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INFLUENCE OF OIL PALM EMPTY FRUIT BUNCH (OPEFB) AGRO-WASTE PROPERTIES AS FILTRATION MEDIUM TO IMPROVE URBAN STORMWATER

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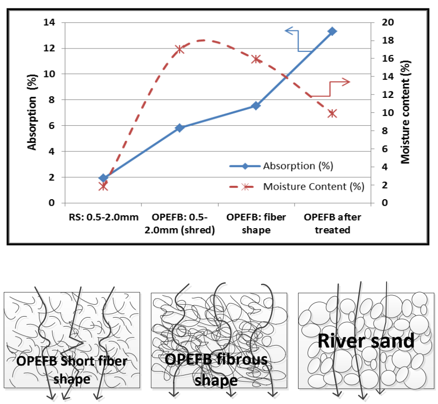
Graphical abstract



Abstract

Oil palm empty fruit bunch (OPEFB) is recommended as a filtration medium due to its fibrous characteristics and abundance as an agricultural byproduct. OPEFB is utilized to treat urban stormwater using a deep bed filter column. Urban stormwater samples were collected from Sembulan River, which flows through the Kota Kinabalu city area of Sabah, Malaysia. The samples were filtered through single and combination designs of OPEFB and river sand (RS) in mix ratios ranging between 25-75%. Each design's performance was evaluated in terms of Total Suspended Solid (TSS), turbidity, colour, temperature, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), and Ammoniacal nitrogen (NH_3-N) removal. Single medium designs demonstrated the poorest performance compared to dual mediums design. The optimum mixed design was 50:50 with ability to remove 52% color, 49% turbidity, 44% TSS, 59% COD, 84% BOD, and 94% NH_3-N. Further OPEFB water-washing treatment followed by a backwashing process achieved better separation results than a straightforward maintenance process. The optimized dual-filtration of stormwater was able to increase the urban stormwater quality from Class III up to Class I according to the Malaysian Interim National Water Quality Standard (INWQS), thus classified as suitable for water supply and conservation for natural environment uses.

Keywords: Urban Stormwater Recovery, Empty Fruit Bunch, Agricultural waste, River Sand, Deep Bed Filter Column, Water Quality Index

Abstrak

Gentian buah tandan kelapa sawit lompong (OPEFB) disyorkan sebagai medium penapis disebabkan oleh ciri serabut fiber dan didapati dengan banyak sebagai hasil sampingan sisa pertanian. Dalam kajian ini, OPEFB digunakan untuk merawat air larian perbandaran melalui kolum penapis. Sampel air larian perbandaran tersebut diambil daripada Sungai Sembulan di Sabah, Malaysia. Sampel ditapis melalui rekabentuk penapis tunggal dan gabungan OPEFB bersama pasir sungai (RS) pada julat 25 hingga 75%. Prestasi setiap rekabentuk dinilai berdasarkan penyingkiran jumlah pepejal terampai (TSS), kekeruhan, warna, suhu, keperluan oksigen kimia (COD), keperluan oksigen biokimia (BOD) dan nitrogen ammonia

(NH_3-N). Rekaan penapis tunggal didapati menghasilkan prestasi paling rendah berbanding rekaan penapis gabungan. Rekaan gabungan optimum adalah pada 50:50 dengan keupayaan untuk menyingkirkan 52% warna, 49% kekeruhan, 44% TSS, 59% COD, 84% BOD, and 94% NH_3-N. Rawatan lanjutan OPEFB melalui cucian air dan proses pembasuhan balik didapati mencapai keputusan rawatan penurasan yang lebih baik. Penurasan air larian menggunakan dua penapis berjaya meningkatkan kualiti air ribut bandar dari Kelas III kepada Kelas I, berdasarkan Piawaian Kualiti Air Kebangsaan Interim Malaysia (INWQS); sekali gus mengklasifikasikannya sesuai sebagai bekalan air dan pemuliharaan untuk kegunaan alam semula jadi.

Kata kunci: Gentian buah tandan lompong, Sisa Pertanian, Pasir Sungai, Kolum Penapis, Indeks Kualiti Air

1.0 INTRODUCTION

Urban stormwater may contribute to many severe health problems and to the loss of valuable natural resources if not properly managed. Capturing stormwater (or stormwater harvesting) is one option to improve water management for restoration and treatment, especially in urban areas. Stormwater harvesting is a sustainable solution due its potential in the management of flash floods and water resource recovery may suitable as water cleansing before being release back into the river streams.

Stormwater harvesting differs from rainwater harvesting because it collects runoff from drains, roads, parks, and playing fields. Any man-made surface is a potential catchment area, making stormwater more challenging to treat for reuse. Recycled stormwater could become one of the most important water resources in Malaysia since the characteristic climatic features of the nation include uniform temperature, high humidity, and abundant rainfall with high rainfall intensity [1]. Additionally, the impervious surfaces in urban areas usually produce high stormwater volume comprising runoff from parking lots and other ground level runoff [2]. Stormwater harvesting systems have been implemented in cities like Melbourne and Brisbane in Australia as a means to achieve their status as eco-cities. In 2012, the City of Melbourne successfully implemented a project to capture an estimated 21 million litres of stormwater each year, which is equivalent to saving more than 18 Olympic swimming pools' worth of water annually [3].

With these motivations, treatment of urban stormwater by filtration using Oil Palm Empty Fruit Bunch (OPEFB) as a filtration medium is proposed in this work. OPEFB is a solid lignocellulosic waste generated as a byproduct of the palm oil industry - the residual from crude oil palm fruit extract. It has low commercial value and constitutes a disposal problem due to the large quantity generated in palm oil production [4]. The use of OPEFB material in deep bed filtration for stormwater treatment in this current work is novel; typical media used in water filtration from various studies are: coal, silica, sand and anthracite, either used singly or in combination [5], [6]. However, previous work using Empty Fruit Bunches (EFB) in biofilters [7], in the treatment of toxic materials from industrial effluents [8], and in dye removal suggests a possible application of OPEFB as a filtration medium - especially in the filtration of suspended solids, phenol, cationic methylene blue (MB) and anionic phynol red [9]. The purpose of this work is to establish the appropriateness of this novel filter medium and the efficiency of the process.

Malaysia produces approximately 47% of the world's supply of palm oil and is considered the world's largest producer and exporter [10]. However, the resulting increase in palm oil production has created great environmental problems due to the escalation of abandoned palm oil waste by-product. Currently in Malaysia, there are more than 3.88 million hectares of land under oil palm cultivation and more than 368 palm mills in operation [11]. Due to this huge scale of production, Malaysia generates massive oil palm biomass wastes. Generally, each fresh fruit bunch (FFB) processed in an oil mill generates 14% fiber, 7% shell, and between 20% and 25% Empty Fruit Bunch (EFB), which is the lignocellulosic fibrous medium left behind after oil extraction [12]. Lignocellulosic fiber contains three major biopolymers which are cellulose, hemicelluloses and lignin [13] and can be used in pulp production and erosion control, and as mattress fillings, fertilizer and reinforcement material [14]. The lignocellulosic fiber characteristics are fast absorption and desorption of water, making it a potential filtration medium [15]. Bench-scaled experiments using OPEFB fiber modified with chitosan solution before being processed into a mat-type filter medium indicate that lignocellulosic fiber filter could be a potential technology as mesh screen in primary wastewater treatment [16], whereas OPEFB modified by grafting Poly(ethyl hydrazide) shows high potential in heavy metal removal [17].

In this research, OPEFB was utilized as a filtration medium in a combination design with river sand to treat urban stormwater in a deep bed filter column. Urban stormwater, which flows through the heart of Kota Kinabalu city center in Sabah, Malaysia was characterized and tested in a deep bed filter column. Five different mix-ratio designs were investigated and optimized. A feasible mix ratio was determined, suggesting that stormwater harvesting using OPEFB as separation medium for water resource recovery is viable. It is noted that for this method to achieve wide-scale implementation, public awareness must be raised and simple techniques to popularize stormwater harvesting as a potential alternative source of fresh water must be developed.

2.0 MATERIALS AND METHODS

2.1 Materials and Urban Stormwater Sampling Location

The OPEFB strands shown in Figure 1(a) were provided by an oil palm mill in Tawau (latitude: 4.282457N, longitude: 117.91478), Sabah, Malaysia. The fibers were transported to the Engineering Faculty of University Malaysia Sabah (UMS) laboratory in raw form as shown in Figure 1(a). River sand (RS), with diameter in the specific range of 0.5 to 2.0 mm shown in Figure 1(b), was bought from a local commercial wholesaler. Both OPEFB and RS were inserted into and tested within a deep bed column: a SOLTEQ® brand model TR13.

Figure 2 shows the point of stormwater collection, which is noted as 'R' (arrow) (latitude: 5.968118, longitude:116.070658). This point is part of Sembulan River, an artificial concrete river located in the vicinity of the Central Business District at Karamunsing and Sadong Jaya in the Kota Kinabalu town area in Sabah, Malaysia.

Figure 1 (a) OPEFB and (b) River Sand (RS)

The sampling point of an artificial concrete river was chosen due its strategic location and proximity to the city area and roadside. When raining, the urban runoff from roads, parking lots and other impervious surfaces flows down through the gully beside the road kerb or flows directly into this larger channel with deep draughts.

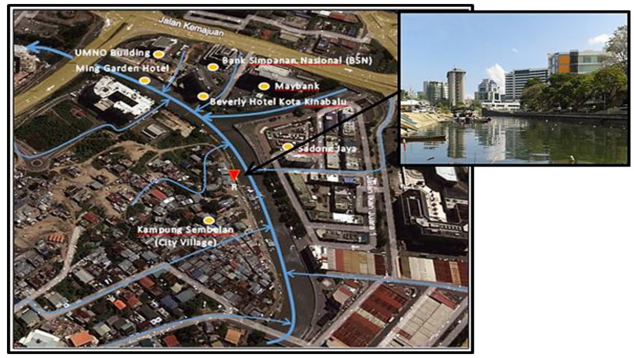


Figure 2 Urban runoff from roads, parking lots and other impervious surfaces to Sembulan River and location of river water sampling point as pointed arrow, R in the concreted artificial Sembulan River shown in the map (modified from google map.com)

The stormwater samples were taken from 4th to 23rd of April 2014 between 10 am to 2 pm and were characterized and investigated prior inserted into the deep bed column filtration. The weather during sampling was primarily sunny.

2.2 Stormwater Characterization and Deep Bed Column Filtration

The physical properties of the filter medium in terms of its specific gravity, adsorption and moisture content were investigated. Test procedures for adsorption and specific gravity were carried out in accordance with ASTM C128, whereas tests for moisture content were based on ASTM C70.

The stormwater samples were tested for Total Suspended Solid (TSS), turbidity, temperature, color, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD) and Ammoniacal nitrogen (NH_3-N). Turbidity and temperature were measured in situ by a Multiparameter Water Quality Meter Model WQC22A and color was measured by a DR/890 Colorimeter. TSS, BOD and COD tests were conducted at the laboratory by following the APHA standard method whereas NH_3-N was measured using the Salicylate Method with a Hach Spectrophotometer DR6000. The stormwater sample characteristics were compared with the Malaysian Interim National Water Quality Standards (INWQS) [18].

The filtration procedure of deep bed filtration using a SOLTEQ® brand model TR 13 was employed in this work. The deep bed filtration schematic diagram was shown in Figure 3. The filtration procedure was run on five filter mix-ratio filter columns, as summarized in Table 1. Each experiment was run in 3 cycles of filtration with 2 rounds of backwashing. Backwashing was conducted at fixed times of 45 minutes and at a constant flow rate of 5 liters per minute ($Q_{backwash}$≈83ml/s). The filtration results (effluents) were taken and recorded after one hour at 4 liters per minute ($Q_{filtrate}$≈67 ml/s) to ensure a constant and stable flow rate.

Table 1 Filter media mix-ratio design in deep bed column

Mix-ratio design (%)	100:0	25:75	50:50	75:25	100: 0
Filter Medium*	OPEFB	OPEFB: RS	OPEFB: RS	OPEFB: RS	RS

*Oil Palm Empty Fruit Bunches (OPEFB) & River Sand (RS)

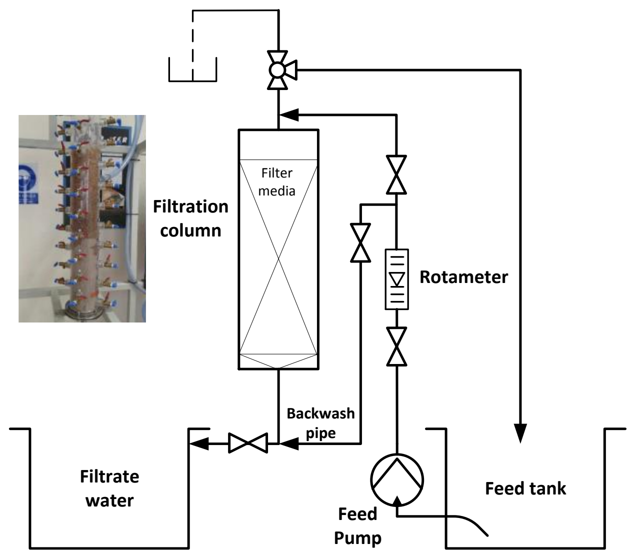


Figure 3 Schematic diagram of deep bed filtration unit

3.0 RESULTS AND DISCUSSION

3.1 Filter Media Characterization and Properties

Characterization of the river sand (RS) and the three types of OPEFB filter medium was conducted in terms of specific gravity, adsorption and moisture content, as shown in Table 2. This inter-relationship between moisture content and absorption properties of the four filter media types are illustrated in Figure 4.

Table 2 Characteristic of the Filter Medium

Properties	**River Sand**	**Oil Palm Empty Fruit Bunches (OPEFB)**		
		Shredded fiber	Fiber shape (raw)	After treatment
size, (mm)	0.5 – 2.0 ϕ	0.5 – 2.0 length	200μ ϕ	Fiber shape
Specific gravity (Sg)	2.65	0.9	0.9	0.9

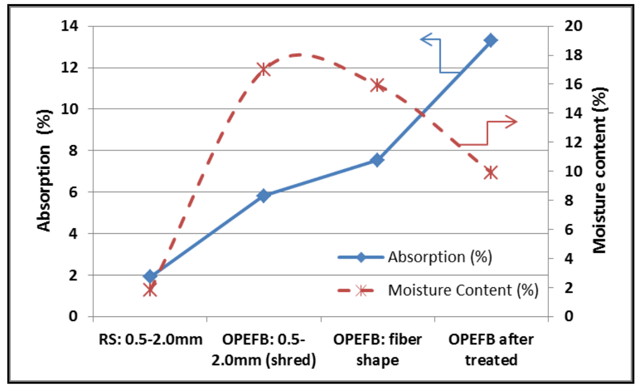


Figure 4 Relation between the filter media moisture content and absorption properties

The specific gravity of the river sand is three times higher than OPEFB, making it a suitable filter bed to be fluidized whilst retaining both the denser and lighter materials during backwash. Based on previous research by [19], finer RS grain size provides more efficient removal of TSS compared to coarse grain size. Smaller filter grains are effective in capturing particles that pass through a filter bed, thus providing better TSS removal. However, backwashing complicates this situation: filter media having a close approximate specific gravity and smaller grain sizes have a higher risk of being fluidized during backwashing and might be washed out when the backwashing rate is increased. Therefore, to decrease the risk of being washed out during filtration and backwashing, the OPEFB in fiber shape was preferred instead of the shredded fiber (size 0.5-2.0 mm). Furthermore, the specific gravity of OPEFB is lower or similar to water, causing it to float and thus the thread-like bundles of fiber have the advantage of retaining the shape and remaining immobile.

Absorption measures a unit's total capacity to absorb gas, liquid, or dissolved solid. The higher the absorption, the better the ability to remove particles and contaminants from water. The absorption percentage measured for the river sand was 1.9% whereas OPEFB in shredded and in raw fiber shape had absorption percentages of 5.8% and 7.5%, respectively. OPEFB has higher absorption than river sand due to its larger surface area. The average fiber diameter of OPEFB is approximately 200μm with length of 30-60 mm [20] which provides larger surface sites for absorption. This absorption property is an important criterion for filtration media as it increases the filtration performance. This is illustrated in Figure 5 which shows that the flow of water onto the OPEFB was better due to entanglement and higher surface area than river sand particles.

OPEFB after treatment with water shows the highest absorption rate of 13.3%. The treatment by soaking in tap water for 24 hours and rinsing until pH≈7 at ambient temperature of 25°C-28°C decreases its ash content and impurity. This result is in agreement with [21]. The treatment produces more 'spaces' that are available to increase its absorbility and to expose hydroxyl groups for the attraction of water molecules into the natural fibers. Also, the shape formed by the loose packing density enables fibers to trap particles from water. This was also observed by [22] where pre-treatment of oil palm empty fruit bunch fibers significantly enhances their digestibility and absorption.

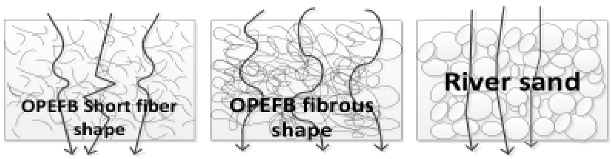


Figure 5 Illustration on the flow permeability during water filtration between OPEFB shred (short), OPEFB raw (fibrous) and River Sand particle

River sand shows the lowest moisture content of 1.8% compared to the other three groups of OPEFB. OPEFB shredded in 0.5-2.0 mm length size had the highest moisture content of 17.0%, followed by raw OPEFB of 15.9%. Treated OPEFB had a moisture content of 9.9%, the lowest within the three type of OPEFB. The absorption of the OPEFB filter media shows an opposite trend to moisture content. Shredded fiber (0.5-2.5mm) has increased moisture content but reduced absorption, possibly due to the hydrophilic surface of OPEFB. A similar trend was observed by [23].

The results also indicate that pre-treatment by water washing has a strong influence on the fibrous material of OPEFB, improving absorption and reducing the moisture content. OPEFB with 10-15% moisture content may weaken interfacial bonding and cause poor physical and mechanical properties [20]. The water washing treatment was found to reduce the moisture content by up to 40%, which might be due to cellulose and ash content disintegration. This relation between moisture content and absorption is illustrated in Figure 4 showing that river sand (RS) has the smallest value for moisture content and absorption compared to OPEFB. Among the three OPEFB types, the shredded size shows increased moisture content but reduced absorption, whilst water-washed treated OPEFB shows a feasible value of absorption and low moisture, making it a promising candidate for a low-cost filtration medium.

3.2 Filtration Performance on the Urban Stormwater Sample

Properties of the collected and characterized stormwater sample are shown in Table 3. Based on the INWQS Class definition, the stormwater sample was categorized as Class IV due to BOD and NH_3-N pollution, Class III in TSS and COD, and the least polluted parameter determined for Turbidity, Color and temperature which categorized as Class II. By taking the worst class category, the stormwater was considered low water quality and requires extensive treatment and may only suitable for irrigation uses.

Calculations on sub-index rating of the parameters are not included here as they are not the main focus of stormwater characterization but to highlight the performance of parameter pollutant removal in OPEFB filtration. Sub index calculation based on relatively variables may unsuitable in this study as explained by Zainuddin [24].

The results of stormwater filtration removal of the five mix design ratio media are shown in Figure 6. Similar trends were observed where optimum removals were obtained at a mix design ratio of 50:50 OPEFB:RS. The 50% OPEFB/RS column design shows optimum performance in the removal of TSS, turbidity, color, COD, BOD, and NH_3-N, with averages of 43.9±2%, 48.6±15%, 52.2±13%, 59.4±19%, 84.3±1%, and 93.6±14% respectively.

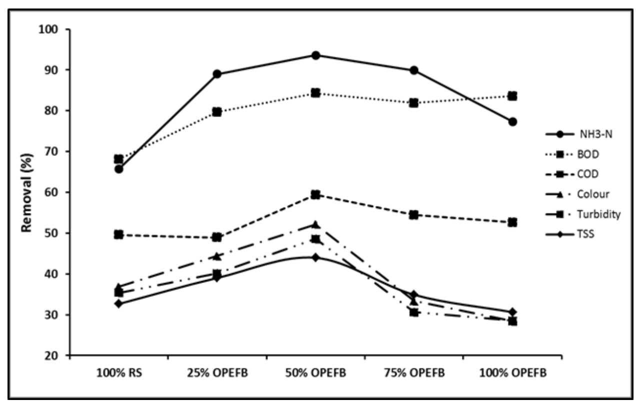


Figure 6 Removal performance of different mix-ratio River Sand (RS) and OPEFB in the filtration column design

When a higher ratio of OPEFB at 75% was used, the system shows a poor ability to remove the suspended solid, turbidity, colour, COD, BOD, and NH_3-N. This is probably due to the small specific gravity of OPEFB making it fluidized or 'soaked' during the filtration and causing an increase in voids that removes less fine material. Performance is further affected by the inability of OPEFB to retain suspended solids due to its large porous packing and surface material charge. But if the column dual filter is designed in the ratio of 50% OPEFB and 50% river sand, the higher absorptive property of OPEFB compared with river sand would act as the filter medium to improve the conventional mechanism of particle separation. Also, the denser river sand helps in decreasing the risk of OPEFB fluidizing in the filter column. However, using 75% to 100% river sand does not give an optimum removal, due to its low absorption property, and particulate less than 0.5mm may easily pass through the medium.

As shown earlier, the stormwater samples were characterized and classified as Class II, III and IV depending on the parameters of concern. Filtration of the urban stormwater sample using 50% OPEFB/RS has improved the water quality from Class III to II in terms of TSS and COD, Class II to Class I for turbidity and color, Class IV to Class II for BOD and significantly improved the NH_3-N parameter from Class IV to Class I. The increase of storm water quality class in accordance to the water stream standard of INWQS was pictured in Figure 7.

3.3 Pretreatment of OPEFB and Backwashing Performance

The optimum removal performance for the mix design of 50% OPEFB was further explored by backwashing and pretreatment (OPEFB washing) performance.

Table 3 Water quality class index of the influent stormwater sample (ST)

Sample	TSS (mg/L)	Turbidity (NTU)	Color (NTU)	Temperature (°C)	COD (mg/L)	BOD (mg/L)	NH_3-N (mg/L)
ST1	86.0	16	40	29	50	7.7	1.20
ST2	67.6	14	30	31	42	6.9	0.97
ST3	78.0	15	44	32	42	6.5	0.95
ST4	74.8	14	43	32	44	7.0	1.00
ST5	73.2	15	41	31	48	7.0	1.10
ST6	88.1	21	47	31	45	7.0	1.10
Average	77.9±7.8	15.8±2.6	40.8±5.9	31±1.1	45.7±3.4	7.2±0.6	1.1±0.11
Water Quality (Class)*	III	II	II	II	III	IV	IV

*Class index according to Malaysian Interim National Water Quality Standard (INWQS)

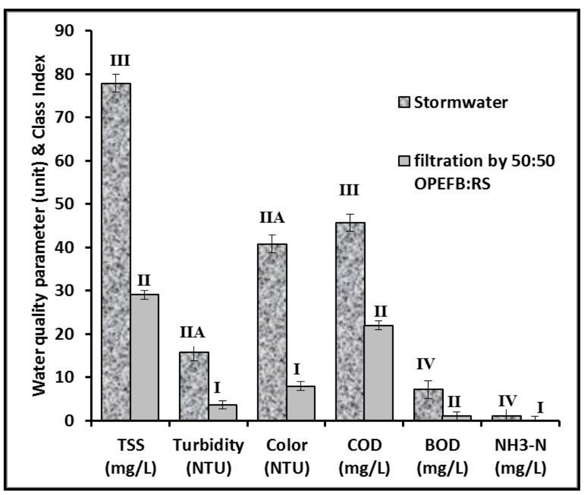


Figure 7 Improvement in urban stormwater water quality performance using 50% OPEFB in accordance to INWQS

In this study, backwashing was conducted after three filtration runs. Graphically shown in Figure 8, the physical separation capability of 50% mix ratio OPEFB increased by up to 8% with the water washing pretreatment, and this improvement was observed for water physical properties (TSS, turbidity and color).

However, chemical and biological parameters were unaffected, remaining similar even after the pretreatment. Removal performance was observed to increase after backwashing and OPEFB pretreatment: 60 to 67% for colour, turbidity 50 to 67%, TSS 53 to 59%, BOD 84 to 85% and NH_3-N 94 to 97%. This shows that cleaning and unblocking any trapped materials in the filter medium mixture are effective and could be due to the high absorption of the net-fiber shaped OPEFB in comparison to river sand and the suitable specific gravity differences between water and OPEFB. Therefore, this study has shown that a dual OPEFB design has high potential as a filter medium for stormwater, and that pretreatment before filtration and subsequent backwashing can minimally improve its separation performance. It is worth mentions that, the water washing pretreatment and backwashing results imply a practical simple maintenance for the filter media without jeopardizing its filtration capability.

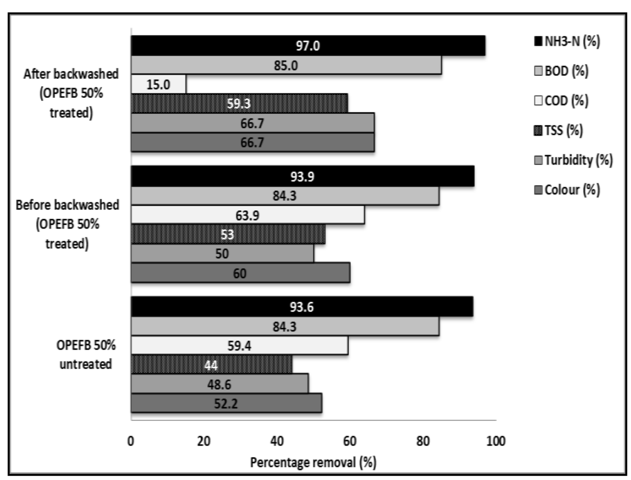


Figure 8 Comparison between filtration and backwashing performance using the 50%OPEFB mix-ratio

4.0 CONCLUSIONS

Experiments with different mix-ratio combinations of river sand (RS) and oil palm empty fruit bunch (OPEFB) as filtration medium were conducted. Filtration results indicated that optimum removal occurs at a dual mix ratio of 50% OPEFB and 50% RS in a deep bed filter column design. Further investigation by treatment of OPEFB by water washing has demonstrated better separation results for the stormwater sample by significantly improving their index of water quality. From these experiments, it can be concluded that the 50% mix-ratio OPEFB filtration has great potential in the removal of physical-chemical parameters such as colour, turbidity, suspended solid, ammoniacal nitrogen, biology and chemical oxygen demand. In addition to its filtration performance, OPEFB has the attractive eco-friendly property of being a highly-abundant by-product of agricultural waste. The reuse of agricultural biomass generated from the palm oil mills may not only solve the problem of environmental agricultural waste byproduct reusability but, in this case, might also offer a valuable addition to water resource management that can be used directly with a simple water washing treatment.

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