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Feasibility of the direct filtration over peat filter media for bathroom greywater treatment

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Abstract

Peat has been identified as one of major groups of soils found in Malaysia, where it covers about 3.0 million hectare or 8 % of the total area of Malaysia. The present study examines the feasibility of using a direct filtration of locally available peat for treating bathroom greywater. The peat was sampled in bulks, remoulded and pressed into a filter cake form, the peat mass was installed in a lab-scale reactor where a raw bathroom greywater percolated through it for 28 days. The raw and treated bathroom greywater was tested and compared for its quality parameter. Complementary one-dimensional consolidation and X-ray fluorescence analysis was carried out on the peat samples to monitor the physic-chemical elemental contents pre and post-filtration. After treated, pH of the greywater was improved from acidic 3.8 to neutral 6.1. The suspended solids were found in the treated water with the highest concentration of 501.33 mg/L. It was suggested the pre-treatment of some sand or gravel media can improve the efficiency for physical parameter. The treatment gave the BOD reduction of BOD_5 up to 74%. It was found that the peat media can effectively improve the quality of the bathroom greywater. The one-dimensional compressibility test results showed negligible effect of the greywater chemistry on the inherent stiffness. The X-ray fluorescence analysis showed the post-filtration peat soil contained a marked reduction in Fe_2O_3 and increased of CaO. The clogging effect inadvertently transformed the peat soil into a more rigid mass, with potential for reuse as an agricultural soil bed.

Keywords: Bathroom greywater, peat soil, village house, greywater treatment

Introduction

Water pollution associates with untreated domestic greywater is currently seen as environmental concern to many, especially to the developing countries. The improper discharge of household greywater for instance for garden irrigation may poses major hazard to the environment for the long run [1, 2, 3, 4]. In Los Angeles, about 21 to 59 gallons per capita untreated domestic greywater discharged into the water bodies daily which represents 53-81% of the total wastewater generated residential [5]. The unsustainable means of greywater discharge from residents affects most of Malaysia's water supply [6]. The untreated greywater may create puddles and small pools that provide an ideal environment for pathogenic bacteria to proliferate as well as providing a breeding environment for insect pests. Besides, the decrease quality of water in many rivers produced major contributing to the water problem in Malaysia. River Water Quality from Environment Quality Report, (2012) stated that out of 473 rivers monitored, there are 278 (59%) clean, 161 (34%) were found to be slightly polluted and 34 (7%) polluted. In this context, greywater should be well treated prior final discharge to the nearest river to protect public health and environmental pollution.

Greywater refers to the untreated wastewater that is generated and can be collected from baths, showers, washing machines, laundry troughs, dishwashers and kitchen sinks, excludes toilet wastes [7, 1]. About 50-80 % of total wastewater discharged is greywater [8, 9, 10]. The characteristics of bathroom greywater effluent are quite variable among households due to the type of personal care, shampoo brand, and inclusion of urine and diaper washing during bathing. Common chemical contaminants typically include soap, shampoo, hair dye, toothpaste and cleaning products [1]. Bathroom greywater also contain pathogenic bacteria and viruses through body washing, soiled clothes and nappy washes [11, 12, 1]. It is expected that the greatest source of nitrogen is urine, as most people might pass urine in the shower rooms if not only from the body washing. Also, the addition of nutrient loads may come from protein-rich shampoos and conditioners, and body wash. Other source of nitrogen (nitrate and ammonia) were contained in nappies and soiled clothing [13]. Thus low-load greywater (bath, showers, and hand basins) which makes up 50-60% of the total greywater [14] seems to be the easiest waste to recycle due to its composition. According to [15, 16] the BOD and COD from residential greywater may ranged from 173 to 424 mg/L and 230 to 645 mg/L, respectively. According to previous reports [16, 17, 18, 19] P levels from bathroom greywater can reach up to >48.8 mg/L. These phosphorus comes mainly from the use of dishwashing.

Peat soil is a highly organic substance derived primarily from plant remains and a representative material of soft soils [20]. From an engineering perspective, peat is commonly classified as being a highly organic soil, with a distinct colour, odour, spongy feel and fibrous texture. As peat is mainly composed of fibrous organic matters, it can be easily distinguished from other organic soils by its lower ash content, i.e. less than 25 % ash by dry weight. Peat is found in all parts of the world except in deserts and arctic regions. In Malaysia, numerous examples of peat deposits can be found, especially along the coastline, as the coastal plain of Peninsular Malaysia is of very low relief and standing a only few metres above sea level. The peat soil layer is generally more than 2 m thick and contains less than 35 % mineral matter. The peat deposit was reported to be of low density and its colour ranges from black to dark brown [21].

Peat is known to be used as a filter media for wastewater and septic tank treatment, like treatment of wastewater from slaughterhouse and dairy plants in a continuous manner for peat filtration system [22]. In terms of slaughterhouse effluent, the peat filter clogged at the end of 5 days, for the period which the system effectively removed suspended solids (SS), BOD_5 and COD up to 95, 66 and 65% accordingly. For the dairy wastewater, clogging occurred 18 hours after operation, attaining SS, BOD_5 and COD removals of 99, 61 and 51% accordingly [23]. However, it was further reported that a 30 cm deep peat filter column could produce reductions of 93% TSS, 96% BOD_5 and 80% COD. It was concurred that peat filtration is an efficient method of domestic wastewater treatment in the case of low volumes requiring a high degree of purification [24]. This makes domestic greywater a potentially treatable effluent using a peat filter, due to its successfulness in removing organics and suspended solid.

The present study examines the possibilities of directly treating bathroom greywater using a peat filter. The reasons are two-fold, i.e. (1) peat is available in abundance in the natural surroundings of the local area, and (2) the treatment system would be useful as an economical and simple DIY approach to reducing the pollution load of bathroom discharge. Hence, this study is able to see the effectiveness of peat to treat bathroom greywater before being discharged and therefore can reduce water pollution.

2. Materials and methods

2.1. Peat soil sampling and analysis

The peat soil was collected from kampung (kg) Parit Nipah, coordinate at 1°88' N / 103°20'E which is located about 10 kilometres from Universiti Tun Hussein Onn (UTHM). It was sampled by using the disturbed sampling technique, where chunks of peat deposit were simply retrieved for remoulding in the laboratory. Sampling was conducted at approximately 300 mm from the ground surface to avoid surface and near-surface debris from the samples collected. Samples were kept in tightly in a plastic bag in order to prevent any change in the moisture content. All samples were then transported to the Geotechnical and RECESS (Research Centre for Soft Soils) laboratory, UTHM for tests in accordance with the British Standards, BS1377: 1990. The soil tests included moisture content (oven-drying Method), specific gravity, loss on ignition, organic content, Atterberg limits, pH and one-dimensional consolidation. Complementary X-Ray Fluorescence (Model S4-Pioneer) analysis was carried out on the peat samples to monitor the elemental contents pre and post-filtration. The one-dimensional consolidation and XRF tests were performed mainly to examine the physico-chemical changes of the peat media post-filtration, and to identify possible chemical reactions resulting from the greywater – peat interaction during percolation in the system. The properties of peat soil used in this study were shown in Table 1.

2.2. Peat Soil Filter Arrangement Set-up

Figure 1 shows the treatment system consists of three layers of peat, mosquito net, and wire mesh, installed in an in-house fabricated miniature reactor. The fine-meshed mosquito net was placed overlying the wire mesh (opening of 2.5 cm x 1.5 cm) to prevent mass loss and escape of suspended solids of less than $\leq 2.0\mu m$ from the peat media, while the wire mesh formed a sturdy platform for supporting the peat mass and bathroom greywater over it. After the peat was sampled from Kampung Parit Nipah, it was first loosened up and then lightly pressed into a semi-compact 7 cm thick layer over the wire mesh and mosquito netting. The loosening-compacting procedure was necessary to ensure uniformity of the peat filter in the initial stage, i.e. to provide a firm load-bearing platform as well as to minimize localized clogging of the filter, which could adversely affect the percolation rate

Table 1: Properties of peat soil in Kg. Parit Nipah, Batu Pahat, Johor

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
Ash content (%)	% Fine Sand
Liquid Limit (%)	50.3
	83

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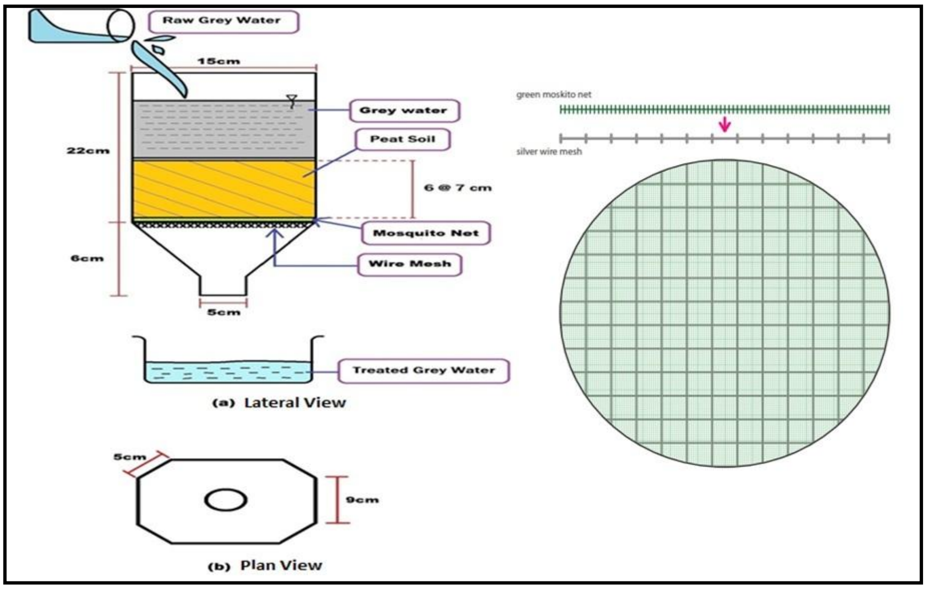

Figure 1: Lateral and Plan View of Peat Filter Media

2.3. Bathroom Greywater Preparation, Pre and Post- Filtration Analysis

The site investigation has shown that the bathroom greywater was discharged directly from the house to the drain outside the residential area. One unit village house in Kg. Parit Nipah was selected because of discharge pipe for bathroom greywater near the drain. An interview for daily activities was needed to know the activities undertaken routinely by the occupants of the house. Composite greywater samples were collected over 24 h using barrels that were previously graduated over the height for the purpose of flow measurement. Contents of the barrels were mixed thoroughly before sampling. The containers that were used to collect the bathroom greywater samples were plastic containers (rinsed) as referring to the Standard Method of Examination of Water and Wastewater (APHA, 2005). Collected samples were transferred to Environmental Engineering lab and analyzed for selected and significant physical and chemical characteristics. Treated effluents were measured for pH (sensION 378 Laboratory Multi parameter Meter), suspended solids (SS) by gravimetric method and biological oxygen demand (BOD) by five-day incubation test. The experiments were conducted in three replicates sample collected from the house from January 2013 to May 2013.

3. Results and discussion

3.1. Bathroom greywater characteristics

A summary of the greywater quality parameters test showing ranges of values is presented in Table 2. In general, the range of concentrations of bathroom greywater was within the range of values reported in the literature. The range of pH values was quite low in bathroom greywater, with maximum value of 6.4 compared with the 8.1 of literature values. Effluent BOD was low concentration compared to COD concentration with values ranging from 40 to 105 mg/L. According to [15], found elevated BOD concentration of similar sources (bath, shower and wash basin) of 173 to 424 mg/L. However, [25] reported slightly lower BOD values of between 129 and 155 mg/L and COD values of between 367 and 587 mg/L from similar sources. Bathroom greywater showed concentration of TSS with reported values of 78.33 to 163 mg/L lower than the range of 78 to 303 mg/L reported by [15]. The use of solid soaps caused the higher amount of TSS, turbidity, COD, DOC and BOD_5 [26] concentration was ranging from 53 to 880 mg/L, which was above the recommended value of 250 mg/L as referred to the [27].

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Other parameters of concern related with greywater were pH, sodium (Na), phosphorus (P), boron (B) and sodium adsorption ratio (SAR). The highest mean concentration of Na, ranging from 72 to 85 mg/L was found in bathroom greywater. The low levels of Ca and Mg were not balanced with Na, attributed to the highest SAR in bathroom greywater, ranged between 6.1 and 16.4. This is a ratio of the amount of cationic (positive) charge contributed to a soil by Na, to that contributed by Ca and Mg. The SAR results were high compared with the recommendation limit for irrigation of 5 [27]. The excess Na levels can cause soil structure deterioration and water infiltration problems [28]. Boron values were also high ranging from 0.09 to 1.78 mg/L. As expected, the use of regular personal cleaners resulted in a high P load in bathroom greywater, with total phosphorus (TP) ranged between 3 and 20 mg/L.

Table 2: Range of minimum and maximum value of bathroom greywater quality compared to value in literature review (no. of samples = 4 for a period of sampling of 28 days)

Parameter	Bathroom greywater	Literature reviews value
Parameter		
Insitu analysis		
pH	6.1 ± 0.06 - 6.4 ± 0.21	6.4-8.1
EC (µS/cm)	120 ± 11.50 - 1150 ± 2.52	82-250
General (mg/L)		
TSS	78 ± 4.55 - 163 ± 7.12	7-207
TDS (calculated)	74.24-736	
COD	445 ± 2.52 - 621 ± 4.02	100-633
BOD	40 ± 0.25 - 105 ± 0.42	44-300
Major ions (mg/L)		
Ca	6 ± 0.63 - 20 ± 0.45	3.5-7.9
Mg	2 ± 2.56 - 5.2 ± 1.52	1.4-2.3
K	0.85 ± 1.72 - 2.5 ± 0.78	1.5-5.2
Na	72 ± 0.78 - 85± 1.03	7.4-18
Cl	53 ± 1.12 - 880 ± 0.76	9.0-18
Nutrients (mg/L)		
NO_3 as N	0.01 ± 0.06 - 0.4 ± 0.01	<0.05-0.20
NH_4 as N	0.022 ± 0.12 - 6.7± 0.24	<0.1-15
TKN as N	1.12 ± 0.88 - 33± 1.45	4.6-20
OP	0.35 ± 1.14 - 6.3 ± 2.08	0.11-2.8
TP	3 ± 0.87 - 20 ± 1.76	0.11->48.8
TN	10 ± 2.90 - 38 ± 0.56	3.6-19.4
NO_3+NO_2	<0.02-3.6	-
Metal		
Boron (mg/L)	0.09 ± 0.06 - 1.78 ± 0.06	<0.1-0.5
SAR	6.1-16.4	4.8-6

Bathroom greywater literature data reference: Christova-Boal (1996); Li (2009); Gross, A (2008); Donner *et al.*, (2010)

3.2. Post filtration of Bathroom Greywater Quality

pH

It is observed that pH concentrations were neutral in untreated greywater but were acidic after being treated with peat soil as in Figure 2. However, the pH was neutral at the day 28 showing the possibility of the time which was needed to decompose the organic compound in bathroom greywater. The pH of the treated greywater gradually increased from 3.8 to 6.1 with increasing duration of time possibly due to decomposition of organic materials into peat soil [24]. Peat is mainly a positively charged and therefore negatively charged particles in the bathroom greywater were expected to attract and adhered with peat. pH concentration in greywater is generally at the range of 5.9-7.4 which mostly contributed by organics compound contained from the ordinary household chemicals like detergents, perfumes, shampoos, preservatives, dyes, glues and cleaners [8, 29].

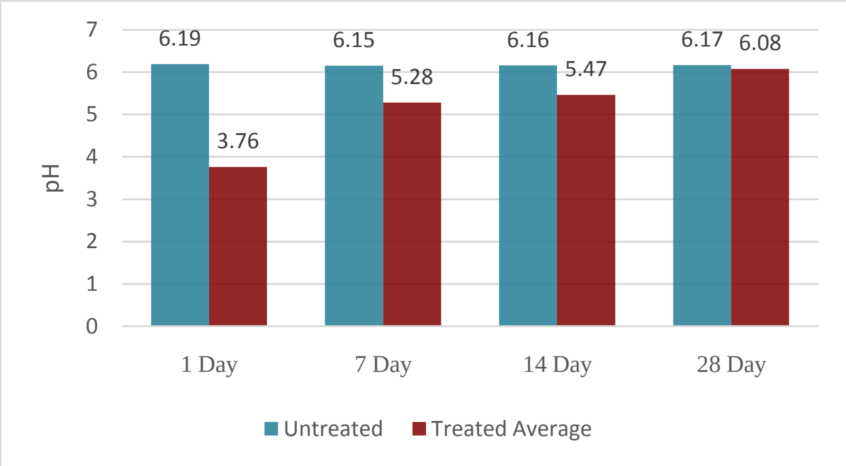


Figure 2: Concentration of pH during the treatment with peat filter

Suspended Solids (SS)

Figure 3 shows the graph of suspended solid (SS) against time for raw and treated raw bathroom greywater. The use of direct peat filter has shown the inclusion of suspended solids of highest concentration 501.33 mg/L after 7 day being treated with peat filter. The suspended solids also was also found high at the day 14 for treated effluent with the concentration of 271.90 mg/L. These two data give indication that the direct peat filter is inefficient to act as a sole filter. The pre-treatment to remove the physical parameter such as suspended solids must be provided in order to optimise the filteration system. For example, a studies of greywater [30] and kitchen wastewater [23] treatment by using a two-stage filter media (i) pre-treatment (gravel + sand) (ii) peat based (peat + charcoal + gravel) has successfully removed total suspended solid up to 81%. In this study, after the day 28, the peat filter however has shown a stability of the peat system and was giving a reduction of 35.27 % suspended solids.

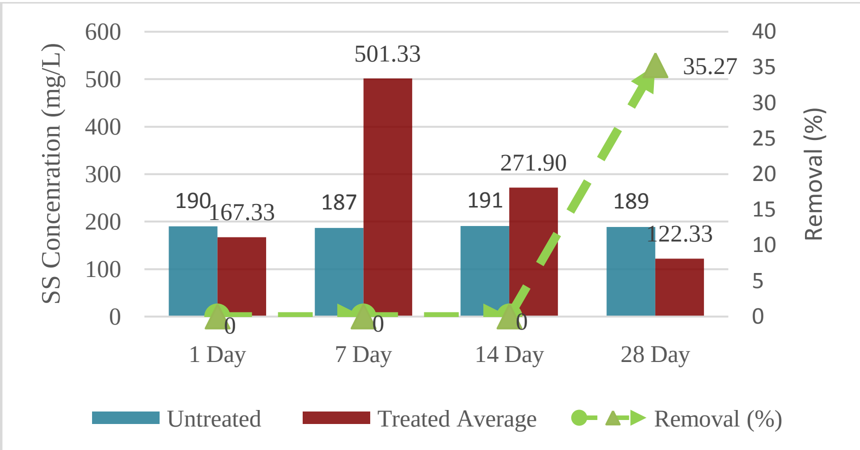


Figure 3: Concentration of SS and its percentage removal during the treatment period

Biochemical Oxygen Demand (BOD)

Figure 4 shows the BOD concentration for untreated and treated bathroom greywater. The concentration of BOD was low of 81-90 mg/L. After filtered with peat filter media, the BOD concentration was decreased gradually to 40.67 mg/L and 30 mg/L and 21 mg/L on the 7th, 14th and 28th day of filtration. The percentages of removals were 52%, 65% and 74% respectively. The application of peat soil was seemingly provide sufficient microorganism for degrading organic pollutant in the bathroom greywater. Microbes in the peat soil break down organic matter in the kitchen wastewaters. Most of the ordinary household chemicals like detergents, perfumes, shampoos, preservatives, dyes, glues and cleaners contributed organic pollutants [8, 1,]. It supported by [31] which BOD and COD concentrations in shower water are higher compared to mixed greywater which about 130 to 200 and 470 to 670 mg/l respectively, while in mixed greywater are 22 to 55 and 80 to 200 mg/l, respectively.

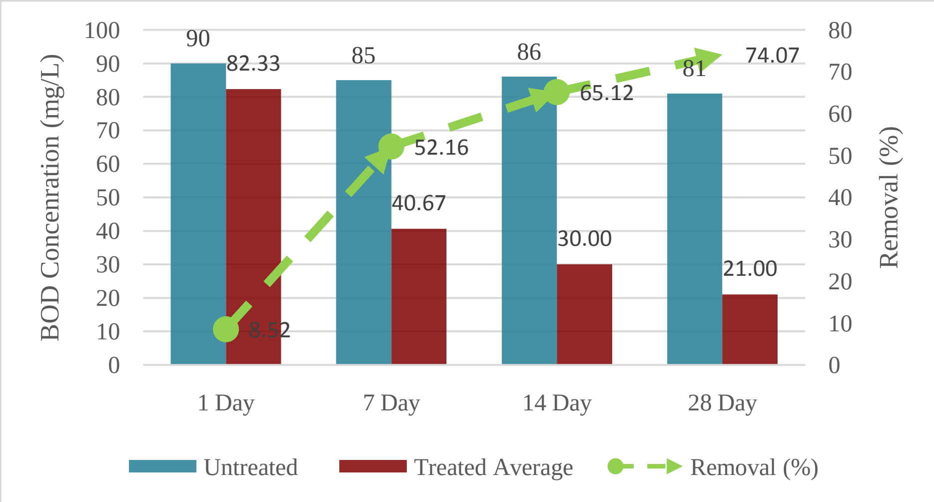


Figure 4: Concentration of BOD and its percentage removal during the treatment period

3.3 Analysis of the Peat Soil

Two tests were conducted on the peat media, pre-filtration and post-filtration, i.e. the X-ray fluorescence (XRF) analysis and the one-dimensional compressibility test. The former captured the chemical changes of the material, while the latter examines the effect of the chemical changes on the mechanical load-bearing response of the peat media.

3.3.1 X-Ray Fluorescence (XRF)

The X-ray fluorescence (XRF) is a quick and inexpensive non-destructive technique for identifying the bulk geochemical composition of a variety of materials in the forms of compressed powder, pellets or fused glass discs. For peat, creating test samples in the form of fused glass discs is not feasible due to the very low quantity of ash residue remaining after fusion, making measurements impossible with the XRF setup. Essentially, the mechanism of the method involves the interaction of the primary XRF with the sample causing ionisation or ejection of discrete inner orbital electrons, resulting in the rearrangement of the remaining electrons accompanied by an emission of measurable XRF. **Table 3** is summarisation of the XRF analysis. Fe_2O_3 was found to be significantly reduced post-filtration (i.e. 38 % reduction), possibly due to the chemical reaction with the greywater, or leaching from the peat mass with the percolating greywater. It was, however, not found to contribute to any reddish brown 'rusty' colouration of the greywater, as commonly associated with Fe_2O_3. CaO, on the other hand, underwent approximately 4 times increment in the post-filter sample, suggesting the high lime content of the bathroom discharge used in the study. This could be attributed to the initially high Ca content in the greywater itself compared with conventional knowledge (see Table 2), suggestive of the proprietary blend of chemicals in toiletry products. Other elements remained largely unchanged, with K_2O, P_2O_3 and MgO showing some reduction in post-filter, while the rest showed marginal increase.

3.3.2 Consolidation Test Analysis

The compression curve is shown in **Figure 5**. It is interesting to note that both the plots, pre- and post-filter, are very similar in the curvature. This indicates a generally unaltered compressibility under load, though the initial void ratio of the samples is telling. Pre-filter, the peat had a much higher void ratio of 12.5 % compared to post-filter, where the void ratio dropped to 10.7 %. As the void ratio is derived by dividing the volume of voids by the volume of solids in the material, it is suggestive that the solids have increased after greywater percolation through it. The enhanced solid stage provided structure to the originally spongy mass of the peat, giving it more load-bearing capacity when subjected to the same loading sequence, as shown in the figure (i.e. 25, 50, 100, 200 and 400 kPa). As such, the settlement registered under each load for the post-filter sample is lower compared to its pre-filter counterpart. Considering that both the samples are but the same, it can be concluded that the filtration process made direct contribution to the improved stiffness of the material.
This enhanced resistance against external load can be explained by the physical entrapment of suspended solids in the greywater percolating through the peat media. These solids would have settled within the gaps of the peat mass and eventually sealing (partially) the voids to form contacts with the existing solids.

Table 3: Peat Soil Composition

Element oxide	Pre-filter (%)	Post-filter (%)
CO_2	0.10	0.10
Fe_2O_3	45.8	17.54
SiO_2	22.3	33.67
Al_2O_3	7.88	10.76
ZnO	6.03	6.56
K_2O	5.15	3.00
SO_3	5.12	5.87
CaO	4.87	18.36
Cl	0.85	1.27
P_2O_5	0.76	0.44
MgO	0.59	0.46
TiO_2	0.30	1.46
Br	0.17	0.51
MnO	0.13	-

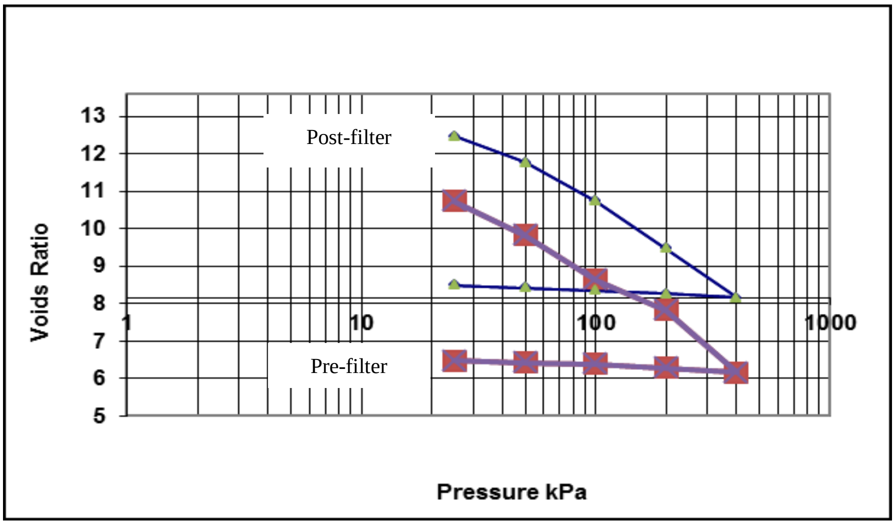
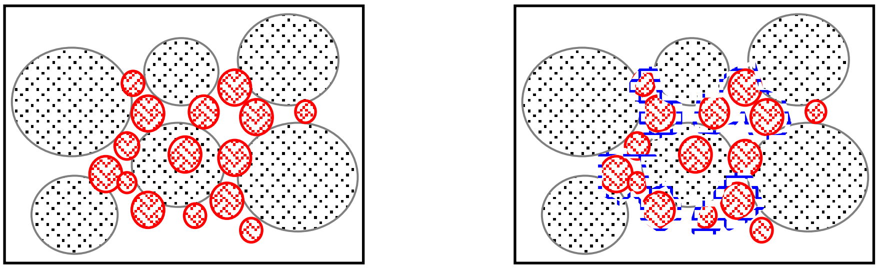


Figure 5: Void Ratio Values against Pressure

Figure 6(a) illustrates this phenomenon. When a load is applied, these contact points help in the transferring and sharing of the load.



(a) Entrapped solids filling the voids.

(b) Chemical binding of the solids and formation of larger aggregates.

Figure 6: Mechanism leading to improved stiffness of the peat mass post-filter

By effectively spreading out the load, weak zones within the peat mass are spared from excessive compression, which could result in localized failure and hence significant overall settlement or failure. Also, chemical changes to the peat mass in reaction with the greywater could produce glue-like substance that binds the solid particles during percolation, Figure 6(b). These aggregates of solids, larger in form than their segregated form, could provide greater load-carrying capacity. In addition, the interconnectivity of the solids would have contributed to the more efficient load transfer mechanism mentioned earlier. Similar observations were reported by [32] in an overall assessment of the compressibility characteristics of peat used as a greywater filter media.

Conclusion

The feasibility of the direct filtration of peat filter in bathroom greywater has increased the amount of suspended solids in the effluent water. The concentration of suspended solids was 501.33 mg/L at the day 7. Therefore, it is suggested that the pre-treatment was needed to remove physical parameter mainly suspended solids to improve the process. However, peat filter has shown a better efficiency in removing BOD from day 7 to day 28 with percentage of 52% to 74%. The treatment process was gradually effective by time during 28th day of treatment most probably due to the oxidation process. The pH was low of 3.8 after first day being treated with peat filter however pH was achieved to neutral (6.1) after prolong period of study.

Analysis of one-dimensional compressibility test results showed negligible effect of the greywater chemistry on the inherent stiffness, but this could be attributed to the rather short retention period preventing further chemical reactions or micro-structuring. From the XRF analysis, the post-filtration peat soil contained a marked reduction in Fe_2O_3, indicator of possible leaching to the greywater, but with no apparent colouration noticed. However, increase of CaO in the peat after filtration was most probably caused by the inherent contents of the toiletry products used for preparing the greywater sample. In overall, the reduced compressibility and voids within the peat mass were attributed to both physical entrapment of suspended solids as well as chemical reactions between the greywater and soil's compounds. Therefore, it requires further detail and more in-depth investigations.

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