Jurnal Kejuruteraan 38(4) 2026: 2005-2016
https://doi.org/10.17576/jkukm-2026-38(4)-35

Physical Characterisations and Contaminant Removal using Palm Shell Charcoal in Multi-Media Filters

Noraini Mat Budari[a,b*], Noor Sa'adah Abdul Hamid[b,c], Ku Halim Ku Hamid[d], Siti Aisyah Ghazali[b,c], Shahrul Azwan Shakrani[e], Mohd Afiq Mohd Fauzi[f] & Jalina Kassim[b]

[a]*Faculty of Civil Engineering, Universiti Teknologi MARA (UiTM), 26400, Jengka, Pahang, Malaysia*

[b]*Bioremediation Research Centre (myBioREC), Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia*

[c]*Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia*

[d]*Faculty of Chemical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia*

[e]*Faculty of Civil Engineering and Technology, 02600 Universiti Malaysia Perlis, Malaysia*

[f]*Faculty of Civil Engineering, Universiti Teknologi MARA, Kampus Samarahan 2, 94300 Kota Sarawak, Malaysia*

**Corresponding author: norainibudari@uitm.edu.my*

Received 10 November 2025, Received in revised form 9 March 2026
Accepted 9 April 2026, Available online 30 May 2026

ABSTRACT

This study was conducted to discover a new palm shell charcoals (PSC) filter medium, for safe drinking water treatment to remove pathogenic microorganism. To determine the PSC performance, a granular medium filtration in dual- and tri-media filters were designed and constructed to assess the physical and biological contaminants. The PSC morphology, porosity, specific gravity, and ball-pan hardness were studied. The physical characteristics of PSC, as evaluated by ball-pan hardness at 97.30%, demonstrate that it is potentially comparable to or greater than commercially available granular filter media. This study also found that, the granular medium filter in dual-media filtration was performed better respect to physical and biological contaminations removal as compared to tri-media filtration. Notably, the PSC/sand filter media with Effective Size (ES) 1.0/0.5 mm dual-media filtration success to remove 73.41%, 69.36%, 57.04% and 0.37 log of turbidity, suspended solid, colour and: Escherichia coli (E. coli) bacteriological respectively. For instance, the tri-media filters of PSC/Granular Activated Carbon (GAC)/sand show the highest bacteriological removal of 0.33 log for total coliform. Besides, the types of media filters to the turbidity, suspended solid, colour and E. coli were in significance interaction with $p < 0.05$ under one-way anova. Additionally, there was statistically significant difference at $p < 0.05$ between the types of media filters and flow rate to the physical removal under two-factor analysis of variance. Therefore, this study offers practical insights for adopting PSC as these materials are available, abundant, easy to maintain and economical for water treatment towards the environmental sustainability enhancement.

Keywords: Escherichia coli; mixed-media filter; palm shell charcoals (PSC); total coliform

INTRODUCTION

Water is the most indispensable requirement in our daily lives. There is a widespread consensus that ensuring the availability of safe water to the community can effectively prevent outbreaks of waterborne diseases. So, the water supply scheme is working hard to achieve that objective. In fact, drinking water that has been contaminated by pathogenic microorganism may cause harm to human thereby put the alarming button on worldwide. Indeed, the total coliform and fecal coliform (E. coli) are the two pathogen microorganism indicators of water health (Castillo-Torres et al. 2019; Okeke et al. 2011). However, the increasing demand on that filtration media causing the search for an alternative option from agricultural so-called waste to wealth filtration transformation. It includes cocoa shells, rubber seed, banana peels and bamboo (Feriyanto et al. 2024; Sawant et al. 2020; Diaz et al. 2018; Bhakta et al. 2017; Diaz et al. 2018; Feriyanto et al. 2024; Sawant et al. 2020).

Filtration is a process of treated water through a medium such as sand or anthracite, which acts as a 'strainer', to retain fine organic and inorganic materials including pathogen microorganism allowing the clean water through. So far, the traditional method adopted anthracite, sand or granulated activated carbon for its media (Cescon & Jiang 2020). Using agricultural wastes as a medium in filtering water and wastewater treatment has become a popular method compared to anthracite, sand or granular activated carbon. In fact, during the last decades, the literatures and knowledge on natural filter media in the water treatment industry have increased substantially (Feriyanto et al. 2024; Nasrizal et al. 2023; Ali et al. 2021). Besides, it is an important consideration to produce a new medium of filter that is abundantly available, easy to maintain, and economical in the water/wastewater treatment industry. Therefore, new agricultural waste products, such as oil palm shells, are introduced as an alternative to new filter medium material. The high rate of oil palm shells generated has increased tremendously due to the advancement of oil palm industries in Malaysia. It was reported that the annual production of the total oil palm kernel in 2022-2023 was about 4.5 million tonnes/ per year (MPOB,2024). The use of oil palm shells as a filter medium is highly advantageous and cost-effective, reducing the need for other raw materials. Palm shell charcoal, made from the solid waste of oil palm fruit shells-a by-product readily available from palm oil factories in Malaysia-offers an efficient and sustainable alternative for filter medium production (Taha et al. 2022; Budari et al. 2014; 2013). So, the charcoal palm kernel exploration as granular medium filtration provides a glimpse and important to be carried out. Therefore, the question whether this charcoal palm kernel can remove pathogen or not will be answered in this study.

Numerous researchers confirming that granular medium filtration could guarantee the contaminant removal to meet the industry water purification standard (Chang et al. 2022; Ali et al. 2021; McIntyre & Hart, 2021). So, this study intended to utilized PSC as dual- and tri- media filtration in rapid depth filtration. Those PSC filtration media performances were evaluated for physical and biological contaminants removal upon six (6) types of water quality parameters namely, turbidity, suspended solid, colour, pH, total coliform, and E. coli.

METHODOLOGY

FILTRATION SYSTEMS

Figure 1 shown conventional deep bed filtration systems were employed. The system consists of influent water pumped into a header tank and processed via gravity flow. The filter column utilized was constructed from transparent PVC with a diameter of 5.2 cm and a height of 150 cm. This column was positioned at a total height of 3.22 m, measured from the influent basin to the header tank. The filtration unit was equipped with a backwashing facility and had a maximum head of 2.28 m. Head loss was measured at every 10 cm depth from the bottom of the column up to a height of 1 meter using 11 manometer tubes. Additionally, an overflow pipe was installed to prevent water overflow.

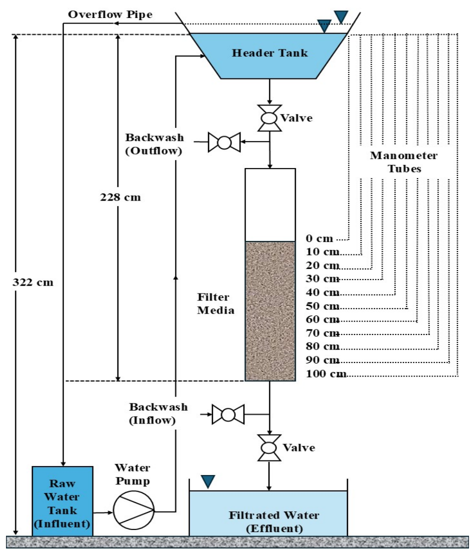

FIGURE 1. Filtration unit schematic diagram (Budari et al. 2013)

Table 1 shown the filtration units that were examined in these studies. These methodologies were adapted from (Emelko, 2003) and (Zouboulis et al. 2007). All filters were operated at varied flow rates of 5 and 10 m/h. Backwashing was conducted when the maximum terminal head loss was reached, employing reverse flow with clean water, which had a turbidity of less than 1.0 Nephelometric Turbidity Units (NTU).

PREPARATION OF PSC MEDIUM

Figure 2 shown a raw oil palm shells that are subjected to a carbonization process in a furnace at 300°C for two hours in an oxygen-free environment, following the method outlined by Jusoh et al. (2009).

FIGURE 2. Raw oil palm shells

Upon completion of carbonization (Figure 3), the resultant palm shell charcoal (PSC) was ground into smaller granules and sieved using a mechanical sieve machine to establish a particle size distribution curve.

TABLE 1. Filtration unit composition

Filter type	Composition layer (cm)	Effective Size, ES (mm)			Uniformity Coefficient, UC		
i) Dual-Media Filter							
		PSC	Sand		PSC	Sand	
PSC/Sand	60 PSC + 40 Sand	1.0	0.5		1.5	1.5	
PSC/Sand	60 PSC + 40 Sand	1.5					
PSC/Sand	60 PSC + 40 Sand	2.0					
		Anthracite	Sand		Anthracite	Sand	
Anthracite/Sand	60 Anthracite +40 Sand	0.9	0.5		1.5	1.5	
ii) Tri-Media Filter							
		PSC	GAC	Sand	PSC	GAC	Sand
PSC/GAC/Sand	65 PSC + 25 GAC + 10 Sand	1.0	0.89	0.5	1.5	1.5	1.0
		Anthracite	GAC	Sand	Anthracite	GAC	Sand
Anthracite/GAC/ Sand	65 Anthracite + 25 GAC + 10 Sand	0.9	0.89	0.5	1.0	1.5	1.0

FIGURE 3. Oil palm shells after carbonization process

The PSC was then thoroughly washed with tap water and double-rinsed with distilled water to remove any residual ash and particles from the heating in non-oxidative environment and grinding processes. The cleaned PSC was subsequently dried in an incubator at 103-105°C for 24-28 hours. Following this, a Raffle Box was employed to determine the size distribution of the PSC medium. Therefore, both PSC and sand were graded into granules to achieve specific uniformity coefficients and effective sizes (ES), with 0.5 mm for sand and 1.0 mm, 1.5 mm, and 2.0 mm for PSC. The effective size parameters of the media filter are consistent with the literature, with sand media ranging from 0.4 to 0.8 mm and anthracite media ranging from 0.8 to 2.0 mm (Richard & Mines, 2014).

POROSITY

Figure 4 shown the method employed for determining porosity and was adapted from Clements (2004). The porosity or the fraction of free space can be defined as the dimensionless ratio of void space volume to the total bed volume and it is calculated using the expression in Eq. 1.

$$\text{Porosity } (\varepsilon) = (\text{void volume})/(\text{total bed volume}) = (b+c-a-d)/c \quad (1)$$

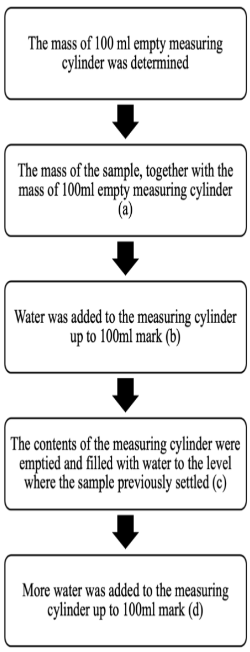

FIGURE 4. Porosity and specific gravity procedure

SPECIFIC GRAVITY

Specific gravity compares the weight of a given volume of a substance to the weight of the same volume of a reference substance. In other words, it's the ratio of the masses of equal volumes of both substances, as shown in Eq. 2.

$$\text{Specific Gravity (SG)} = a/(a+d) \quad (2)$$

BALL-PAN HARDNESS

The Ball-pan hardness test was conducted in accordance with ASTM D3802 methods. Initially, the PSC samples were screened to exclude fractions above the maximal (5% mass retention) and below the minimal (95% mass retention) nominal particle sizes using particle size distribution test. A 50-gram sample was placed in a 20 cm hardness pan, along with fifteen 12.7 mm steel balls and fifteen 9.5 mm steel balls. After 30 minutes of agitation in a mechanical sieve shaker, the steel balls were removed. The sample was then transferred to a hardness test sieve with openings that were half the size of the smallest nominal PSC particle size, which was estimated based on the particle size distribution. The sieve was shaken for 10 minutes, and the mass of the PSC retained on the sieve was recorded (ASTM 2023; Qiu & Guo 2010). Once the test was completed, the samples were sent to the Laju Group of Companies in Shah Alam. The ball-pan hardness number was calculated as outlined in Eq. 3.

$$H=100 \times [B/A] \quad (3)$$

Where: H = ball-pan hardness; B = mass of sample retained from the hardness test sieve (g) and; A = weight of the original PSC sample (g).

MORPHOLOGY OF FILTER MEDIUM

The medium of filter morphology figures was taken by Quanta 450 FES Environmental Scanning Electron Microscope (FEI, Oregon USA).

WATER SAMPLING

The water samples were taken from the Klang River (influent) and were filled in 25L polypropylene sampling bottles. All water sampling was conducted in accordance with APHA et al. (2023). The samples were then stored at a 4^{o}C for further physical and biological analyses. The characteristics of the samples were described in Table 2 below. As for filtrate water, about 500ml samples were taken.

TURBIDITY, PH, SUSPENDED SOLID AND COLOUR CHARACTERIZATION

The turbidity of both the influent and treated water samples was measured with a 2100P Turbidimeter (HACH) using the nephelometric method, and the results were given in Nephelometric Turbidity Units (NTU). The pH levels of the influent and effluent water samples were checked using a pH meter (HACH SensION3) with electrodes that determine pH electrometrically. The pH results for drinking water were within the acceptable range specified by the WHO (pH 6.5 - 7.5). To measure the colour of the water, a DR 2800 Spectrophotometer (HACH) was used, following Method No. 2120C. The colour measurement was reported in Platinum-Cobalt (PtCo) units, with the sample absorbing light at 455 nm. The water quality assessment by turbidity (NTU), pH, and colour analyses were performed according to the Standard Methods for the Examination of Water and Wastewater (APHA et al. 2023). The suspended solid was measured using a DR 2800 spectrophotometer (HACH) using the photometric method with 810 nm sample absorbed and resulted in mg/l (Hach, 2014).

TOTAL COLIFORM AND E. COLI

A single pack of formulation powder was added to a 100 ml sample in a sterile vessel. 5-10 ml of the sample was placed in a separate sterile vessel as a precaution to ensure adequate volume for the Quanti-Tray. The capped vessel was then shaken until the powder was completely dissolved. The prepared sample mixture was poured into a Quanti-Tray/2000 and sealed using the IDEXX Quanti-Tray Sealer. To ensure the prevention of leakage, the tray was sealed twice. The sealed tray was then incubated at 35°C ± 0.5°C for 24 hours.

The optimal time to read the results was within the range of 24-28 hours. Positive results could be observed in less than 24 hours, while negative results could be confirmed after 28 hours. The presence of coliforms was indicated by a yellow colouration, and the detection of E. coli was confirmed by the production of a fluorescent chemical under UV light (APHA et al. 2023; IDEXX 2024; Okeke et al. 2011).

TABLE 2. The characteristics of raw water from the Klang River sampling station

Variable	Mean± SD (N)	Min	Max	Class III[a]
Turbidity (NTU)	224.93±217.44 (99)	56.40	977.00	-
Suspended Solid (mg/l)	228.61±138.88 (99)	98.00	695.00	150
Colour (PtCo)	1097.62±559.03 (99)	600.00	3650.00	-

[a] Class III of Interim National Water Quality Standard (INWQS) recommended by Department of Environment (DOE) Malaysia.
Source: Environmental Quality Report 2020, National Water Quality Standards for Malaysia (2024)

STATISTICAL ANALYSIS

Statistical analyses were performed using IBM SPSS Statistics 29 software. The procedures included one-way and two-way analyses of variance (ANOVA), with a significance value at $p < 0.05$.

RESULTS AND DISCUSSION

PHYSICAL CHARACTERISTICS OF PSC

The specific gravity (SG) units for PSC were 1.3 for effective sizes (ES) of 1.0, 1.5, and 2.0 mm. In general, specific gravity (SG) is essential for characterizing filter media, as it ensures that the media are arranged in a specific size order, which is particularly important in mixed media filters, such as dual- and tri-media systems. SG is also important during the backwashing process, as a reduction in SG value would increase the loss of the filter medium. Consequently, SG affects the arrangement and stratification of the media in the filter column, where sand (SG: 2.65) is arranged at the bottom due to its higher SG, while PSC (SG: 1.30) is positioned at the top. In terms of performance, larger particles are captured by the PSC, while smaller particles attach to the sand medium. During filtration, particles in the influent water accumulate within the void spaces in the filter bed, with sand, having a higher SG, significantly arranged at the bottom, thus increasing resistance to water flow (Parsons & Jefferson, 2006).

The porosity of PSC was 0.49 for effective sizes (ES) 1.0, 1.5, and 2.0 mm. This porosity depending on its production method and intended application, often aligns with that of commercial filter media used in industrial contexts. Commercial filter media are designed to achieve porosity that optimizes filtration efficiency while maintaining suitable flow rates, with standard porosities typically ranging from 0.4 to 0.6 in water filtration applications (Crittenden et al. 2012). Porosity is a critical factor in the filtration process. It significantly impacts head loss and overall filtration performance. The porosity of the filter bed determines the capacity for particle retention within the media. Lower porosity, however, can lead to increased head loss and a reduction in the total operating time of the filter.

It shall be highlighted that, the raw oil palm shell used as filter medium offers value-added benefits and environmentally beneficial approach to transforming waste into valuable products. In this study, the physical performance of PSC was systematically assessed, with particular emphasis on its resistance to degradation and attrition, as determined by the ball-pan hardness test (ASTM 2023; Qiu & Guo 2010). This test serves as a crucial measure of the material's capacity to maintain structural integrity and withstand frictional forces during the backwashing process.

A higher ball-pan hardness value indicates greater resistance to mechanical abrasion, with typical values for commercial applications ranging between 70 and 100. The ball-pan hardness of palm shell charcoal (PSC) was measured at 97.30%, indicating that PSC exhibits a comparable quality to other commonly used materials in the production of activated carbon. As reported by (Qiu & Guo 2010), PSC's hardness is slightly lower than that of bituminous coal activated carbon, which has a hardness of 98.10%. However, PSC demonstrates superior hardness compared to coconut shell activated carbon, which has a hardness of 92.40%, and PUR-RF carbon used for water filtration, which has a significantly lower hardness of 55.40%. Additionally, the hardness of palm shell charcoal exceeds that of coconut-shell derived MC450, which stands at 95.00%. These results highlight the durability and resilience of palm shell charcoal, making it a viable option among various types of activated carbon.

The morphology structure of PSC medium demonstrated that the use of palm shell charcoal (PSC) and sand as filter media closely aligns with the initial head loss results predicted by the Carman-Kozeny equation for non-spherical particles and its modified version. Figure 5 revealed its non-spherical characteristics and rough surface morphology. In morphological studies, the combination of non-spherical PSC and sand media resulted in significantly higher contaminant removal.

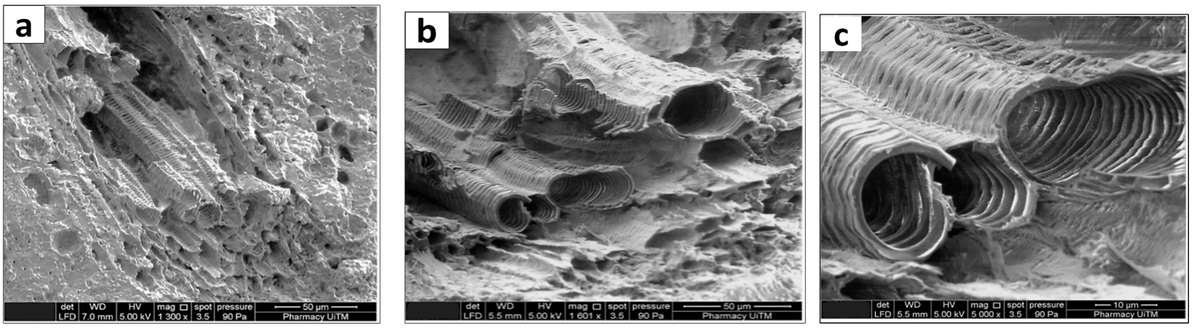

FIGURE 5. PSC medium under Environmental Scanning Electron Microscope: (a) 1300 x; (b) 1601 x and; (c) 5000 x

The non-spherical and rough surfaces of the filter media particles increase the surface area and create more complex surface interactions, thereby enhancing adsorption and filtration efficiency by providing more active sites for contaminant deposition. The rough surface morphology contributes to slower head loss development and greater bed porosity, attributed to the extended transport path required for contaminant particles to reach the filter media (Cescon & Jiang 2020; Xie et al. 2022).

STATISTICAL ANALYSIS OF PSC PERFORMANCE IN DUAL- AND TRI-MEDIA FILTERS

In general, the best performance of granular medium filter was the dual-media of PSC/sand ES 1.0/0.5mm for the removal of turbidity (73.41%), suspended solid (69.36%), colour (57.04%) and E. coli (0.37 log), while tri-media of PSC/GAC/sand performed better under total coliform removal (0.33 log). The physical parameter characteristics, including turbidity, suspended solids, and colour, were consistent across all filters.

Figure 6 represents the range of pH value during the filtration process. In this research, the impact of pH was evaluated for both influent and effluent water samples. Table 3 show that the paired sample t-test result was average and the pH in influent raw water was higher (Mean + SD =7.18 + 0.26) than the effluent (Mean + SD =7.14 + 0.24). This difference was significant, $p < 0.001$ (4.0836E-4). Furthermore, the result showed that the decrease of pH value was affected by the filtration process. Moreover, the result indicated that there was a significant change in the pH of influent to the pH of effluent (significant value = $0.001 < 0.05$). The significant change was estimated between 0.0198 and 0.0670. In addition, there was a statistically significant difference at 0.05 level as determined by one-way anova for the turbidity % removal ($p < 0.001$), suspended solid % removal ($p < 0.001$), colour % removal ($p < 0.001$), E. coli ($p = 0.040$) and but none for total coliform ($F = 0.536$, $p = 0.859$). The relationship between the independent variables (types of media) and the dependent variables (physical and biological parameters) was in optimum condition in PSC/sand ES 1.0/0.5mm for turbidity, suspended solid, colour and E. coli removal, whereas PSC/GAC/sand was found to result in higher removal of total coliform.

The general linear model results for the two-factor analysis of variance with significant value of filter performance ($p < 0.05$) are shown in Table 4. The analysis was conducted to examine the effect of flow rate in different types of media filter for the performance outcome. The independent variables were the six types of media filter and flow rate value. Meanwhile, the dependent variables were the performance outcomes; total coliform, E. coli, turbidity, suspended solid, and colour.

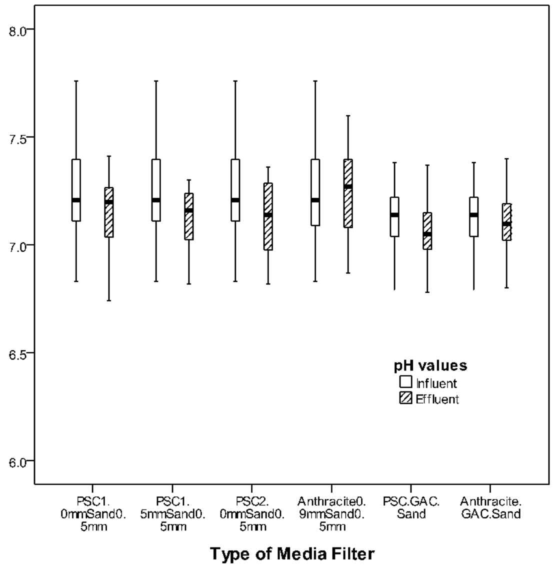

FIGURE 6. pH of influent and effluent water quality during filtration process

Similar analysis was also conducted with the Univariate General Linear Model. Table 4 show the two-factor analysis of variance where significant interaction between the types of media filter to the flow rate value for turbidity ($p = 0.000$), suspended solid ($p = 0.013$) and colour ($p = 0.040$). Moreover, total coliform ($p = 0.536$) and E. coli ($p = 0.479$) were not significant in the difference for the effect of media filter to the flow rate value. The p-value result proved significant interaction between the filter media to the flow rate specifically to turbidity, suspended solid, and colour. Figure 7-9 shown the significant patterns that 5m/h led to high removal compared to 10m/h. Furthermore, the flow rate emerged as the one of the most important design factors in the present study. Greater flow rate increased bacteria passage through the filter media and the trend was the same for physical parameters. Furthermore, increase in the flow rate decreased the particles' deposition at the top of the medium and higher particles were attached in the deeper medium section, and hence, increased flow rate caused an increase in the head loss and reduced the service time of filter, as reported in the literature (Cescon & Jiang, 2020; Williams et al. 2007).

Besides, the type of medium in the filter was highly a significant variable and followed by the flow rate value. Moreover, the effects on independent variables were significant interactions to the E. coli and the physical removal by media filtration.

REMOVAL OF TURBIDITY

The mean of the filter performances across the six types of filter media are shown in Table 3. Anthracite/sand with an effective size (ES) of 0.9/0.5 mm achieved the highest turbidity removal, followed by PSC/sand with an ES of 1.0/0.5 mm. The performance of PSC was comparable to that of the commercial anthracite filter medium. Turbidity removal efficiency was inversely proportional to the increase in the flow rate (Baig et al. 2011; Gao, 2012; Williams et al. 2007).

TABLE 3. Mean performance for the six types of filter media

Media Filter	Log_{10} Total coliform	Log_{10} *E. coli*	Turbidity (%)	Suspended solid (%)	Colour (%)
PSC/Sand					
Mean $\pm$ SD	0.30 $\pm$ 0.18	0.37 $\pm$ 0.08	73.41 $\pm$ 11.28	69.36 $\pm$ 11.00	57.04 $\pm$ 8.48
Min - Max	0.11 - 0.70	0.19 - 0.52	46.21 - 88.43	42.40 - 82.70	34.52 - 69.27
PSC/Sand					
Mean $\pm$ SD	0.29 $\pm$ 0.18	0.30 $\pm$ 0.09	72.23 $\pm$ 11.38	67.83 $\pm$ 10.15	54.18 $\pm$ 7.90
Min - Max	0.10 - 0.61	0.19 - 2.45	52.51 - 92.64	52.67 - 88.37	42.07 - 71.46
PSC/Sand					
Mean $\pm$ SD	0.22 $\pm$0.18	0.26 $\pm$ 0.09	66.61 $\pm$ 19.08	62.59 $\pm$ 17.32	49.43 $\pm$ 13.01
Min - Max	0.08 - 0.61	0.06 - 0.36	11.52 - 91.94	10.13 - 87.50	10.36 - 68.93
Anthracite/Sand					
Mean $\pm$ SD	0.20 $\pm$0.19	0.16 $\pm$ 0.09	74.31 $\pm$ 12.59	70.54 $\pm$ 12.19	56.34 $\pm$ 17.49
Min - Max	0.02 - 0.61	0.03 - 0.27	49.05 - 93.33	45.04 - 90.26	2.26 - 77.85

continue...

...cont.

PSC/GAC/Sand					
Mean $\pm$ SD	0.33 $\pm$0.32	0.27 $\pm$ 0.18	67.82 $\pm$ 10.50	63.28 $\pm$ 14.95	52.43 $\pm$ 12.00
Min - Max	0.03 - 1.22	0.04 - 0.69	44.05 - 83.54	5.74 - 77.56	13.12 - 66.05
Anthracite/GAC/ Sand					
Mean $\pm$ SD	0.33 $\pm$0.31	0.26 $\pm$ 0.21	66.14 $\pm$ 13.12	62.25 $\pm$ 15.48	49.80 $\pm$ 12.79
Min - Max	0.01 - 1.12	0.08 - 0.79	29.79 - 96.08	4.92 - 76.09	6.51 - 61.13

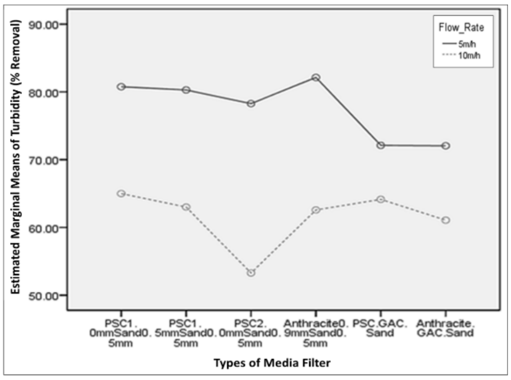

FIGURE 7. Interaction between filter media and flow rate for turbidity removal

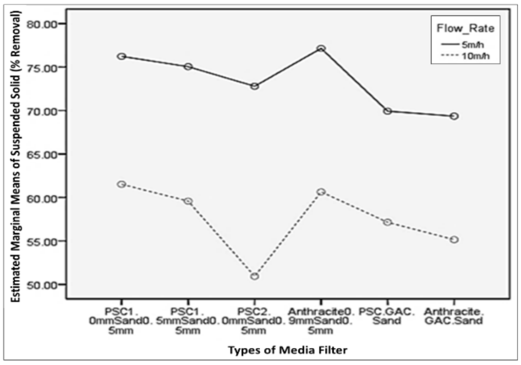

FIGURE 8. Interaction between filter media and flow rate for suspended solid removal

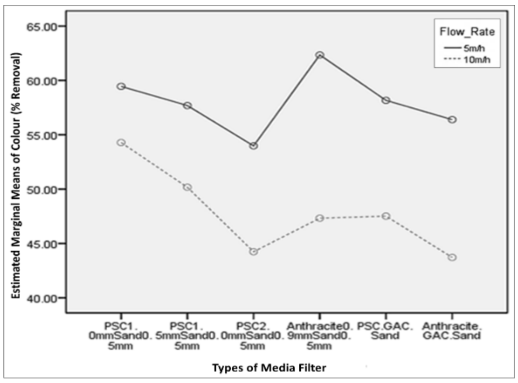

FIGURE 9. Interaction between filter media and flow rate for colour removal

Figures 10(a) and 10(b) shown PSC performance as dual- and tri-media filters treated the influent water with higher reduction, whereas the percentage of turbidity removal via dual-media filters using PSC/Sand: 1.0/0.5mm was 73.41%, and anthracite/sand: 0.9/0.5mm was 74.31%. Overall, using PSC as a filter medium resulted in greater turbidity reduction of influent water and demonstrated superior performance compared to anthracite, the standard filter medium in the worldwide water treatment industry.

REMOVAL OF SUSPENDED SOLID

The third characteristic evaluated is suspended solids. It was found the suspended solid content result in treated water was similar turbidity removal trend. The percentage reduction in suspended solids increased as the effective size of the media filter decreased at the same flow rate. Dual-media of PSC/sand with an effective size of 1.0/0.5 mm demonstrated a 69.36% reduction, compared to PSC/sand with an effective size of 2.0/0.5 mm, which resulted in a 62.59% reduction (Table 3). The percentage of removal also decreased when the flow rate was increased from 5 m/h to 10 m/h.This findings is in line with Acarer (2023) and Fajar et al. (2022) studies, where in fine-grain media produce better filtrate quality than coarse-grain media. Additionally, flow rates played a crucial role in the performance of granular media filtration. In this study, specifically, the physical removal variable (Table 4) showed that a flow rate of 5 m/h resulted in a higher percentage of reduction compared to 10 m/h at the same effective size value. This is due to a lower flow rate captures and traps suspended particles within more layers of the filter bed, removing larger amounts of suspended particles from the feed water.

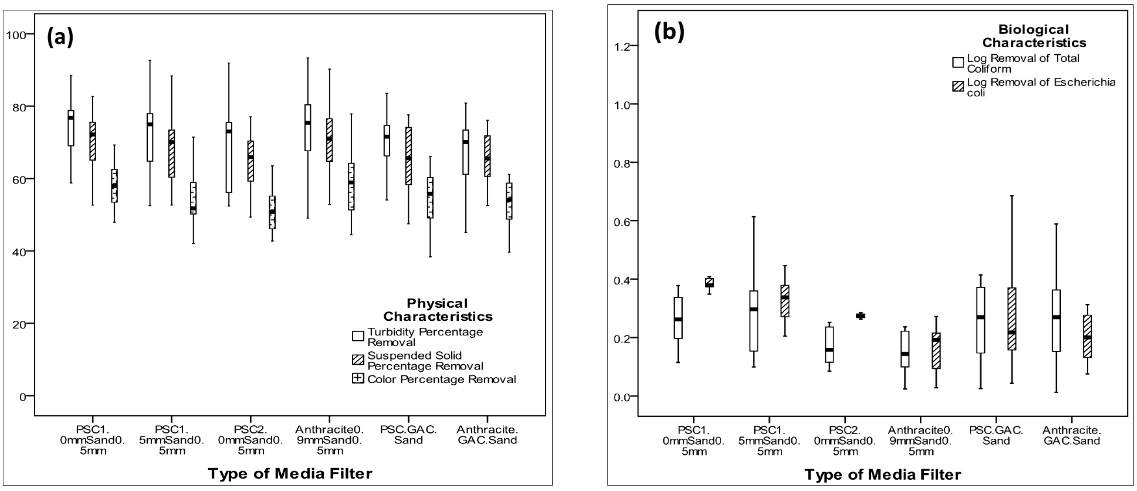

FIGURE 10. Filter media performance based on performance outcome of: turbidity % removal, suspended solid % removal and colour % removal (a), $\log_{10}$ total coliform and $\log_{10}$ E. coli (b)

REMOVAL OF COLOUR

Colour in the water samples was resulted by the decomposition of organic matter present in humic acid, where it is responsible for colouration and acidity issues in water sources (Aziz et al. 2007; Zouboulis et al. 2007). These findings align with the conclusions of prior research conducted by Alomar et al. (2023); (Hriciková et al. 2023). High turbidity and suspended solid water samples were treated by PSC.

The result in Table 3 indicated higher reduction in dual-media of PSC/sand: 1.0mm/0.5mm (57.04%) and this was compared to the commercial filter media, anthracite/sand: 0.9mm/0.5mm (56.34%) (Table 4). The combination of PSC/sand: 1.0mm/0.5mm filter media exhibited the best result for colour removal. Overall, higher colour removal was obtained via dual-media filtration, followed by tri-media filtration and the phenomenon was same for both flow rates of 5 and 10 m/h (Table 4).

REMOVAL OF BIOLOGICAL CONTAMINANT

The removal efficiency of total coliform by different filter media is summarized in Table 4 and Figure 10(a) and 10(b), showing the viable count of total coliform bacteria removed through granular filtration in both dual-media and tri-media filters. Significant levels of total coliform bacteria were detected in both the influent and effluent water samples.

During filtration, dual-media filters using PSC/sand with an effective size (ES) of 1.0/0.5 mm achieved a removal rate of Mean ± SD = 0.3008 ± 0.1802, while tri-media filters using PSC/GAC/sand and anthracite/GAC/sand achieved removals of Mean ± SD = 0.3303 ± 0.3200 and 0.3282 ± 0.3082, respectively (Table 3). The most significant coliform removal occurred with tri-media filtration, followed by dual-media filtration. The results indicated that PSC in mixed media outperformed the commercial anthracite medium.

Additionally, it was observed that total coliform removal can be influenced by the operational conditions during the assessment. The study suggested that dual-media filtration may allow a higher passage of total coliforms compared to tri-media filters during the filtration cycle. The enhanced removal in tri-media filters could be attributed to the increased depth and optimized combination of filter media, particularly with PSC/GAC/sand (ES 1.0/0.89/0.5 mm).

TABLE 4. Presents the significant value of filter performance ($p < 0.05$)

Type of analysis	Variable	Performance outcome				
		Log_{10} Total coliform	Log_{10} *E. coli*	Turbidity (%)	Suspended solid (%)	Colour (%)
		p-value	p-value	p-value	p-value	p-value
2-factor analysis (two-way anova)	Type of Media Filter	0.794	0.019	0.000	0.000	0.000
	Flow rate 5 and 10 m/h	0.630	0.320	0.000	0.000	0.000
	Type of Media Filter * Flow rate	0.536	0.479	0.000	0.013	0.040

The difference in total coliform removal depended on the type of filter media used. The study underscores the importance of precise experimental operations and suggests further research is needed to explore the removal of bacteria and other pathogens. Contrary to some literature, this study found that the type of filter media whether dual- or tri-media did not significantly affect microorganism removal, as the differences in removal efficiency between these filters were minimal during the filtration process (Emelko 2003).

E. coli removal by dual-media and tri-media filters is summarized in Table 3 and Figure 10(a) and 10(b). The dual-media filter using PSC/sand (ES 1.0/0.5 mm) achieved the highest removal efficiency (Mean ± SD = 0.3740 ± 0.0843) during filtration, followed by the tri-media filter of PSC/GAC/sand (Mean ± SD = 0.2750 ± 0.1820). The findings indicate that the dual-media filter is an effective option for E. coli removal.

The effectiveness of bacterial removal was largely influenced by the choice of filter media and the effective sizes of the media, with the PSC combination with commercial filter media-anthracite and sand-providing the highest barrier against bacterial passage in this study. These results support the broader understanding that locally sourced PSC is advantageous for bacterial removal, reducing reliance on non-renewable and non-degradable materials.

On average, the combination of PSC with commercial media in both dual- and tri-media filters effectively removed total coliform and E. coli. The filtration process involved a straining mechanism in the upper bed depth, followed by an attachment process deeper in the bed. The combination of these processes was used as an indicator of bacterial removal efficiency in this study. One-way ANOVA analysis showed that E. coli removal via filter media filtration was significant ($p = 0.040$). The increase in removal efficiency correlated with the inclusion of PSC in mixed media filters, both dual- and tri-media. Additionally, two-way ANOVA analysis revealed that while E. coli removal was not significantly affected by flow rate, it was highly significant with respect to the type of filter media used.

CONCLUSION

The performances of PSC as a new filter medium in removing physical and biological contaminants were evaluated along with its physical characteristics (SG of 1.3, porosity of 0.49, and ball-pan hardness of 97.30%) under conventional deep bed filtration. Under optimum condition, the dual-media filtration of PSC/sand ES 1.0/0.5 mm performed better in removing 73.41% of turbidity, 69.36% of suspended solid, 57.04% of colour, and 0.37 log of bacteriological removal of E. coli, while PSC/GAC/sand demonstrated the highest bacteriological removal of 0.33 log in total coliform.

Besides, there were statistically significant differences between the types of media filters to the physical removal, and flow rate with $p < 0.05$ under one-way anova and two-factor analysis of variance. Thus, the PSC offer advantages as this material is abundantly available, easy to maintain and economically reduces water treatment and raw material costs, as well as enhances environmental sustainability.

For future studies, the performance of PSC as granular medium filter in specifically for the removal of microorganisms needs to be established under filtration with direct filtration, in-line filtration and pre-chemical treatment process (coagulation-flocculation and sedimentation). This is an important measurement criterion for PSC as an emerging granular filter medium to act as a barrier for one of the greatest health risk management challenges in drinking water supplies, especially water related diseases.

ACKNOWLEDGEMENT

The author would like to express gratitude to the Universiti Teknologi MARA (UiTM) Cawangan Jengka, Pahang for their support. Additionally, the authors would like to thank Universiti Teknologi MARA (UiTM) Shah Alam, Selangor for providing facilities for conducting this research.

DECLARATION OF COMPETING INTEREST

None.

REFERENCES

Acarer, S. 2023. Abundance and characteristics of microplastics in drinking water treatment plants, distribution systems, water from refill kiosks, tap waters and bottled waters. *Science of the Total Environment* 884:163866.

Ali, A. N. A., Bolong, N., & Taha, N. A. 2021. A review on the application of granular filter media and the utilization of agro-industrial wastes for stormwater quality improvement. *Jurnal Teknologi* 83(4): 75-90.

Alomar, T., Qiblawey, H., Almomani, F., Al-Raoush, R. I., Han, D. S., & Ahmad, N. M. 2023. Recent advances on humic acid removal from wastewater using adsorption process. *Journal of Water Process Engineering* 53: 103679.

APHA, AWWA, & WEF. 2023. *Standard methods for the examination of water and wastewater*, American Public Health Association.

ASTM. 2023. Astm D3802-23 : Standard Test Method for Ball-Pan Hardness of Activated Carbon. In ASTM D3802-23: 4.

Aziz, H. A., Alias, S., Adlan, M. N., Asaari, A., & Zahari, M. S. 2007. Colour removal from landfill leachate by coagulation and flocculation processes. *Bioresource Technology* 98(1): 218-220.

Baig, S. A., Mahmood, Q., Nawab, B., Shafqat, M. N., & Pervez, A. 2011. Improvement of drinking water quality by using plant biomass through household biosand filter–a decentralized approach. *Ecological Engineering* 37(11): 1842-1848.

Bhakta, J. N., Rana, S., Lahiri, S., & Munekage, Y. 2017. Sorption of mercury onto waste material derived low-cost activated carbon. *Applied Water Science* 7: 199-206.

Budari, N., Ali, M., Kassim, J., & Omar, S. 2013. Burnt oil palm shell filter media for bacterial removing by single-and dual-media filtration. *Proceeding-2013 IEEE Business Engineering and Industrial Applications Colloquium (BEIAC)*.

Budari, N. M., Ali, M. F., & Kassim, J. 2014. Physical contaminants removal from continuous process of water filtration by a new low-cost palm shell charcoal. *Advanced Materials Research* 911: 397-404.

Castillo-Torres, K. Y., McLamore, E. S., & Arnold, D. P. 2019. A high-throughput microfluidic magnetic separation (Mfms) platform for water quality monitoring. *Micromachines* 11(1): 16.

Cescon, A., & Jiang, J. Q. 2020. Filtration process and alternative filter media material in water treatment. *Water* 12(12): 3377.

Chang, H., Yu, H., Li, X., Zhou, Z., Liang, H., Song, W., Ji, H., Liang, Y., & Vidic, R. D. (2022). Role of biological granular activated carbon in contaminant removal and ultrafiltration membrane performance in a full-scale system. *Journal of Membrane Science* 644: 120122.

Clements, M. 2004. Changes in the mechanical behaviour of filter media due to biological growth, Doctoral Thesis, University of Johannesburg.

Crittenden, J. C., Hand, D. W., Howe, K. J., Trussell, R. R., & Tchobanoglous, G. 2012. *Mwh's Water Treatment: Principles and Design*, Third Edition.

Diaz, V. J. M., Nakayo, J. L. J., & Alfaro, E. B. 2018. Use of coffee grind with cocoa shell as the basis for a filter to reduce lead from contaminated water from a river, Peru. *Journal of Energy & Environmental Sciences* 2(2): 24-29.

Emelko, M. B. 2003. Removal of viable and inactivated cryptosporidium by dual-and tri-media filtration. *Water Research* 37(12): 2998-3008.

Environmental Quality Report 2020, National Water Quality Standards for Malaysia. 2024. https://www.doe.gov.my/en/national-river-water-quality-standards-and-river-water-quality-index/

Fajar, M., Sembiring, E., & Handajani, M. 2022. The effect of filter media size and loading rate to filter performance of removing microplastics using rapid sand filter. *Journal of Engineering & Technological Sciences* 54(5).

Feriyanto, D., Noviyanto, A., & Alva, S. 2024. Physical properties analysis of rubber seed shell activated carbon as alternative media for bio-air and water filter. *Rasayan Journal of Chemistry* 17(1).

Gao, M. 2012. Genetical and physiological studies of Photocatalytic Disinfection of Escherichia Coli, Doctoral Thesis, Chinese University of Hong Kong.

Hach. (2014). *Suspended Solid Photometric Method (9th ed.)*. Hach Company/ Hach Lange GmbH.

Hriciková, S., Kožárová, I., Hudáková, N., Reitznerová, A., Nagy, J., & Marcinčák, S. (2023). Humic substances as a versatile intermediary. *Life* 13(4): 858.

Jusoh, A., Nora'aini, A., Halim, A., & Norsani, W. 2009. Effective depth, initial head loss and backwashing criteria as the key factors of burned oil palm shell (Bops) granular filtration. *Desalination and Water Treatment*, 10(1-3): 80-86.

Malaysian Palm Oil Board. 2024. *Production of Palm Kernel for the of December 2023*. https://bepi.mpob.gov.my/index.php/production/301-production-2023/1137-production-of-palm-kernel-2023

McIntyre, H. M., & Hart, M. L. 2021. Photocatalytic porous silica-based granular media for organic pollutant degradation in industrial waste-streams. *Catalysts* 11(2): 258.

Nasrizal, A. A., Farzana, W., Saad, I., & Bolong, N. (2023). Carbonized coconut shell media applicability for stormwater pollution control. *LARHYSS Journal* 2521-9782(54): 43-52.

Okeke, B. C., Thomson, M. S., & Moss, E. M. 2011. Occurrence, molecular characterization and antibiogram of water quality indicator bacteria in river water serving a water treatment plant. *Science of the Total Environment* 409(23): 4979-4985.

Parsons, S., & Jefferson, B. 2006. Introduction to potable water treatment processes. https://onlinelibrary.wiley.com/doi/abs/10.1002/9781444305470.fmatter

Qiu, G., & Guo, M. 2010. Quality of poultry litter-derived granular activated carbon. *Bioresource Technology* 101(1): 379-386.

Richard, O., & Mines, J. 2014. *Environmental Engineering: Principles and Practice*. John Wiley & Sons.

Sawant, N., Pathan, D., Pawase, A., Tibile, R., & Desai, P. 2020. *Maturation of Different Filter Media Using Culture Water*.

Taha, N. A., Ali, A. N. A., Aziz, A. A. A., & Bolong, N. 2022. Comparison of selected agro-based filter media for stormwater quality improvement. *International Journal of Integrated Engineering* 14(1): 251-259.

Williams, G. J., Sheikh, B., Holden, R. B., Kouretas, T. J., & Nelson, K. L. (2007). The impact of increased loading rate on granular media, rapid depth filtration of wastewater. *Water Research* 41(19): 4535-4545.

Xie, Z., Wang, S., & Shen, Y. 2022. Particle-scale modelling of rapid granular filtration in a dual-media filter. *Separation and Purification Technology* 302: 122076.

Zouboulis, A., Traskas, G., & Samaras, P. 2007. Comparison of single and dual media filtration in a full-scale drinking water treatment plant. *Desalination* 213(1-3): 334-342.