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Removal of Coliform, Suspended Solids, UV_{254} and Colour Using Zeolite and Activated Carbon in Riverbank Filtration System

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ABSTRACT

River bank filtratio filtration (RBF) is one of the novel water abstraction alternatives to tackle poor water quality problem in Malaysia. This study was conducted to investigate the potential use of zeolite and activated carbon as filter media in the laboratory RBF system. Characteristics of the materials were first determined using the surface analyzer and X-ray fluorescence method. Filter column and filtration rate that resembles the RBF system at one of the rivers in Malaysia was designed and pre-determined. The removal performance of the total coliform in terms of the Most Probable Number (MPN), *Escherichia coli*, suspended solids (SS), UV_{254} representing the Natural Organic Matter (NOM), and colour was determined at 2 different configurations; Column A which consists of a mixture of zeolite and activated carbon, and Column B which has two distinctive layers of zeolite (bottom) and activated carbon (top). Results indicated that the filtration rate of 18.3cm^3/min and retention time of 30 minutes had shown good removal performance for almost all the parameters. The removal of total coliform and *E. coli* were excellent with 95 and 99% reduction, respectively and 67 to 84% removal efficiency for SS. Column A performed better in removal of SS and colour whereas for Column B, performed better in removal of total coliform, *E. coli*, and UV_{254}.

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NOMENCLATURE

$V\varepsilon$	Empty volume (cm^2)	A	Cross sectional area (cm^2)
$V\varepsilon/Q$	Empty bed contact time, EBCT (min)	h	Bed height (cm)
Q/A_{eff}	Filtration (cm/min)	V	Adsorbent Volume (cm^3)
Greek Symbols		A_{eff}	Effective cross sectional area (cm^2)
ε	Empty volume percentage (%)	Q	Flow rate (mL/min)
Subscripts		h	Bed height (cm)
p	Particle	V	Adsorbent Volume (cm^3)
g	Gas	A_{eff}	Effective cross sectional area (cm^2)
D	Diametr of column (cm)	Q	Flow rate (mL/min)

1. INTRODUCTION

Riverbank filtration is a technique that consists of withdrawing water from rivers by pumping wells located adjacent to the river. The riverbed serves as a natural filter to remove the contaminants that present in the surface water by combining a series of physical, chemical and biological processes [1]. Riverbank filtration (RBF) has been proven as one of the best water treatment technique for its cost-effectiveness and simple skill requirements[1].

The type of media used to treat the water will greatly affect the performance of the riverbank filtration. Activated carbon has been considered as one of the oldest

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[1] https://sswm.info/water-nutrient-cycle/water-purification/hardwares/semi-centralised-drinking-water-treatments/bank-filtration

way and widely used adsorbent for water treatment in removal of organic and inorganic pollutants and coliform [2]. Besides, natural zeolites can also be used as adsorbents, for the removal of ammonia using hollow fibre ceramic membrane (HFCM) system [3], and water treatment [4]. Microporous zeolites can offer of sorption sites due to their high surface area, ordered crystalline structure and developed pore system [5]. Various works have been reported in combining activated carbon with other media to enhance the performances [6-9]. A combination of activated carbon and zeolite is expected to further enhance the performance of the RBF system. Hence, this study was conducted to evaluate the removal and enhance the performance of activated carbon and zeolite as the RBF filter medium for removal of the total coliform, E. coli, Suspended Solids (SS), UV wavelength at 254 nm (UV_{254}) and colour.

2. MATERIALS AND METHODS

2. 1. Preparation of Zeolite and Activated Carbon.

The positively charge zeolite used in this study mainly contains 78.9% SiO_2, 13.1% Al_2O_3, 2.7% K_2O and 2.2% CaO, with the Multipoint BET and total pore volume of 4.4 m^2/g and 0.1618 mL/g, respectively. The activated carbon was derived from coconut shell with 93.4% C and 4.2% SiO_2 with the Multipoint BET and total pore volume of 703 m^2/g and 0.4907 mL/g, respectively. Both media were supplied by Tangkas Laksana Sdn. Bhd. (Penang, Malaysia). Before the experiment, both media were crushed and sieved to the required size of 1.18mm to 2.0mm in accordance with ASTM E11-15 method and then rinsed with distilled water to avoid unnecessary contaminants and impurities. Finally, they were oven-dried at 105°C for 24 hours to remove the moisture. They were enclosed in a container after cooling down.

2. 2. Site Description

Figure 1 shows the coordinate of the sampling point and the location of the RBF tube well in Lubok Buntar, Perak, Malaysia. The well is located at 22 m east of the river. It was installed with 10-inch stainless steel screens at 24-30 m and a 1-m sand trap at 30–31 m. The upper part (ground level to 24 m depth) of the well was installed with a 10-inch-diameter PVC blank and a 1-m steel wellhead protector. The upper part of Lubok Buntar aquifer is dominated by stiff and sandy clay from the ground level to a depth of 16 m, followed by 1 m of gravely sand and 6 m of sandy gravel. The deepest part of the aquifer comprised of 8 m gravely sand. The presence of a coarse sand and gravel layer provide a good condition for this site to abstract clean water from the river through the RBF system. The static water level is approximately 2-4 m below the ground surface.

Figure 1. Sampling location

2. 3. Site Description

Three samplings were carried out from the RBF tubewell on 1st, 2nd and 9th February 2018. Water was pumped by using HCP Pump Model Pond-150A and stored in 100 litres barrels. The water samples were transported back to the laboratory and stored in a cold room at 4oC and characterized for colour, SS, UV254 (representing the natural organic matter, NOM), total coliform and E. Coli in accordance to the Standard Methods for the examination of water and wastewater [10].

2. 4. Column Study

A column study (Figure 2) was conducted to examine the removing performance of the contaminants in water samples using zeolite and activated carbon. The zeolite and activated carbon with the size of 1.18 to 2.00mm were filled up to 30cm mark in the column. Column A was filled with 50%: A 50% by volume of zeolite and activated carbon mixed whereas Column B was filled with 15cm of zeolite as the bottom layer and 15cm of activated as a top layer above it. The system was run continuously for 15 consecutive days, and the samples were collected at defined intervals.

The adsorption column parameters are shown in Table 1. The upward flow rate in the designed column was determined to achieve a similar hydraulic loading rate (HLR) of 1 cm/min and retention time of 30 minutes for both to mimic the kinematic similitude with the pumping well onsite.

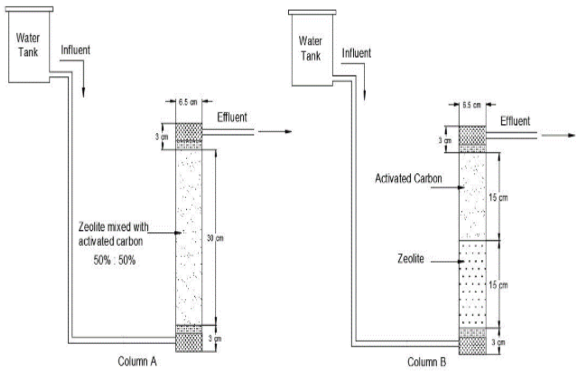

Figure 2. Schematic diagram of the column study

TABLE 1. Column design parameters

Parameters	Unit	Column A (50% activated carbon:50% zeolite)	Column B (activated carbon above the zeolite)
Size of zeolite and activated carbon	mm	1.18-2.0	1.18-2.0
Diameter, D	cm	6.5	6.5
Cross sectional area, A	cm^2	33.2	33.2
Adsorbent height, h	cm	30.0	30.0
Adsorbent volume, V	cm^3	996	996
Empty volume percentage, ε	%	55.0	55.0
Empty volume, Vε	cm^3	547.8	547.8
Effective cross-sectional area, Aeff	cm^2	18.3	18.3
Flow rate, Q	mL/min	18.3	18.3
Empty bed contact time, EBCT, Vε/Q	min	30.0	30.0
Filtration rate, Q/Aeff	cm/min	1.0	1.0

3. RESULTS AND DISCUSSIONS

The mean water quality parameters mainly contain Colour (35 PtCo), SS (72 mg/L), total coliform (758/100 mL), and E. coli (101/100 mL, and UV254 (0.113 cm-1). Total coliform (MPN) and E. coli removal performances are shown in Figures 3 and 4.

For the removal of total coliform, the graph shows some initial reductions for both columns. The removal improved over time and achieved 80% reduction after day 7 for Column B and on day 8 for Column A. From

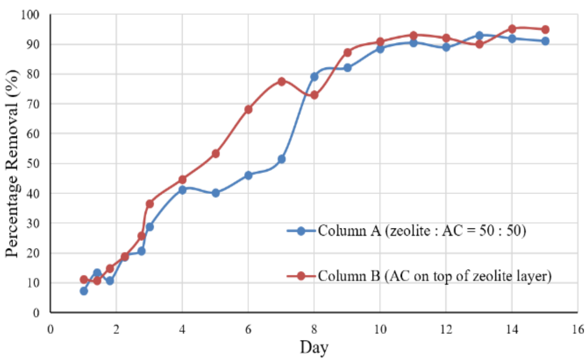

Figure 3. Removal of Total Coliform (MPN)

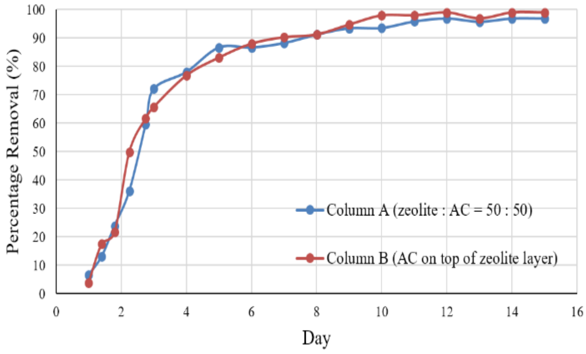

Figure 4. Removal of E. coli

day 10 onwards, both columns achieved 90% removal and almost complete removal occurred for Column B on day 14.

Column B exhibited slightly better performance compared to Column A. Almost the same pattern happened in the removal of E. coli. At the early stage of filtration, the removal for both columns increased over time and exceeded 80% reductions on day 5. On day 8, both columns have reached 90% removal efficiencies and almost complete removal was obtained from day 12 onwards. This is in agreement with Mwabi et al. [11] who obtained 93-100% reductions in E. Coli using bucket zeolite filter. The difference in the performance between both columns are not significant.

The activated carbon offered a good site for the microbes to adsorb on its surface. At the same time, the presence of divalent cation in the zeolite (mainly SiO_2) increases the adsorption capacity of the microbes. The presence of divalent cation increased the attachment of bacteria to the surface of adsorbent [12]. According to Bradford et al. [13], 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. Also, adsorption of bacterial cells to the porous medium is 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 [14].

The true colour, suspended solids and UV254 (representing NOM) removal efficiencies are shown in Figures 5 to 7, respectively.

For the colour and SS (Figures 5 and 6), the removals for both columns increased with respect to time, until it reaches a maximum reduction of 70 and 90% for colour and SS respectively, on day 15. Granular size is an important factor governing SS removal. Benamar et al. [15] suggested that the removal of large colloid particles (>10 μm) is mainly influenced by hydrodynamics, gravity and inertial effects. The SS reduction from the liquid phase was probably associated by straining or interception mechanisms as the particle size of SS is

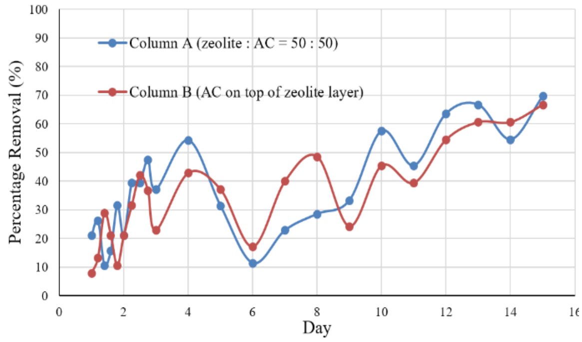

Figure 5. Removal of the true colour

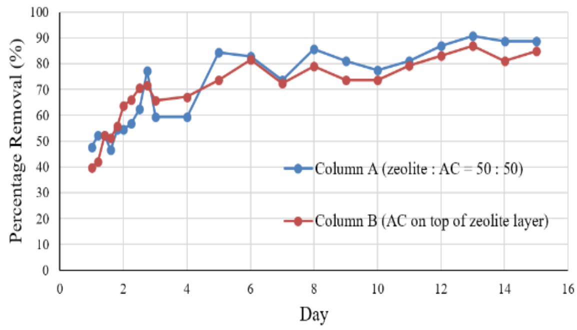

Figure 6. Removal of Suspended Solids (SS)

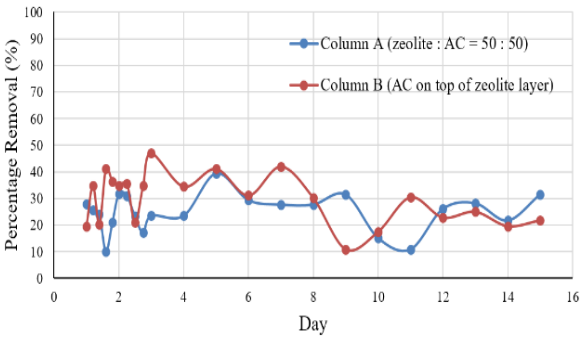

Figure 7. Percentage removal of UV_{254}

usually heavy and larger than the pore size of the column bed. The adsorption of colour on the external surface of activated carbon is the most common mechanism occurred in the filtration process. Also, the colloidal substances as SS in the sample which normally present as negatively charged particles could also favour their sorption by the cationic zeolite [6].

Column A shows a slightly better performance than Column B for the UV254 (representing the NOM) reduction (Figure 7). The removals for both columns ranged from 10 to 50%. Column B exhibited slightly better performance at early days where almost 50% reduction occurred on day 3. On day 15, Column A performed better than Column B with reductions of 32 and 21%, respectively. Adsorbability of the remaining NOM fractions is expected to increase with decreasing molecular size in activated carbon [16]. The removal shows a declined pattern as the filtration time increased. 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 respect to time and finally could not receive further pollutants [17].

The removal performances for all parameters are summarized in Figure 8 and Table 2.

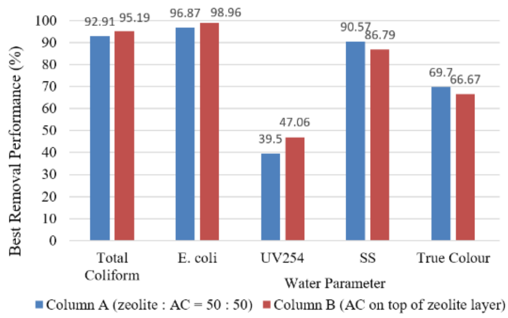

Figure 8. Comparison of Removal Performance between Column A (zeolite: AC= 50: 50) and Column B (AC on top of the zeolite layer)

TABLE 2. Removal Performances of selected parameters (retention time 30 minutes, filtration rate 1cm/min)

Parameter	Best performance (%)	Column	Day
Total Coliform	90-95	Column B (AC on top of zeolite layer)	10-15
E. coli	95-99	Column B (AC on top of zeolite layer)	9-15
UV_{254}	20-47	Column B (AC on top of zeolite layer)	1-5
SS	85-89	Column A (zeolite:AC= 50:50)	8-15
True Colour	45-70	Column A (zeolite:AC= 50:50)	10-15

4. CONCLUSIONS

A filter column was designed to mimic the kinematic similitude with the pumping well with a flow rate of $18cm^3/min$ and retention time of 30 min. The results proved that the column design was capable of creating a dynamic RBF system in removal of the pollutants. Both adsorbent arrangements with zeolite and activated carbon show a potential application as the RBF media. For total coliform, *E. coli* and UV_{254}, Column B (AC on top of zeolite layer) performed better, compared with suspended solids and colour where better performance was observed for Column A (zeolite: AC= 50: 50).

5. ACKNOWLEDGEMENTS

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Persian Abstract

چکیده

تصفیه آب رودخانه بروش فیلتراسیون ساحل رودخانه (RBF) یکی از گزینه های جدید جذب ناخالصی آب برای مقابله با مشکل کیفیت آب در مالزی است. این مطالعه به منظور بررسی استفاده احتمالی از زئولیت و کربن فعال به عنوان بستر فیلتر در سیستم RBF در مقیاس آزمایشگاهی انجام شد. مختصات مواد برای اولین بار با استفاده از آنالایزر سطح و روش فلورسانس اشعه X مشخص گردید. ستون فیلتر و میزان فیلتر که شبیه به سیستم RBF در یکی از رودخانه های مالزی است طراحی و از پیش تعیین شده است. عملکرد حذف کلیفرم از نظر تعداد محتمل ترین (MPN)، *اشرشیاکلی*، مواد جامد معلق (SS)، UV254 نماینده ماده آلی طبیعی (NOM)، و رنگ در ۲ ستون مختلف تنظیم تعیین شد. ستون A که از ترکیبی از زئولیت و کربن فعال تشکیل شده است، و ستون B که دو لایه متمایز از زئولیت (پایین) و کربن فعال (بالا) دارد. نتایج نشان داد که میزان فیلتراسیون ۱۸.۳ cm3/min و مدت زمان ماندن ۳۰ دقیقه عملکرد حذف خوبی برای تقریباً تمامی پارامترها نشان داده است. حذف کلیفرم و *E. coli* با کاهش ۹۵٪ و ۹۹٪ به ترتیب، به ترتیب عالی و ٦٧٪ تا ٨٤٪ راندمان حذف SS بود. ستون A در حذف SS و رنگ بهتر عمل کرد را داشته، در حالی که برای ستون B برای از بین بردن تمامی کلیفرم ، *E. coli* و UV254 بهتر عمل کرده است.