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Adaptive method for the purification of zinc and arsenic ions contaminated groundwater using in-situ permeable reactive barrier mixture

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Abstract

This study investigated the purification process of groundwater contaminated with zinc and arsenic using a permeable reactive barrier with a zero-valent iron/pumice mixture. We determined the removal rates of the contaminants for 30 days. In this study, column reactor filled with the zero-valent iron/pumice reactive mixture was used. Experimental results showed that the mixture exhibited an almost complete removal of the zinc and arsenic ions. Arsenic was removed via co-precipitation and adsorption processes while zinc ions were asorbed in active sites.The purification process of water from the metal ionscontinued for 30 days with constant hydraulic conductivity because of the enhanced porosity of the pumice and interparticle distance between the zero-valent iron and pumice. Contaminants removal rates and the remediation mechanism for each reactive system are described in this paper.

Keywords: *underground contamination, permeable reactive barrier, heavy metals, hydraulic conductivity, purification*

1. INTRODUCTION

Suburban residential areas heavily depend on the water wells for their daily source of water. The aquifers are usually affected by the drainage systems near the suburbs or neighboring areas, from soil leaching and other underground economic activities [1]. These contaminants in groundwater make groundwater purification among the most challenging and expensive task, and often the primary factor creating socio-economic problems in the suburban areas [2,3]. Zinc is one of the contaminants generated as a result of different economic activities, e.g., mining. A survey showed that the concentration of zinc ions exceeds 10mg/L [1,4]. Besides, aquifers are known to be sources of arsenic ions and that the concentration in the groundwater exceeds the recommended threshold limit value [5]. Although it is easy to filter out these ions using filter cartridges (e.g., cartridges in water coolers), it is challenging to conduct a similar purification process for a large quantity of water in the aquifers. The permeable reactive barrier, a multi-purpose remedial technique, is one of the techniques used to remediate acid rain drainage and contaminated groundwater, which could be used for the purification of zinc and arsenic ions. One of the advantages of this remediation technique is that it utilizes a passive hydraulic gradient to remove contaminants and that it is possible to set up this barrier on any terrain without interfering with the groundwater hydrology [6]. Likewise, cost and purification efficiency is the dominating factor in as far as any purification process is concerned. Zero-valent iron and pumice are reactive

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materials that are readily available. The zero-valent iron and pumice are cheap to obtain and that their mixture provide an additional advantage in the purification process which has been documented by other researchers [7].

In this experimental study, we used zero-valent iron and pumice to purify aquifer from zinc and arsenic ions. The goal of this research was to determine the removal rates of zinc and arsenic ions. In the column reactor. Also, this study investigated the impact of in-situ heavy metal purification on the hydraulic conductivity of the column reactor. This study also focused on possible purification mechanisms of water.

2. EXPERIMENT

In this experiment, groundwater containing zinc ions (approximately 25 mg/L) was used. Also, an equivalent amount of arsenic (III) oxide was also added so that the corresponding concentration in the feed tank was approximately 0.1 mg/L. In this experimental study, the experimental setup was based on different types of reactors used by other researchers [8,9]. Figure 1 shows the experimental setup and workflow diagram. The experimental setup consisted of a column reactor filled with the reactive mixture and connected to the feed tank, peristaltic pump, and purified water storage tank. The column was filled with a mixture of zero-valent iron and pumice, and the mixture vol/vol ratio was 1:1. Also, the particle size of the zero-valent iron and pumice was 50 mesh size and 1-3mm, respectively. The reactors consisted of vertical column acryl tube washed sand and the reactive material. The first 10 cm height was filled with washed sand. The reactive material mixture was filled for 25 cm height, followed by 5 cm height washed sand

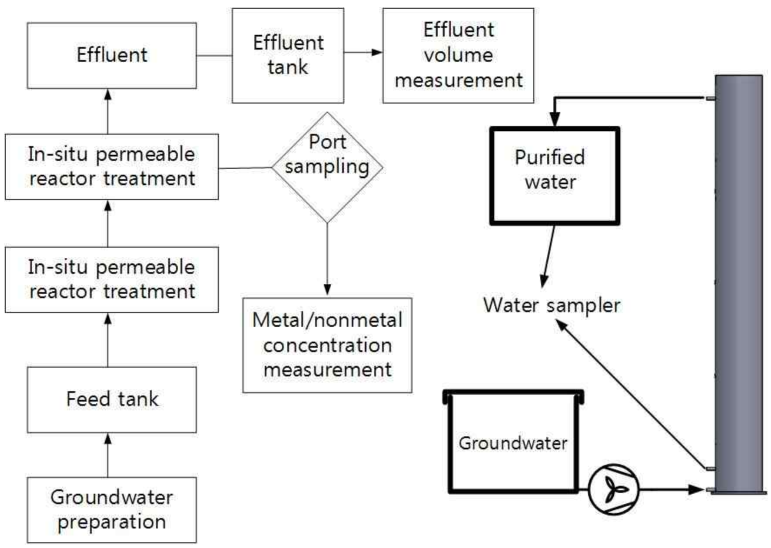

Figure 1. Column reactor and the workflow process diagram

Therefore, 3 cascade layers (each 25 cm height) of reactive material intertwined with the washed sand (each 5 cm) formed the reaction volume. In this experiment, the contaminated water was pumped into the column reactor using a peristaltic pump and permeated through the reactive material where it was subjected to the purification process. The permeated upwards towards the effluent chute, and daily effluent volume was collected and recorded. The concentration of the zinc and arsenic ions in the feed water and treated water were determined using inductively-coupled plasma optical emission spectrometer (ICP-OES) from Perkin Elmer every 2 days. We did not analyze the concentration of arsenic and zinc ions for the first three days. The removal rate was calculated based on the difference of theconcentration at the inlet ant outlet.

3. RESULTS AND DISCUSSION

The removal rate of the Arsenic and Zinc ions are shown in Figures 2 and 3.Experimental results show that there was almost complete removal of all the investigated metal irons at lower and higher metal concentrations in the influent. Almost complete removal was effected thanks to the combined effect of both the zero-valent iron and pumice. Both the zero-valent iron and pumice are useful in the removal of arsenic and zinc ions through precipitation and adsorption process [10–12].

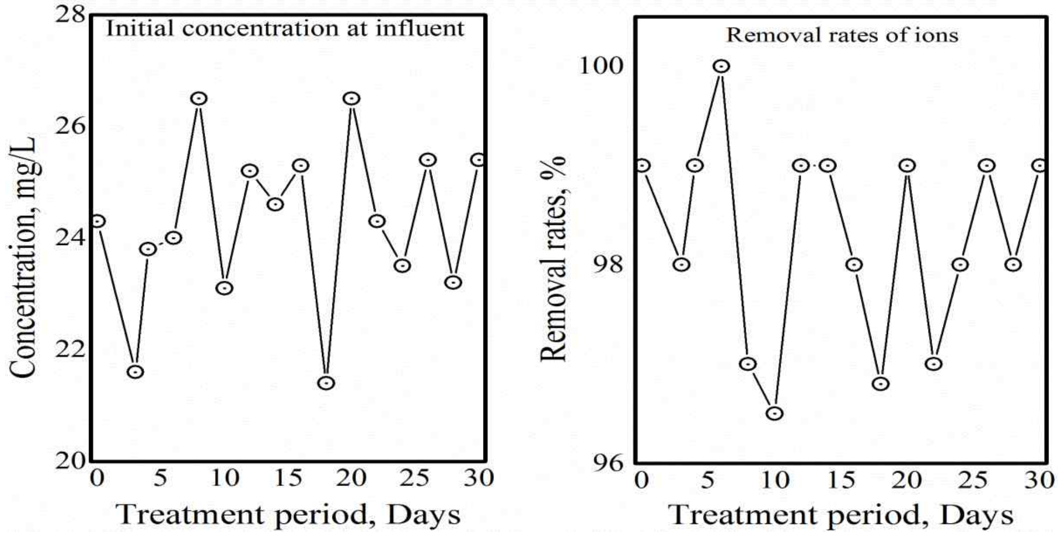

Figure 2. Removal rates of zinc ions using the in-situ permeable reactive barrier

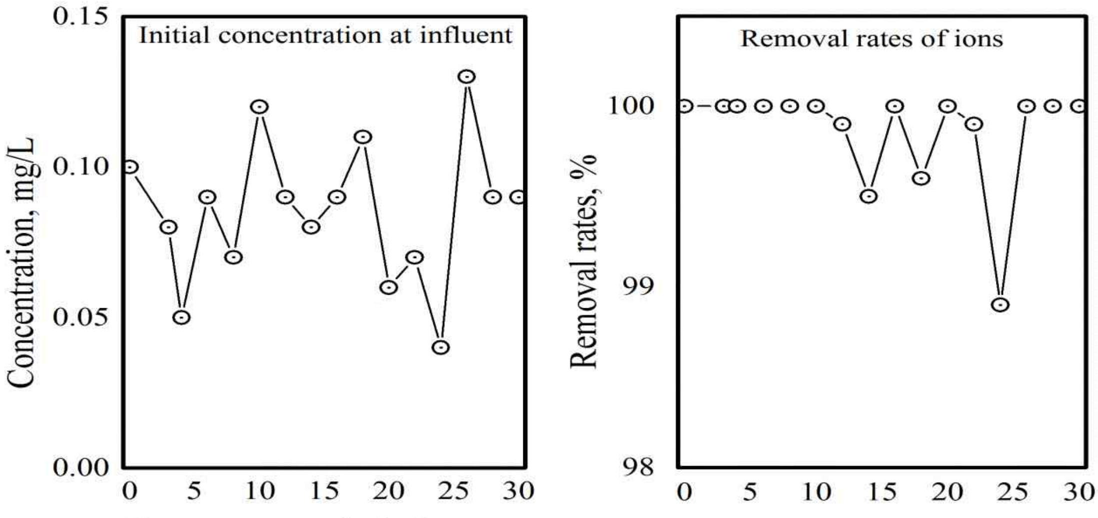

Figure 3. Removal rates of arsenic ions using the in-situ permeable reactor

Batch experiments carried by other researchers showed that the adsorption process at an even higher concentration of arsenic ions was because of the highly developed porous structure in the pumice [11,13]. Pumice has an extensive surface area and pore volume enough to adsorb the arsenic ions. Zero-valent iron removes the arsenic ions from the water through adsorption and co-precipitation[14]. Usually, the co-precipitation process occurs as a result of the presence of corrosion products generated from the zero-valent iron [15]. The corrosion products are different forms of ferric hydroxide, which increases the pH, thereby creating conditions for the formation of radical ions that react with arsenic ions to form precipitates. These precipitates are in the form of sludge. During the zero-valent ion-water interaction, an equilibrium is generated. This means that there are available adsorption sites for both zinc and arsenic ions. Thus these ions are adsorbed in these sites, and their removal mechanisms are shown in Figure 4.

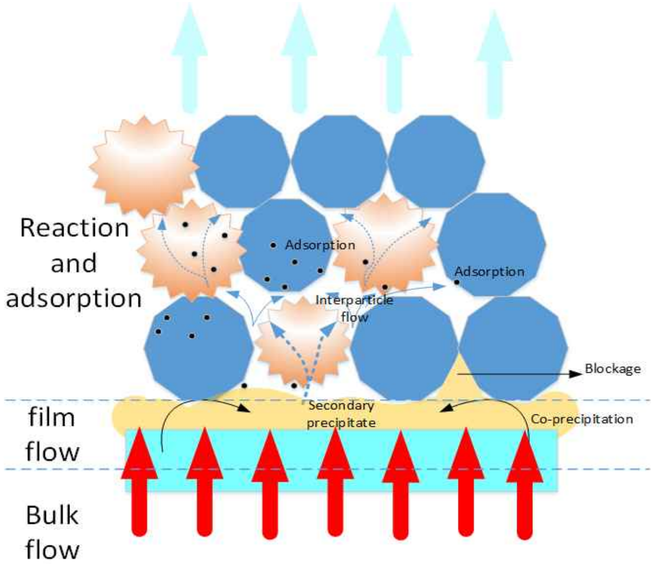

Figure 4. Removal mechanism of zinc and arsenic ions from water

Another essential aspect of the mixture used was the capacity to filter out the metal ions while maintaining continuous flowrate. Discharge through reaction area is an indication of the hydraulic permeability and long-term application of the reactive material in the in-situ permeable reactive barrier. The column reactor used in this study had a constant discharge flow rate throughout the reaction period despite precipitation formation in the first layer of sand in the inlet chute. Such a continuous discharge rate was facilitated thanks to particle distribution of the mixture and the porous structure in the reactive materials used in the reactor as shown in Figure 5.

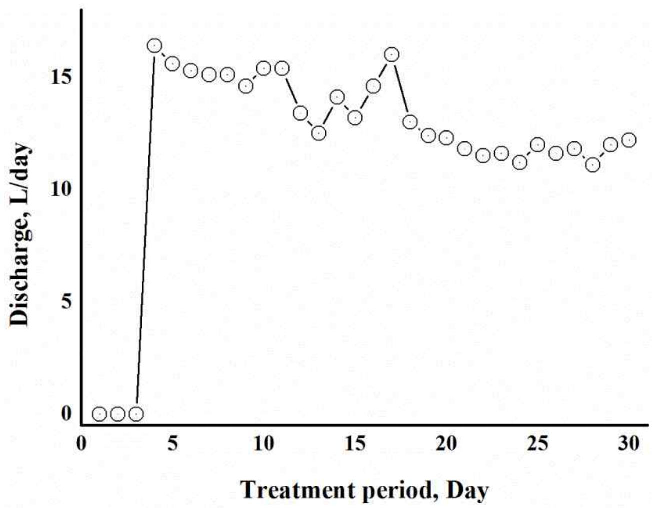

Figure 5. Daily discharge through the column reactors

Both reactive materials (zero-valent iron and pumice) have a certain level of permeability, and their porous structure enhanced the movement of liquid through the reactive material. Likewise, the inter-particle (zero-valent iron and pumice) distances created pathways to facilitate the upward movement of liquid around the particles[16,17]. Therefore, the untreated contaminants could easily move up the column for further treatment.

4. CONCLUSION

This experimental study investigated the application of zero-valent Iron:pumice mixture as reactive barrier materials for the purification of groundwater from zinc and arsenic ions. Combination of pumice and zero-valent-iron was effective in ensuring complete remediation of water with a constant hydraulic conductivity. The iron:pumice mixture ensured complete removal of metal ions and steady flow of treated water through the porous structure of the mixture because of the combination of reaction mechanisms between the zero-valent iron and pumice. The arsenic and zinc ions were removed through complex sorption andprecipitation processes.This experimental study revealed the importance of using mixtures rather than singular material as reactive barriers. Further research will focus on the application of different mixtures to remediate multi-species contaminated groundwater, removal mechanisms of the ions and anions and the hydraulic conductivity phenomena of the reactive mixtures.

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