

The removal efficiency of total coliform, *Escherichia coli*, suspended solids, UV₂₅₄ and colour using Zeliac filter in riverbank filtration system

Hamidi Abdul Aziz, Nurazim Ibrahim, Motasem Y. D. Alazaiza and Cheong Kah Win

ABSTRACT

Addition of composite adsorbent Zeliac to a riverbank filtration system can enhance the removal of micropollutants in polluted river water. This paper aims to investigate the potential use of Zeliac to remove pollutants, such as total coliform, *Escherichia coli*, suspended solids (SSs), UV₂₅₄ and colour, from the Sungai Kerian River. Two columns filled with Zeliac of different granular sizes were established and continuously run for 15 days. Maximum SS removals of 93% and 98% were recorded for Zeliac with granular sizes of 1.18–2 mm and 0.42–0.6 mm, respectively. Meanwhile, 99%–100% of total coliform was removed from the system, and no *E. coli* was detected in the effluent up to 15 h of the experiments. High removal efficiencies were also recorded for UV₂₅₄ (>80%) and colour (>90%). Granular size showed no significant effect on the removal of the selected parameters, especially total coliform and *E. coli*. Zeliac showed good potential as an adsorbent to improve water treatment.

Key words | adsorption, bio-colloid, composite adsorbent, filter media

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INTRODUCTION

Malaysia is drained by a dense network of rivers and streams. The total internal water resources of Malaysia are estimated to be 580 km³ annually (Food and Agriculture Organization of the United Nations 2011). According to the data published by the Malaysian Department of Irrigation and Drainage (DID) (2016), more than 90% of the drinking water supply in Malaysia originates from river water. However, sources of river water are not properly protected. Continuous urbanisation and industrialisation have resulted in severe water pollution, especially to water bodies located near urban areas. Klang and Labu Rivers in Selangor are the best examples of frequently polluted rivers as a result of the rapid urbanisation (Hasan *et al.* 2011). Sources of pollution

originate from a point or non-point sources, such as domestic discharges, industrial discharges, urban storm water, waste dumping and sediments from construction sites (DOE 2015). These sources have contributed to the rise of organic contaminants, inorganic contaminants, temperature and pathogens in natural water bodies. In Malaysia, the water supply is typically treated by conventional treatment systems consisting of several treatment processes, such as pre-chlorination/oxidation, coagulation, flocculation, sedimentation, filtration and chlorination. However, these methods are only suitable and cost-effective for water under Classes I and II in the National Water Quality Standards (NWQS) of Malaysia (Zainudin 2010). Hence, an

alternative treatment process which offers an effective and economical removal of various types of pollutants is necessary.

Among economically feasible water treatment techniques, river bank filtration (RBF) has been recognised as an economical and sustainable method for treating heavily polluted river water (Sandhu *et al.* 2016). RBF is a water treatment technology that extracts water from rivers by pumping wells in adjacent alluvial aquifers (Jaramillo 2012). RBF can be classified into natural and forced RBFs. In natural RBF, percolation occurs because of the head difference or hydraulic gradient between the river water and groundwater (Caldwell 2006). Under forced RBF, the effective stress is generated from the pumping action of pumping wells, and river water is bound to enter the soil matrix (Ojha & Thakur 2010). Water contaminants are attenuated because of a combination of processes, such as filtration, biodegradation, sorption to sediments and aquifer sand and dilution with background groundwater. The performance of RBF in improving water quality depends on key factors, such as source water quality, temperature, predominant redox conditions in the aquifer, capability of the indigenous microbial community and aquifer properties (Grünheid *et al.* 2005). RBF exhibits high efficiency in removing biological contaminants when the groundwater velocity is low and the aquifer consists of small granular materials with high surface contact. The amount of organic micropollutants can be reduced or even eliminated during aerobic and anaerobic underground passages (Maeng *et al.* 2009; Mueller *et al.* 2010). The attenuation process is extremely dependent on the underlying redox processes in an RBF system (Schmidt *et al.* 2004). Moreover, pathogenic microorganisms can migrate long distances, that is, from 1 m to 450 m, in different types of soil (Gerba *et al.* 1975; Stewart & Reneau 1981). Migration of pathogens leads to groundwater contamination and waterborne disease outbreak (Graun 1985; Efstratiou *et al.* 2017). Therefore, the performance of an RBF may be enhanced by adjusting or improving this process using other techniques.

The objective of this study is to investigate the application of adsorbent media as packing materials and as a final barrier to RBF. Thus, a fixed-bed column study was conducted to determine the potential of Zeliac as the composite adsorbent in an RBF system. Zeliac is a composite

adsorbent made from the combination of a low-cost adsorbent, such as zeolite, limestone, rice husk carbon and coconut shell carbon, and ordinary Portland cement (OPC) as a binder. Halim *et al.* (2010a) and Mojiri *et al.* (2014) showed that Zeliac exhibits hydrophobic and hydrophilic surfaces which facilitate its adsorption of organic and inorganic pollutants. Natural zeolite characteristics, such as high cation exchange capacity, cation selectivity, higher void volume and remarkable affinity for NH_4^+ , were retained in Zeliac. The anions within the pores are neutralised by cations, such as sodium, potassium and calcium (Rožić *et al.* 2000). These cations are exchangeable with certain heavy metal cations in solutions, such as lead, cadmium, zinc and manganese (Barrer 1987). Wang & Peng (2010) showed that natural zeolite typically exhibits high adsorption of heavy metals and ammonia but not anions and organics. However, the hydrophobic characteristics of Zeliac are inherited from activated carbon. Activated carbons are widely used to remove organic pollutants, because of the oxygen-containing functional groups, such as carboxylic acid in the former that can form hydrogen bonds (Yousef *et al.* 2011). The effectiveness of activated carbon has been proved in a study in which organic (COD, phenols and colour) and inorganic ($\text{NH}_3\text{-N}$ and metals) compounds were successfully removed from leachate and wastewater (Halim *et al.* 2010a; Mojiri *et al.* 2014). However, this porous medium has not been explored yet for drinking water treatment. Therefore, the removal of several parameters related to water quality for drinking water was tested to examine the potential of Zeliac in RBF system application. The ability of Zeliac to remove organic and inorganic contaminants makes it valuable to be tested as an alternative medium/adsorbent to enhance RBF performance.

MATERIALS AND METHODS

Adsorbent (Zeliac) preparation

The Zeliac composite materials consisted of 45.94% zeolite, 15.31% limestone, 4.38% activated carbon and 4.38% rice husk carbon. These materials were mechanically mixed together with ordinary Portland cement (30%) which acts

as a binder (Halim *et al.* 2010a). The materials were mixed, and 50% (by weight) of water was added to produce slurry. The mixture was poured into a $5 \times 5 \text{ cm}^2$ mould and allowed to harden for 24 h followed by curing. After 3 days of curing, the composite medium was air dried before being crushed and sieved with sieves that complied with ASTM E11-15 to produce Zeliac with different sizes (1.18–2.0 and 0.425–0.6 mm). Standard sieve analyses were conducted on the Zeliac samples. For particle size 0.425–0.6 mm, the measured effective size d_{10} and d_{60} was 0.4308 mm and 0.520 mm, respectively, and the uniformity coefficient, d_{60}/d_{10} was 1.2. For particle size 1.18–2.0 mm, the measured d_{10} and d_{60} was 1.16 mm and 1.58 mm, and the uniformity coefficient, $d_{60}/d_{10} = 1.36$. Both sizes are considered as uniformly graded with d_{60}/d_{10} value less than 4. Distilled water was used to wash the Zeliac to remove impurities. After cleaning, Zeliac was oven-dried (105°C) for 24 h to remove all moisture content before the adsorbent was stored in an airtight container for later use. The chemical composition of Zeliac was determined using X-ray fluorescence (XRF). The results indicated that Zeliac mainly encompasses 55.1% silicon (Si), 29.8% calcium (Ca), 8.7% aluminium (Al) and 2.5% iron oxide (Fe_2O_3). The multi-point BET, total pore volume and average pore diameter of the zeolite as determined by the BET instrument (Model Autos orb[®]-1 Series Quanta Chrome Instrument) are $33.12 \text{ m}^2/\text{g}$, 0.1643 cc/g and 19.81 nm , respectively, for particle size 1.18–2.0 mm, and $40.56 \text{ m}^2/\text{g}$, 0.1698 cc/g and 16.74 nm , respectively, for particle size 0.425–0.6 mm.

River water sampling

Water samples were collected from Sungai Kerian, Lubuk Buntar, which is located in Kedah, Malaysia. The area is surrounded by oil palm plantations and located near to housing communities/villages. This river provides potable water to the residents of this area. Four sampling sessions were performed during the 15-day filtration period. The sampling point was located at approximately 3 m from the riverbank. A rod was inserted down into the river bed, and a water pump was placed at the middle of the wetted portion of the rod. Thus, the river water was collected at the mid-depth of the river. The water was then pumped and collected in 100-L and 25-L volume plastic containers. The water

samples were then immediately transferred to the laboratory and stored in a cold room at 4°C for subsequent column studies to characterise the river water.

River water characterisation

The river water from Sungai Kerian was characterised using *in situ* and laboratory techniques to determine the water quality from this river. The parameters measured *in situ* using YSI Pro Plus Multiparameter Probe included temperature, dissolved oxygen (DO), total dissolved solids (TDS), pH and conductivity. The parameters tested in the laboratory included true colour, ammoniacal nitrogen ($\text{NH}_3\text{-N}$), UV_{254} , dissolved organic carbon (DOC), chemical oxygen demand (COD), suspended solids (SS) and TDS in accordance with the *Standard Methods for the Examination of Water and Wastewater* (APHA 2005). Meanwhile, total coliform and *E. coli* were determined by IDEXX Colilert test kit. The concentration of turbidity was measured by turbidimeter (model 2100 Q) while DR6000 UV-Vis spectrophotometer was employed for colour, UV_{254} and DOC determinations. Samples of water for these parameters (colour, UV_{254} and DOC) were pre-filtered with a $0.45 \mu\text{m}$ nylon syringe filter from Whatman as soon as the sample arrived in the laboratory. The concentrations of UV_{254} and DOC were measured based on the US EPA method 415.3.

Fixed-bed column set-up and experiment

Fixed-bed columns were established to evaluate the removal of contaminants in water samples using Zeliac. Two 1-L volume plastic measuring cylinders with 6.1-cm inner diameter were modified and used as columns. The columns were separately packed with 1.18–2 mm and 0.425–0.600 mm of Zeliac granules and designated as Columns A and B, respectively. Table 1 summarises the major parameters for both columns. Plastic net and glass wool were applied at the inlet and outlet of the columns to prevent the Zeliac particles from entering the tubing. Both columns were filled with Zeliac up to 34 cm high.

Given the difference in empty volume V_ϵ of the Zeliac with different sizes, distinct flow rates are required to achieve similar hydraulic loading rate (HLR) of 1 cm/min to establish kinematic similitude with the pumping well in

Table 1 | Column adsorption parameters

Parameters	Unit	Column A	Column B
Size of Zeliac	mm	1.18–2	0.425–0.6
Diameter, D	cm	6.1	6.1
Cross-sectional area, A	cm ²	29.2	29.2
Adsorbent height, h	cm	34.0	34.0
Adsorbent volume, V	cm ³	993.6	993.6
Empty volume percentage, ε	%	63.0	65.0
Empty volume, $V\varepsilon$	cm ³	625.6	646.0
Effective cross-sectional area, A_{eff}	cm ²	18.4	19.0
Flow rate, Q	mL/min	18.4	19.0
Empty bed contact time, EBCT, $V\varepsilon/Q$	min	34.0	34.0
Hydraulic loading rate, HLR, Q/A_{eff}	cm/min	1.0	1.0

Lubuk Buntar. The velocity of groundwater movement measured by a colloidal bore scope was 1.014 cm/min, which is approximately 1 cm/min. Therefore, river water was pumped in the upflow mode into the column at a volumetric flow rate of 18.4 mL/min in Column A and 19.0 mL/min in Column B. The headloss was minimum and the flow rate was constant at the effluent. The empty volume for each Zeliac size was determined by adding water into a beaker containing a specific volume of Zeliac. Therefore, the volume of water V_w filling the empty volume was equal to the empty volume $V\varepsilon$ of Zeliac:

$$V_w = V\varepsilon \quad (1)$$

The empty bed contact time (EBCT) was calculated as follows:

$$EBCT = h/HLR \quad (2)$$

As it is known, there is a proportional relationship between the EBCT and the removal efficiency. In this study, we found that the EBCT for both Zeliac columns was similar. Therefore, we did not assess the Zeliac removal in terms of EBCT.

The flow rate Q was calculated as follows:

$$Q = \frac{V\varepsilon}{EBCT} \quad (3)$$

Glass wool acts as the buffer to prevent turbulent flow at the inlet and ensure uniform distribution of colloidal materials in water entering the column.

The constant and steady flow rate was provided and maintained by peristaltic pumps (Masterflex L/S HV 07522-20) and connected with columns using chemical-resistant tubing (Masterflex Tygon E-LFL). Effluent or treated river water samples were collected at various time intervals up to 15 days for analyses. The schematic diagram of the column is shown in Figure 1.

Analytical test for influent and effluent water sample

The quality of water samples collected at the influent and effluent of the column were evaluated based on the following parameters: particle size, total coliform, *E. coli*, TDSs, SSs, UV₂₅₄ and colour. The pH level was also tested to determine the effect of Zeliac on the pH of water flowing through it. The test was conducted using the Colilert method (Vergine et al. 2017).

RESULTS AND DISCUSSIONS

Characteristics of the river water

Information on the quality of the river water is the key to determine the range of pollutants and extent of treatment needed to meet the required quality for drinking water. Table 2 summarises the average values obtained from the experimental columns. The results showed that Sungai Kerian had high SS and total coliform contents with mean values of 62 mg/L and 1.4×10^4 MPN/100 mL, respectively. Thus, water from this river should be treated to make the water fit for drinking and daily use. Ammonia-N level in the river water was classified as Class III (NWQS) but within the recommended concentration for raw water quality and drinking water standard set by the Ministry of Health (MOH) of Malaysia. The presence of natural organic matter (NOM) in the river water was also measured. High levels of NOM in water will affect the performance of water treatment plants at different stages of water treatment processes. Previous studies showed that

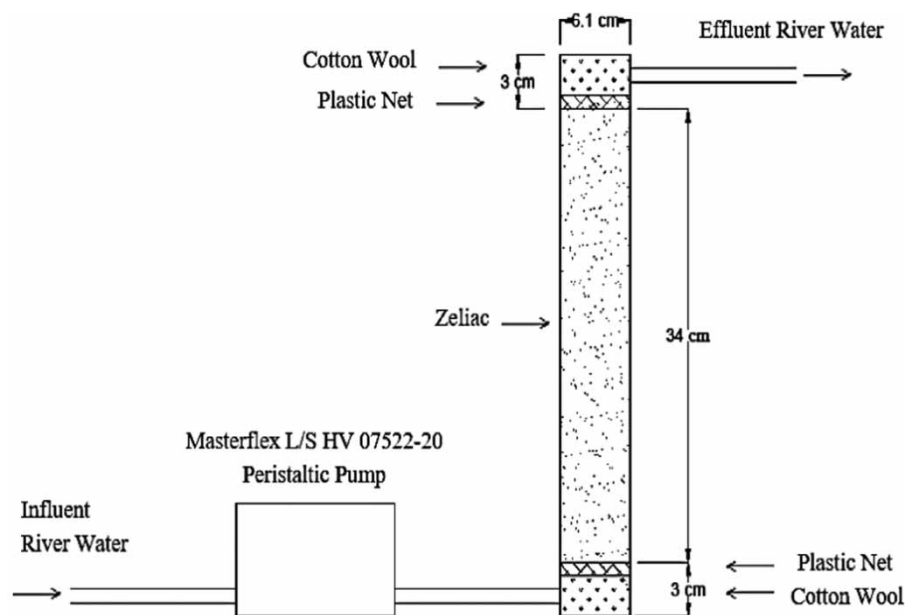


Figure 1 | Schematic diagram of the column used.

Table 2 | River water characteristics

Parameters	Units	Values Min.	Standards Max.	Mean	NWQS	Recommended raw water quality	Drinking water quality
Temperature	°C	30.3	31.6	30.8	–	–	–
DO	mg/L	4.5	5.6	5.2	Class IIA	NA	NA
TDS	mg/L	22.8	26.0	24.4	Class I	1,500	1,000
pH	–	6.65	7.87	6.98	Class I	5.5–9.0	6.5–9.0
Conductivity	µS/cm	38.8	45.3	41.9	Class I	–	–
Colour	Pt-Co	36	45	39	Class IIA	300	15
NH ₃ -N	mg/L	–	–	0.95	Class IV	1.5	1.5
UV ₂₅₄	cm ⁻¹	0.088	0.107	0.094	–	NA	NA
DOC	mg/L	–	–	3.1	–	NA	NA
COD	mg/L	–	–	10	Class I	10	–
SS	mg/L	39	92	62	Class III	Nil/100 mL	–
Turbidity	NTU	68	72	70	–	150	30
Total coliforms	MPN/100 mL	12,342	14,136	13,239	Class III	Nil/100 mL	0
<i>E. coli</i>	MPN/100 mL	47	92	67	–	Nil/100 mL	0

NOM will react with coagulants, causing an increase in coagulant demands to achieve effective removal of turbidity (Yan *et al.* 2008; Matilainen & Sillanpää 2010). During disinfection, NOM also reacts with disinfectants, and this process leads to higher dosage requirement (Crittenden *et al.* 2012).

However, the more crucial problem is the possible formation of harmful disinfectant by-products (DBPs) (Krasner *et al.* 2006). In this study, NOM as UV₂₅₄ (0.094 cm⁻¹) and DOC (3.1 mg/L) exhibited moderately high concentrations typically obtained in river water (Croue *et al.* 2000; Gibert *et al.* 2015). The concentration of total organic

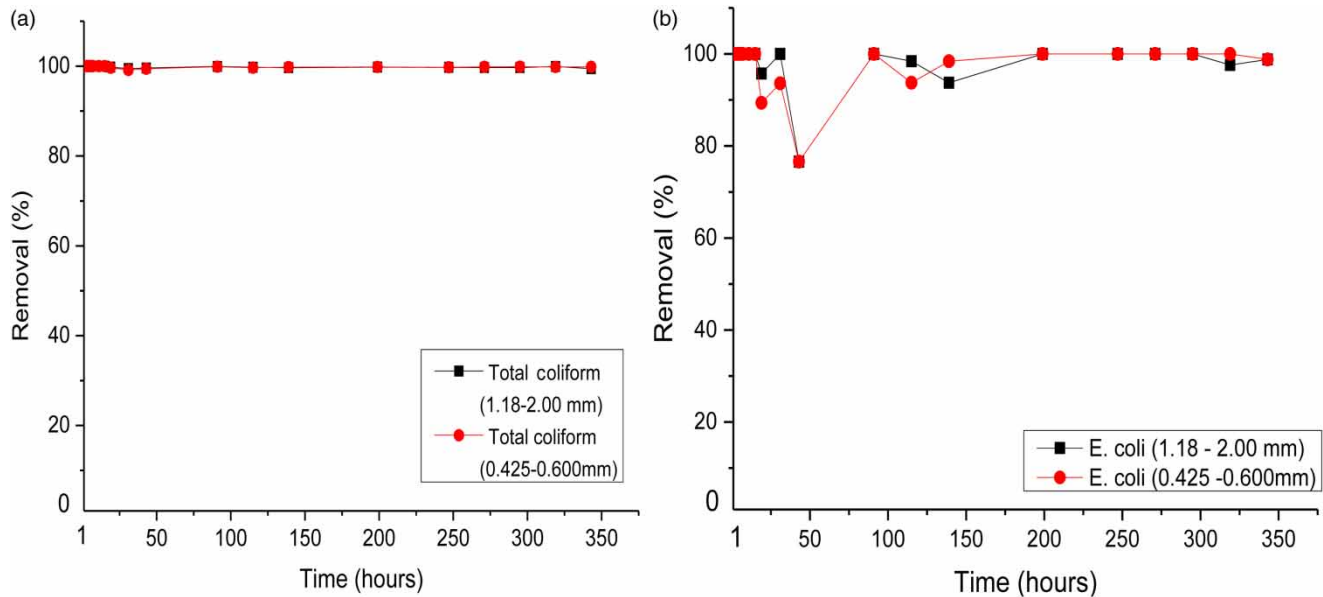


Figure 2 | Removal efficiency of (a) total coliform and (b) *E. coli* using Zeliac with different particle sizes.

carbon in water is not regulated but suggested to be lower than 2 mg/L by US EPA (Edzwald & Tobiasson 1999). UV₂₅₄ represents the compounds with double bonds, such as aromatic substances (Matilainen & Sillanpää 2010) and reported as the main precursor for generating DBPs (Richardson *et al.* 2007). Therefore, NOM compounds should be eliminated prior to the disinfection process.

Removal efficiency of selected parameters by Zeliac

Figure 2(a) shows the removal efficiency of total coliform as percentage removal after passing through the porous medium Zeliac.

The removal efficiency was assessed with time change for both Zeliac particle sizes in order to show the influence of the particle size of Zeliac on the removal efficiency. The results exhibit the constant removal of total coliform from the first day until day 15. However, no significant difference in the performance was observed between the two grain sizes. A similar range of removal (99% to 100%) was observed in both columns. This outcome indicated that the different grain sizes of Zeliac had no significant effect on the removal efficiency of total coliform. Thus, size of Zeliac is not the main factor that determined the removal of total coliform in this study.

A similar pattern was observed for *E. coli* removal. Based on the colloidal removal in a granular media filter, several mechanisms, such as interception, straining, flocculation, sedimentation, adhesion, adsorption and/or biological growth, may be involved throughout the filtration process depending on the properties of the filter bed (e.g., porosity and grain size) and operating condition (e.g., filtration rate) (Keller & Auset 2007; Tufenkji 2007; Crittenden *et al.* 2012). Figure 2(b) shows that no *E. coli* was detected in the effluent from both columns until 15 h of the experiment. The grain size of the porous medium plays an important role in removing bacteria, that is, smaller grain size will create smaller pore size of bed filter. Pore size smaller than the bacterial cell size will facilitate the elimination of bacteria through physical straining (Stevik *et al.* 2004). The cumulative distribution showed that 90% of Zeliac in Column A and Column B were <2 mm and <0.586 mm in diameter, respectively. However, the large difference in grain size distribution of Column A and Column B served no significant differences in the removal efficiency recorded between Column A (1.18–2 mm) and Column B (0.425–0.6 mm). This result indicates that the main removal mechanism of *E. coli* by Zeliac in the first 15 h was not controlled by physical straining. Instead, the removal mechanism of *E. coli* was governed by adsorption

and adhesion. According to Bradford *et al.* (2002), for small particles or colloid materials, such as bacteria (0.1–10 µm), smaller than that of the filter medium pore size, attachment becomes the more important mechanism to be considered instead of straining. However, the possibility of *E. coli* attachment on Zeliac pore space can be ruled out since the average pore diameter of Zeliac (16.5 nm) is smaller than that of *E. coli* diameter (0.1–10 µm). Mahmood *et al.* (2011) and Elliott *et al.* (2015) suggested adsorption as an important mechanism responsible for *E. coli* removal. Adsorption of bacterial cells to the porous medium was probably influenced by the organic matter, degree of biofilm development and electrostatic attraction caused by the ionic strength of the solution or electrostatic charges of cell and particle surfaces (Stevik *et al.* 2004).

Under this experiment, *E. coli* is expected to carry net negative charges at the pH of the column test (range 7–8.3). This fact is supported by Elliott *et al.* (2008) who reported that *E. coli* in the mentioned pH range is negatively charged. Thus, it has a high tendency of electrostatic interactions with opposite charge of particle surface. Zeliac surface mainly consists of SiO₂ (38.1%), CaO (24.7%), Al₂O₃ (5.8%), Fe₂O₃ (1.5%), K₂O (0.9%) and MgO (0.7%). The presence of Al and Fe oxyhydroxide that carry a positive charge at near neutral pH could adsorb *E. coli* that are negatively charged. Although enhanced bacteria reduction due to metal oxides is possible, it is likely to be short-lived and sensitive to feed water quality (Elliott *et al.* 2015) because the presence of dissolved organic matter commonly found in surface water is reported to block the metal oxide sites that can sorb *E. coli* (Foppen *et al.* 2008).

E. coli was detected in the effluent after 19 h of continuous inflow of river water. The concentration of *E. coli* in the effluent continued to increase until day 4 (91 h) with 23.4% of *E. coli* present, but started to decrease afterwards. From day 6 to day 15, the removal percentage was maintained at 99%–100%. It seems that the *E. coli* removal potential further increases due to the fact that the void area between the granules of the filter medium became smaller with time (Torkzaban *et al.* 2008) as a result of the SS or accumulation of larger colloidal particles (Stevik *et al.* 2004). Therefore, *E. coli* immobilisation through straining may occur at this time, thereby increasing the percentage removal. Previous studies (Bradford *et al.* 2005) have demonstrated that

colloids accumulate in the narrow region of the pore spaces near the contact of irregularly shaped porous media under unfavourable attachment conditions through X-ray microtomography study.

The efficiency of removing SS using Zeliac as filter medium is illustrated in Figure 3. Zeliac with smaller particle size ($D_{60} = 0.5$ mm) demonstrated slightly higher removal than that with large particles ($D_{60} = 1.5$ mm).

This phenomenon is due to the difference in pore sizes of the filter bed, in which the filter medium with smaller granular size having a smaller void is more effective for restraining SS from flowing through. This result shows that granular size is an important factor governing SS removal. In addition, turbidity is also related with SS where 1 mg/L (ppm) SS is equivalent to 3 NTU of turbidity. Benamar *et al.* (2007) suggested that removal of large colloid particles (>10 µm) is mainly influenced by hydrodynamics, gravity and inertial effects. Therefore, SS was mainly removed from the liquid phase through straining, flocculation, sedimentation or interception because the particle size of SS is usually heavy and larger than the pore size of the column bed (McDowell-Boyer *et al.* 1986). The graph in Figure 3 shows that the removal efficiency of Zeliac is nearly constant from day 2 to day 15 with percentage removals ranging between 90% and 98% for Zeliac with granular size of 0.425–0.6 mm and from 83% to 90% for the granular size of 1.18–2 mm. Zeliac with larger granular size demonstrated lower removal efficiency. The performance of filter bed

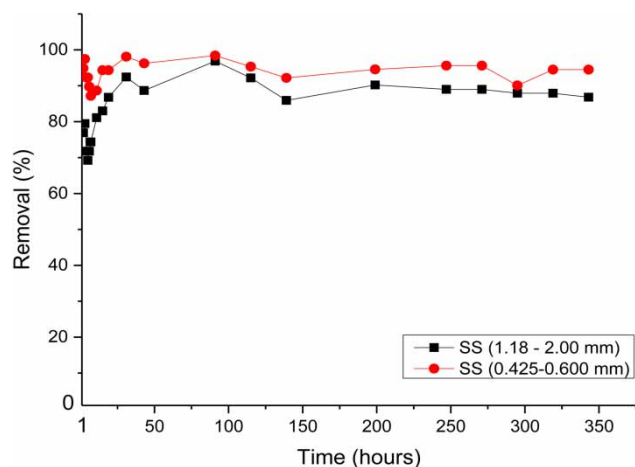


Figure 3 | Removal efficiency of SSS using Zeliac with different particle sizes.

slightly declined, because surface straining and interstitial removal leads to the accumulation of deposits in the filter medium at the influent (Torkzaban *et al.* 2008). The removal efficiency of pollutants was consistent during the 15 days of the experiment. No irregularity in data was observed, which indicates that a proportion of water from influent may form a channel and travel through preferential routes leaving some part of the bed without contact with contaminants. The reduced pore area resulted in increased velocity of water through the remaining voids. This process sheared off pieces of captured floc and carried impurities deeper into the filter bed. The effective zone of removal passed deeper and deeper into the filter. Turbulence and the resulting increased particle contact within the pores promote flocculation, resulting in the trapping of larger floc particles. Eventually, a clean bed depth was no longer available, and breakthrough occurred. This phenomenon results in the carrying of solids out in the underflow and causing termination of the filter run.

The microscopic particulate matter in raw water that has not been chemically treated typically passes through the relatively larger pores of a filter bed. The main removal mechanism for this type of pollutant is adsorption. High percentage removal (>80%) was observed for UV₂₅₄ and colour at the beginning of the experiment, but the removal continuously decreased as the filtration time increased as shown in Figures 4 and 5.

This condition fits well with the mass transfer zone theory, in which the clean filter bed was fully available to receive pollutants at the beginning of the experiment. However, the available adsorption zone eventually decreased with time and, finally, could not receive further pollutants (Sousa *et al.* 2010).

The variations were most likely due to the difference in the adsorption surface areas of the grains. Smaller particle size will provide larger surface area for the adsorption of sorbate. Approximately 50% of UV₂₅₄ and colour remained in the water for both columns after day 8. In a previous study (Halim *et al.* 2010b), we monitored that the column was exhausted during the experiments. Therefore, we regenerated the adsorptive materials in order to give good efficiency of removal during the experiments. The exhausted column was subjected to desorption to regenerate the composite adsorbent using a regeneration solution, which was composed of 0.5 M sodium chloride at pH 12 (adjusted using sodium hydroxide). To regenerate the column, the regeneration solution was pumped through the adsorbent in the up flow mode at a volumetric flow rate of 2 mL/min.

TDS is one of the parameters tested, because porous medium with high TDS content is not suitable for filtration in drinking water treatment. TDS recorded from the experimental data clearly demonstrated that the effluent concentrations of TDS (64–200 mg/L) in both columns were higher than that of the inlet concentration (26–27 mg/L).

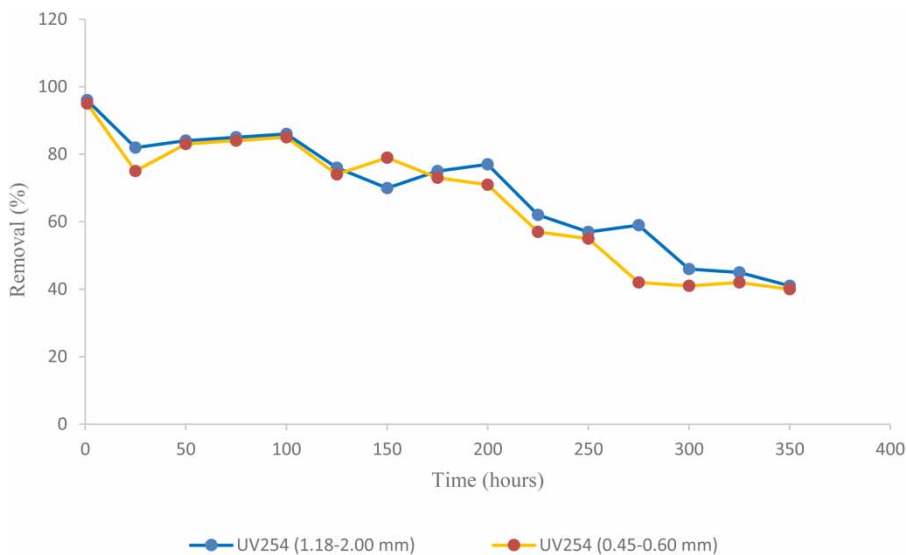


Figure 4 | Removal efficiency of UV₂₅₄ using Zealac with different particle size.

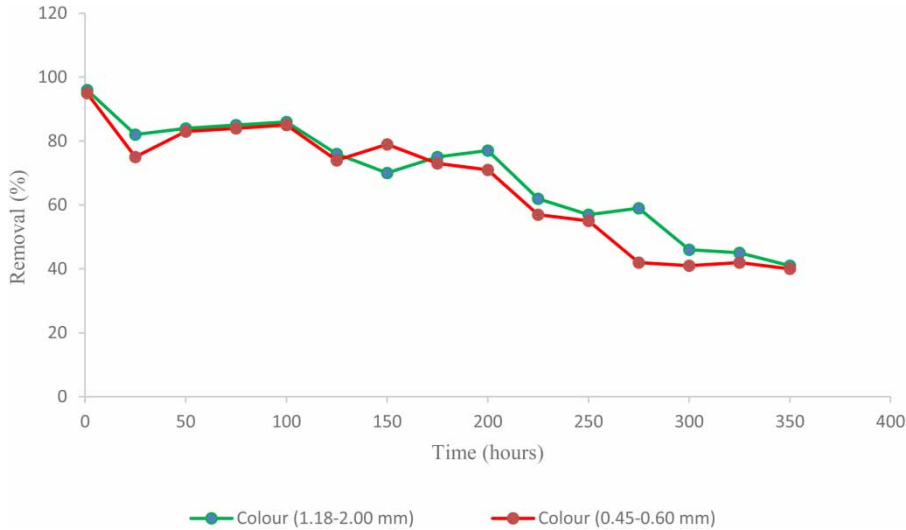


Figure 5 | Removal efficiency of colour using Zeliac with different particle size.

TDS is composed of inorganic salts and a small amount of organic matter. Thus, an elevation in TDS concentration indicates that dissolved compounds leached from the Zeliac. Previous studies reported that Zeliac contains high exchangeable cations (Halim *et al.* 2010a; Mojiri *et al.* 2014). Thus, high TDS in the effluent is a result of the dissolution of exchangeable cations, such as K^+ , Ca^{2+} and/or Mg^{2+} , in the Zeliac into the water. Although the TDS level in the effluent was higher than that of the river water fed into the column, the concentration did not exceed the permissible limit of 1,000 mg/L set by the MOH for drinking

water. In addition to TDS, dissolution of mineral elements from Zeliac into flowing water potentially elevated the pH water. Thus, pH was another important water quality parameter considered in this experiment. The permissible values of pH for drinking water are between 6.5 and 9.0 (MOH 2000). Figure 6 shows the pH levels of the influent and effluent from the fixed-bed column experiment.

The graph demonstrates that the pH of the influent was within pH 7.0–8.3, whereas that of the effluent increased to approximately pH 9. The increase in pH in the effluent could be related to the presence of minerals, such as Ca

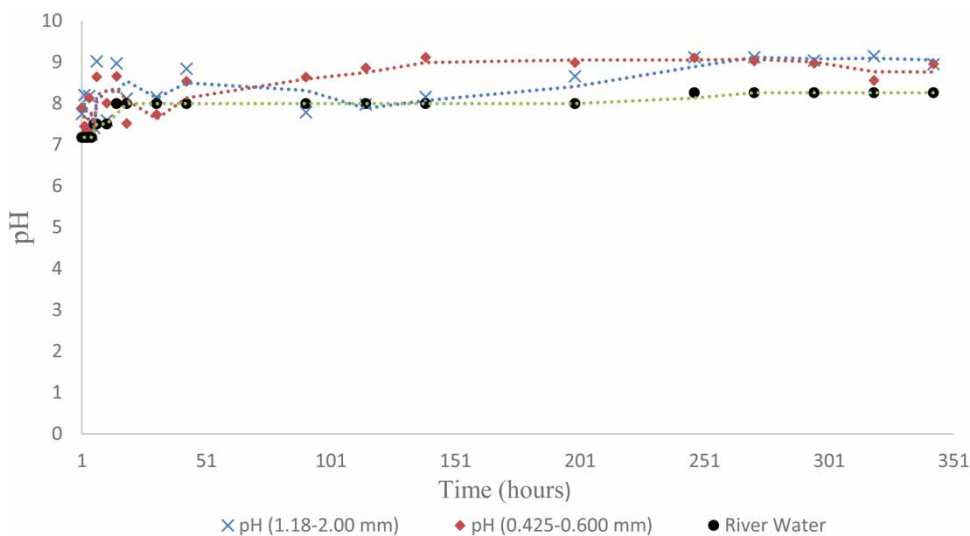


Figure 6 | pH of raw water (influent) and effluent using Zeliac with different particle sizes.

Table 3 | Removal efficiency of pollutants using different sizes of Zeliac

Parameter	Zeliac (1.18–2.00 mm)	Zeliac (0.45–0.60 mm)
Total coliform	>99%	>99%
<i>E. coli</i>	>99%	>99%
SS	83–90%	90–98%
UV ₂₅₄	>80%	>80%
Colour	>90%	>90%

and Mg, released from the Zeliac. Hydrolysis of these cations was responsible for the increase in alkalinity of the filtered river water. The source of pH increase is most likely from the dissolution of the limestone component of the Zeliac media. The hardness value was checked after limestone dissolution and it was approximately 40 mg/L as CaCO₃. Table 3 summarises the maximum removal efficiency for the different parameters using the two Zeliac particle sizes.

CONCLUSIONS

A fixed-bed column experiment was conducted to determine the potential of composite medium Zeliac as an alternative adsorbent for water treatment in RBF. Excellent removal of total coliform and *E. coli* by Zeliac was observed. The percentage removal for total coliform throughout the experiment was in the range of 99%–100%, whereas no *E. coli* was detected until hour 15. In this study, no significant difference was found in the removal of total coliform and *E. coli* by Zeliac with different sizes. Adsorption/adhesion and straining were suggested as the main mechanisms for removing bacteria. Moreover, the percentage removals of SSs ranged between 90% and 98% for Zeliac with a granular size of 0.425–0.6 mm and from 83% to 90% for the granular size of 1.18–2 mm. The results showed lower removal efficiency for Zeliac with coarse particle size. Slightly higher removal efficiency for UV₂₅₄ and colour by Zeliac with smaller grains was observed. These results indicated that porous medium with smaller particles provided larger surface area for adsorption. The maximum removal efficiencies were more than 80% and 90% for UV₂₅₄ and colour, respectively. Elevations in pH and TDS concentration were observed, but the values were still within the limit set

by MOH. Therefore, Zeliac shows promising performance in the removal of the selected parameters and can be used as a final barrier in RBF.

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