and water contents as the peat in the present study. A dashed line parallel to the Urmia regression line was drawn through the current data and the compatibility is seemingly acceptable, though the corresponding C_c value when $C_s = 0$ would be negative. Similarly in the plot of C_s against initial void ratio, e_o (Figure 4), Badv and Sayadian [12] established a linear correlation which when applied to the present data, produced a plot which lies far above that of the present study (parallel dashed line through the current data). However e_o was found to be approximately 10 when $C_s = 0$ based on this regression line. The compatible gradients in both figures suggest a common pattern of linear relationship between the parameters, but the C_s values obtained in the present study were obviously far lower than those reported.

Void Ratios (e) and Water Contents (w): Figure 5 shows the comparison between the initial and final void ratios, i.e. e_o and e_f. The correlation is fairly good with R^2-value over 90%, suggesting that the amount of void ratio reduction with compression was apparently unaffected by the type of greywater filtered by the peat. As such, irrespective of the type of greywater the peat media interacted with, subsequent 1-dimensional compression would cause the soil to undergo approximately 40% void ratio reduction.

The water content changes are depicted in Figure 6, i.e. final water content (w_f) plotted against initial water content (w_o). A linear relationship can be derived at

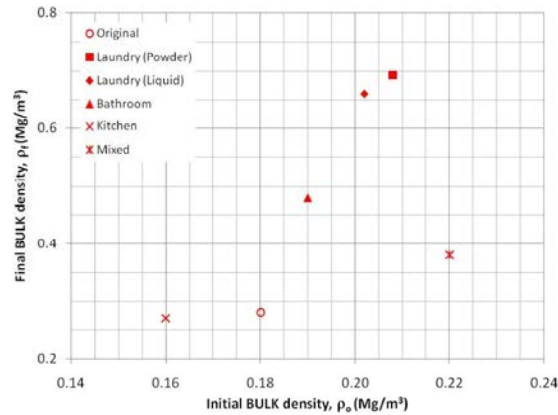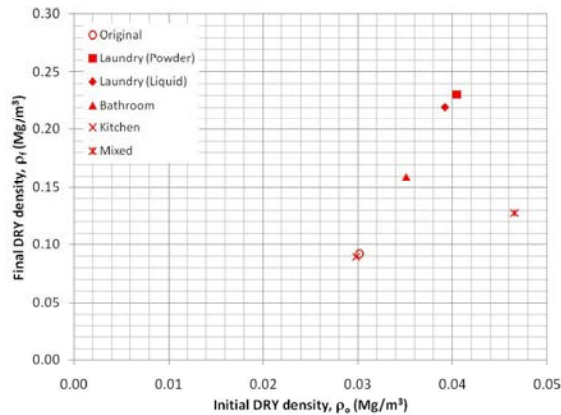Fig. 7a: Bulk densities, ρ_f - ρ_o plots

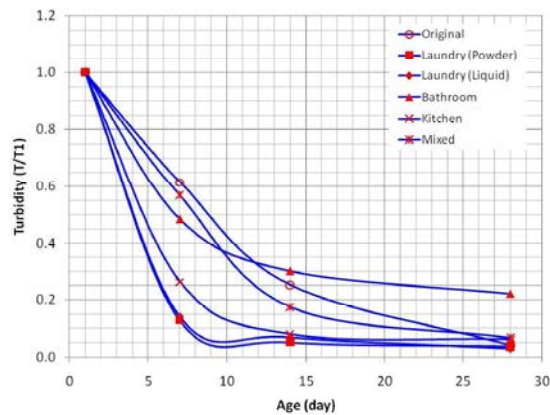Fig. 7b: Dry densities, ρ_f - ρ_o plots

Fig. 8: Turbidity vs. time.

$R^2 = 96\%$ for quick estimations of the water loss in the peat subjected to compression. Again the specimens showed negligible post-filtration effect of the different greywater used.

Bulk (ρ_b) and Dry (ρ_d) Densities: The density changes (initial and final) are plotted in Figure 7, where figure (a) shows the bulk density (ρ_b) while figure (b) illustrates the
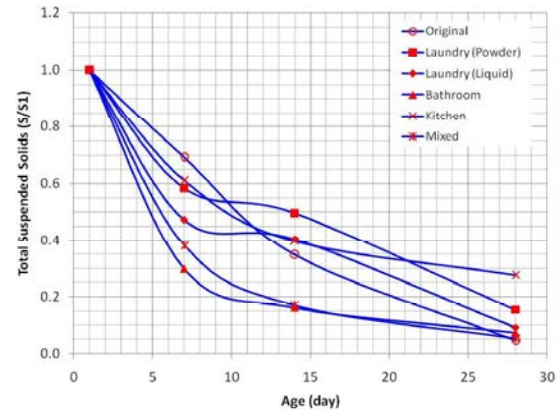

Fig. 9: Total Suspended Solids vs. time.

dry density (ρ_d), calculated using the fundamental geotechnical equation of $\rho_d = \rho_b/1+w$. Interestingly, the dry densities seemed to line up better (with exception of the 'Mixed' specimen which is in discord with the rest) compared to the bulk densities. Post-compression, the bulk density was found to increase by approximately 3 times (Figure 7a), whereas the dry density recorded an increment factor of almost 6 (Figure 7b). As dry density is the mass of solids per unit volume, clearly a more robust and dense structure was attained by the post-compression peat soil. This could potentially enhance the load-bearing capacity of the originally weak soil body by the reducing its compressibility, i.e. displacement when subjected to external loading.

Correlations Between Water Quality Parameters and Compressibility of Peat Media: Figures 8-12 summarize the individual water quality parameters for all the post-filtration greywater samples, normalized against the levels recorded on day 1 for easy assessment of the changes with time. Furthermore, considering the similar trends exhibited by the greywater samples for all the paramaters measured, the Average Reduction Factor was derived simply by combining the individual trend lines and computing an average representative plot (Figure 13). Notably Turbidity, Total Suspended Solids and BOD were reduced to 8-13% of the original levels (Figures 8, 9 and 12). On the other hand, pH showed increment with time (i.e. 1.6 times increment in 28 days), as shown in Figure 10. From the same figure, it can be observed that the Kitchen, Bathroom and Mixed greywater recorded pH increment ranging between 1.6-2.1 times, with the Kitchen sample showing the highest pH increment. This could be attributed to the highly alkaline detergent and shower foam used in the preparation of the greywater samples. The COD underwent an initial drop followed by a rise
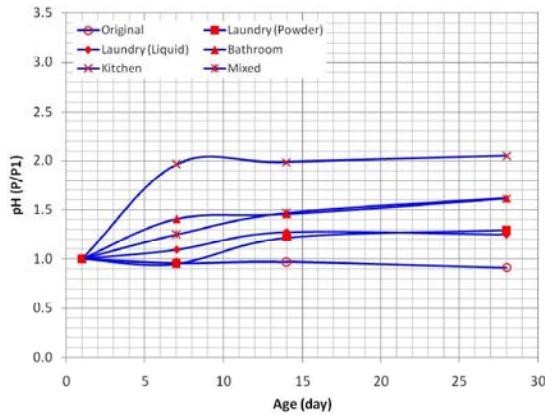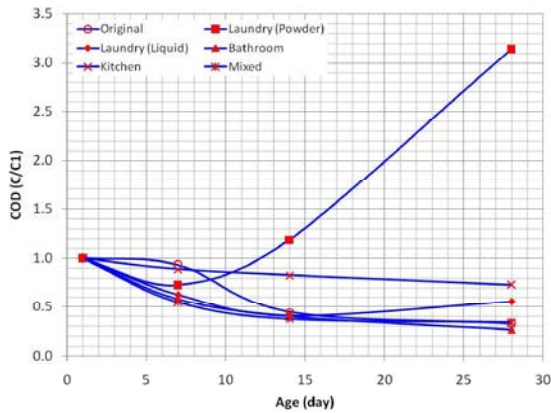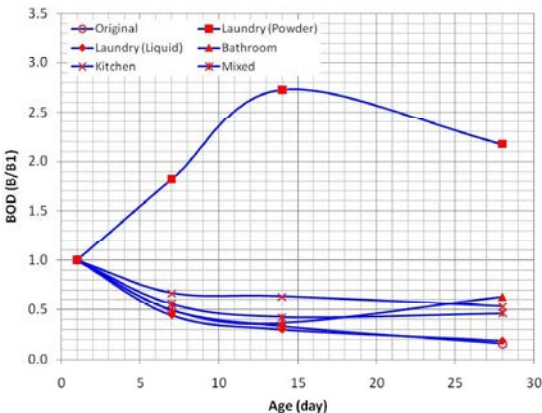
Fig. 10: pH vs. time.

Fig. 11: COD vs. time.

Fig. 12: BOD vs. time.

back to the initial reading, but this is actually masked by the overwhelming effect of the Laundry (Powder) sample, which registered a staggering 3 times increment of COD level (Figure 11). This is cautionary of the highly reactive chemical compounds possibly present in the powder form laundry detergent.
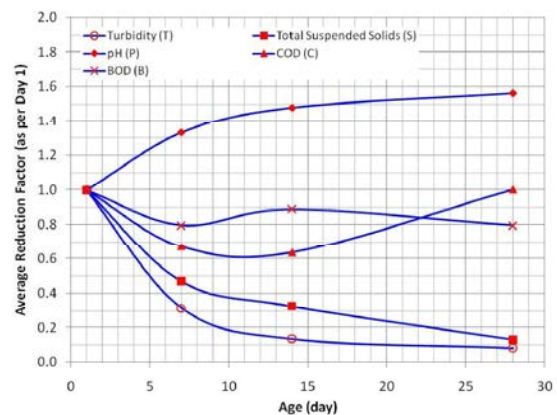

Fig. 13: Average Reduction Factor vs. time

The dramatic increment in both BOD and COD of the Laundry (Powder) greywater sample (Figures 11 and 12) tempts one to speculate the presence of high organic material and reactive chemicals, which was can be plausibly explained as (1) the more caustic powder form detergent used and (2) the leaching of organic matter from the peat media itself. This surely requires further investigation to ascertain the underlying chemical and physical reactions that take place in the interaction between peat and the greywater.

In general, these changes in the water quality parameters indicate effectiveness of the peat media in the entrapment and removal of impurities and pollutants. These entrapped particles most probably contributed to the enhanced stiffness discussed earlier based on the oedometer test results.

CONCLUSIONS

Following are the primary conclusions drawn from the present study using peat as a filter media for treating household greywater, with emphasis on the compressibility characteristics of the peat soil post-filtration:

- The post-filtration peat soil appeared to have improved compressibility, with the initial void ratio of all the specimens markedly reduced.
- The overly consolidated and normally consolidated demarcation can be easily distinguished in the compression curves, not unlike similar soft materials with some intrinsic structure.

- The rebound paths of all specimens, including the original peat sample, were found to be parallel to one another. This suggests minimal change to the soil's original structure when unloaded from a point along the normally consolidated line in the compression plot, a sign of the tenuous effect filtration of the greywater has on the inherent soil's structure.

- The C_s-C_c and C_c-e_s relationships share the same patterns respectively as those reported of similar peat soil Badv and Sayadian [12], but the current Cs values are significantly lower than those in the literature.

- Subjected to compression up to 400 kPa with a final unloading to 25 kPa would result in 40% void ratio reduction, regardless of the type of greywater filtered by the peat soil. Similarly the water content loss due to compression did not appear to be affected by the constituents of the greywater entrapped within the soil mass.

- The densities pre- and post-compression showed marked increment, especially with the dry density, where $\rho_f \approx 6\rho_o$.

- The overall water quality parameters showed effectiveness of the peat filter in removing impurities, especially the suspended solids. COD level in the Laundry (Powder) greywater is suggestive of excessive chemical contents in the detergent.

- The entrapped impurities from the filtration of the greywater could have contributed to the void ratio reduction and stiffeness enhancement of the peat soil, both before and after the compression test.

ACKNOWLEDGEMENT

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