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Column Study of Aluminum Adsorption from Groundwater by Natural Pumice

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***Abstract*— Contamination of groundwater by heavy metals is an environmental problem worldwide. Metal poisoning leads severe damage to human health that can cause the death. One of metals contained in the ground water is aluminium, which can be selectively leached from rock and soil to enter any water source. The removal of aluminum from groundwater by natural pumice from Sungai Pasak, West Sumatera, Indonesia was investigated in a continuous fixed-bed column. The performances of column were evaluated by varying the adsorbent bed depth (65–85 cm) and influent flow rate (2 - 4 gpm/ft^2 equal to 43–87 mL/min). The results revealed that the increase in bed depth increased the amount of adsorbent used, thus increasing the total removal of aluminum and prolonged the lifespan of the natural pumice column. However, the increase in influent flow rate resulted in the shortened lifespan of the column. The increased flow rate also led the column exhaustion time to reach earlier. Therefore, to obtain optimum performance, suitable parameters are necessary for the column system operation. The column system with a bed depth of 85 cm and flow rate of 2 gpm/ft^2 (43 mL/min) showed the best aluminum uptake performance in this study with a total removal of 59.5% and an adsorption capacity of 0.056 mg/g. The results showed that the natural pumice has potential for removing of aluminum from groundwater by column.**

***Keywords*— adsorption; aluminum; column; pumice.**

I. INTRODUCTION

Pollution of heavy metal in the water environment has become a great concern over the last decade. Metal poisoning leads serious damage to human health that can cause the death [1]. Contamination of groundwater by heavy metals is an environmental problem worldwide. One of metals contained in the ground water is aluminum. Aluminum can be leached selectively from rock and soil to enter any water source. In groundwater, Al^{3+} is known to exist in concentrations ranging from 0.1 ppm to 8.0 ppm [2], [3].

Many types of treatment for metal removal from water have been developed through water treatment systems like flocculation, coagulation, ion-exchange, membrane filtration, chemical precipitation, chemical oxidation, , reverse osmosis and ozonation [4]–[7]. Nevertheles, for these methods, the procedures and operational costs are known to be expensive due to the complicated operational procedures, the high maintenance cost and time consuming as well as manpower requirements..

Several studies have been conducted to improve the operational period and minimize the operational costs of the treatment process by using natural materials which are abundantly available to search alternative methods. Some kinds of adsorbents have been used for metal removal from water in the recent literature, such as seashells, crab shells, eggshells, palm husks, rice husks, fruit seeds, fruit peel, zeolites, and pumice [2], [8]–[13]. Among these natural materials, pumice which is a volcanic stone and can be found in many regions of the world has a low weight and a porous structure (up to 85%). Because of its micro-porous structure, pumice has a high specific surface area, so that, pumice recently has been also utilized as adsorbent to remove pollutant from water and wastewater [14].

This research was performed to evaluate the performance of natural pumice for aluminum removal from actual groundwater through a fixed-bed column. The natural pumice was collected from Sungai Pasak, West Sumatera, Indonesia. In this location, pumice is available in a high abundance, as byproduct of sand mining process. This local mineral has potential for removal of iron and manganese from water, as previous investigations [13], [14]. On the other hand, the application of column adsorption is practical and economic since the operation is performed continuously and the process is controllable [15], [16]. The effect of parameters like bed depth and flow rate on the shape of the breakthrough curve was studied. The column performance was examined by the total removal percentage of aluminum ions and the capacity of adsorbent required for aluminum ions removal.

II. MATERIALS AND METHOD

A. Preparation of Adsorbent

Pumice samples were obtained from riverside of Sungai Pasak, West Sumatera, Indonesia as by product of the sand mining process. Pumice samples were washed with distilled water several times and dried out at room temperature, then to obtain the desired particle size fractions, the natural pumice was crushed and sieved. Energy dispersive x-ray (EDX) spectroscopy was employed to obtain information on the oxide content of the natural pumice. The surface morphology of pumice was observed by a scanning electron microscopy (SEM, model S-3400N, Hitachi, Japan).

B. Preparation of Adsorbent

Groundwater sample was collected from one of the residence wells in the settlement area located in Padang, West Sumatera, Indonesia, with a 1.14-3.25 mg/L of aluminium concentration of and 6.2 of pH.

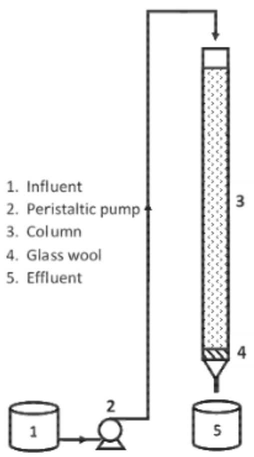

Fig.1 A schematic of fixed-bed column of natural pumice for aluminum adsorption.

C. Fixed-bed column studies

The experiments was used a glass column with a length of 130 cm and an inner diameter of 2.6 cm. At the bottom of the column, a glass wool were placed to avoid loss of adsorbent during the adsorption process. Figure 1 presents the schematic of fixed-bed column system. A known weight of pumice with the particle size of 0.5 – 1 mm as adsorbent was packed into the column. Before the experiment began, to attract the trapped air between the particles, the deionised water was used in downward flow direction for wetting the adsorbent in the column. The groundwater sample were fed downward continuously into the column by a peristaltic pump (Kamoer, China). The experiment was conducted at room temperature 27 ± 2°C. Effects of process parameter like flow rates (2 gpm/ft^2, 3 gpm/ft^2 and 4 gpm/ft^2 equal to 43, 65 and 87 mL/min) and bed depth (65, 75, and 85 cm) were investigated. Samples were collected every 60 minutes from the bottom of the column and were measured for the remaining aluminum by Inductively Coupled Plasma–Atomic Emission Spectrometer (Shimadzu, ICPE-9000, Japan). The column performance was investigated by calculating the breakthrough time and adsorption capacity.

D. Mathematical formula of fixed bed column studies

The performances of column were evaluated through the breakthrough curve of the fixed bed column. The breakthrough curve was expressed by C_t/C_0, in which C_t and C_0 respectively symbolize the concentration of effluent and influent. The curve was described as C_t/C_0 against the contact time. The concentrations of adsorbed metal ion in the column were confirmed by a plot of the adsorbed metal concentration (C_{ad} = inlet concentration (C_0) - outlet concentration (C_t)) or normalized concentration assigned as the ratio of effluent metal concentration to influent concentration (C_t/C_0) as a function of time or volume of effluent (V_{eff}), as shown in equation (1) [17].

$$V_{eff}\,(mL) = Qt_{total} \tag{1}$$

In equation (1), the Q and t_{total} respectively reflect the volumetric flowrate (mL/min) and total flow time (min). By integrating the plot of adsorbed concentration (C_{ad}) versus the flow time (t), the total adsorbed metal ion (q_{total}) by the column can be calculated. The area (A) under this integrated plot is substituted in equation (2) to determine q_{total}.

$$q_{total}\,(mg) = \frac{QA}{1000} = \frac{Q}{1000}\int_{t=0}^{t=t_{total}} C_{ad}\,dt \tag{2}$$

The total amount of metal ions passed to the column system (m_{total}) *is gained from equation* (3).

$$m_{total}\,(mg) = \frac{C_0 Q\, t_{total}}{1000} \tag{3}$$

The performance of column can be examined by the percentage of total metal ion removal from the ratio of total adsorbed metal ions in the column to the total amount of metal ions delivered to the column, as shown in equation (4).

$$Total\ removal\ of\ metal\ ions\ (\%) = \frac{q_{total}}{m_{total}} \times 100 \tag{4}$$

To obtain the adsorbent capacity required for metal ions removal, the equilibrium adsorption was calculated from the column data. Equation (5) declares the equilibrium metal ion uptake (q_{eq}), also known as the column maximum capacity.

$$q_{eq}\,(mg/g) = \frac{q_{total}}{X} \tag{5}$$

where, X is the unit mass of adsorbent packed in the column.

III. RESULTS AND DISCUSSION

A. Physical Characteristics of Natural Pumice

Si, Al and Fe are the major elements in natural pumice from Sungai Pasak, as shown in Table 1 as determined by EDX. Other elements, except K, Ca, Na and Mg were present in relatively smaller amounts (less than 3%). The elemental compositions of the pumice also indicate the absence of hazardous or carcinogenic substances, thus the pumice are considered appropriate as adsorbent to treat polluted water. The SEM image showed the surface morphology of natural pumice from Sungai Pasak, West Sumatra was displayed in Figure 2. The image denoted that the pumice had an irregular texture, cellular, smooth surface, and highly porous with great cavities, that serves compatible sites for adsorption.

TABLE I
CHEMICAL COMPOSITION OF NATURAL PUMICE FROM SUNGAI PASAK, WEST SUMATRA, INDONESIA

Constituent	Percentage (%)
SiO_2	76.586
Al_2O_3	13.913
K_2O	3.604
CaO	2.11
Fe_2O_3	1.485
MgO	0.876
P_2O_5	0.822
TiO_2	0.197
Ag_2O	0.143
MnO	0.044
Other materials	0.22

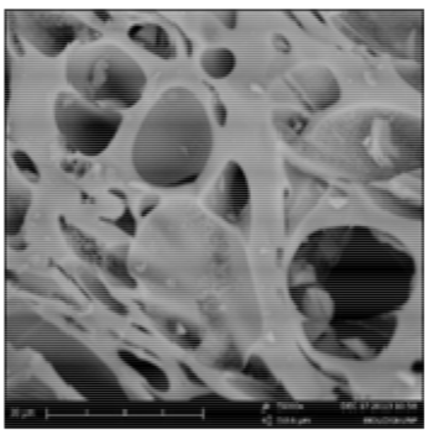

Fig. 2 SEM image of natural pumice from Sungai Pasak, West Sumatra, Indonesia.

B. Column Studies

The ratio of effluent metal concentration to the metal inlet concentration (C_{eff}/C_0) against the flow time (t) was used to represent the plot of the breakthrough curve, to evaluate the performance of the continuous fixed-bed column system. The breakthrough takes place when the concentration of the counter ion in the effluent start to increase primarily until it finally achieves the same concentration as in the influent. No more ion exchange takes place after this point.

1) Effect of bed height:

The effect of a bed depth of 65, 75, 85 cm on the breakthrough curve at a various flow rates of 2 gpm/ft^2, 3 gpm/ft^2 and 4 gpm/ft^2 (equal to 43, 65 and 87 mL/min, respectively) was investigated (Figure 3). The results reveal that with the variation in bed depth, the shape and gradient of the breakthrough curve was slightly different. Aat the beginning of the fixed-bed column, the higher uptake of aluminum was observed, but the aluminum concentration in the effluent increased quickly after breakthrough time. The lower bed depth reaches saturated earlier than higher bed depth.

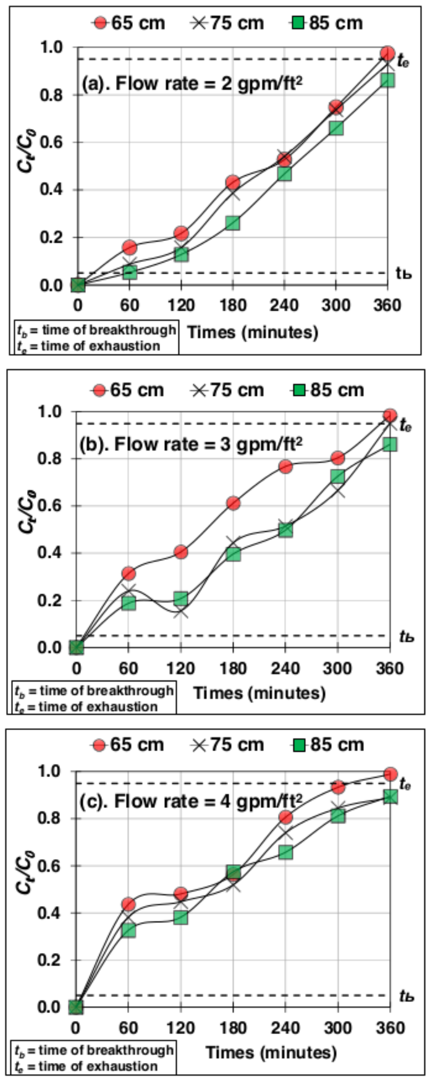

Fig. 3. Effect of various bed depth on the breakthrough curve of aluminum adsorption onto natural pumice at various flow rates: (a). 2 gpm/ft^2, (b). 3 gpm/ft^2 and (c). 4 gpm/ft^2 (aluminum concentration = 1.14 mg/L; pH 6.2).

From the Figure 3, at all of various flow rates, it is observed that time of breakthrough (t_b) and time of exhaustion (t_e) increase as the bed depth increase. The breakthrough time of column and the performance of adsorbent bed are strongly influenced by the length of the bed depth [1], [18]. From the results, it can be resumed that the aluminum uptake in in a column increase as the bed depth increase which in consecequence of the increasing of contact time for aluminum adsorption. At lowest bed depth there is no sufficient time for aluminum ions to admit into the pores of pumice. The longer bed also postponed the exhaustion time of the adsorbent, reflecting a longer period of the bed operation without changing the adsorbent. However, the exhaustion approached faster for the shorter bed, thus the performance degenerated [19].

2) Effect of flow rate:

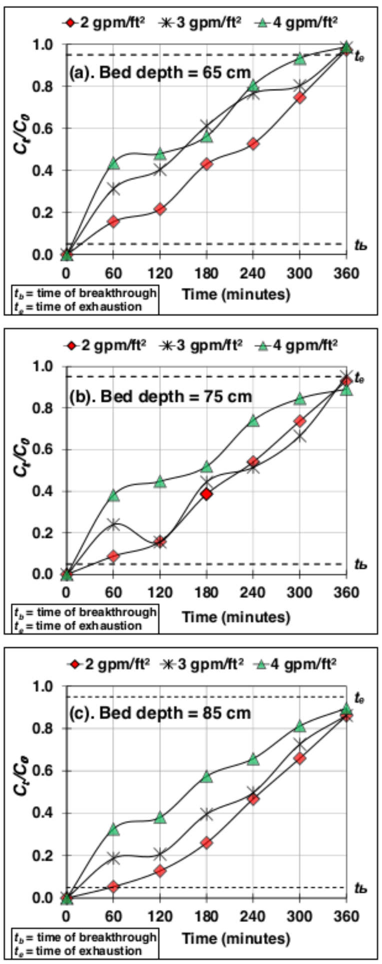

Fig. 4 Effect of various flow rates on the breakthrough curve of aluminum adsorption onto natural pumice at various bed depths: (a). 65 cm, (b). 75 cm dan (c) 85 cm (aluminum concentration = 1.23 mg/L; pH 6.2).

As shown in Figure 4, the results indicate that a decrease in flow rate at all various bed depth increased the breakthrough time (t_b). The results also show that at higher flow rates, the shape of the breakthrough curve is saturated earlier since the front of the adsorption zone rapidly attained the top of column. Conversely, a shallow adsorption zone was observed at lower flow rate and longer contact time. Moreover, the increased flow rate resulted the contact time between the adsorbate and adsorbent were relatively short. Consequently, the adsorption was not complete and at the beginning of the operation, led to steep breakthrough results [9], [19]. From the effect of flow rate study, it was indicated that lower flow rate or longer contact time would be needed for aluminum adsorption in the column of natural pumice.

C. Total Removal and Adsorption Capacities

To present information on the effect of parameters, the column data were calculated into the mathematical theories of the column system. The total removal percentage of columns aluminum tends to increase with the increase in adsorbent bed depth and decrease in flow rate (Figure 5(a)). Moreover, it is observed that the adsorption capacity of the columns increased as the flow rates increased for all various bed depth, as shown in Figure 5(b).

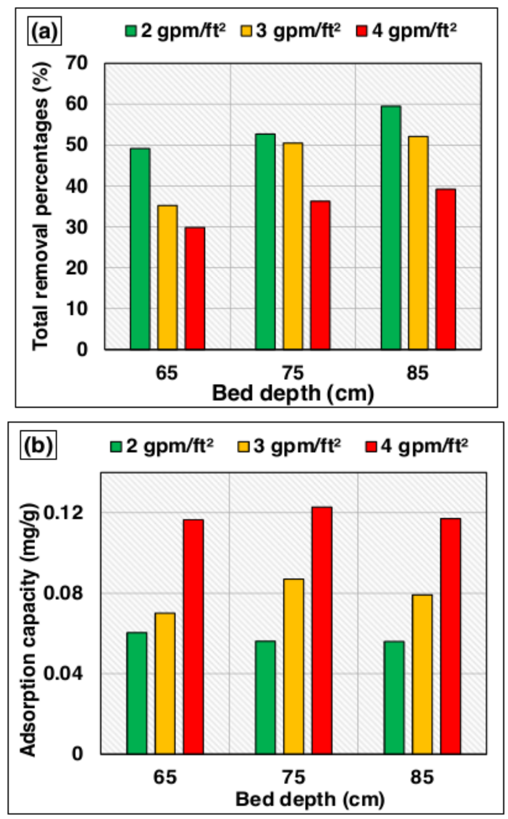

Fig. 5 Total removal percentages and adsorption capacities of aluminum by column of natural pumice at various bed depths and flow rates (aluminum concentration = 1.14 mg/L, pH 6.2)

IV. Conclusions

The removal of aluminum from groundwater was carried out in a continuous fixed-bed column system with variation of the bed depth and flow rate. The results show that the aluminum adsorption through fixed-bed columns depended on the bed depth and flow rate. The change in bed depth extremely influenced the performance of column by decelerating the exhaustion time and enhancing the column quality. The increase in the bed depth and decrease of the flow rate resulted the greatly increase of the total removal percentage of aluminum. However, the increase in flow rate led to accelerate the exhaustion of the column. Accordingly, to obtain optimum performance, suitable parameters are necessary for the column system operation. Therefore information obtained from the fixed bed column study suggested that the natural pumice has potential to be used as adsorbent for treatment of aluminum from groundwater or other polluted waters.

Acknowledgment

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