Technical note

Removal efficiencies of constructed wetland and efficacy of plant on treating benzene

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A B S T R A C T

Leaking underground petroleum storage poses human and environmental health risks as it contaminates the soil and the groundwater. Of the many contaminants, benzene — a major constituent of gasoline, is of primary concern. It is an identified carcinogen with a permissible limit set at a low level of 0.005 mg L^{-1}. This poses technical and regulatory challenge to remediation of contaminated sites. Various specialized treatment methods are available, but despite of the high removal efficiencies of sophisticated treatments, the residual level still poses health risks. Thus, additional alternative ways that are cost effective and require minimum technical expertise are necessary, and a constructed wetland (CW) is a potential alternative. This study evaluates the performance of a surface flow type CW for the removal of benzene from the contaminated water. It further determines the efficacy of a common reed plant *Phragmites karka* in treating benzene. Planted and unplanted CW were acclimated with benzene for 16 wk and tested for an 8-d hydraulic retention time at benzene levels of 66 and 45 mg L^{-1}. Results indicate that the planted CW performed better and gave reliable and stable results.

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1. Introduction

Constructed wetlands (CWs) have been used to treat wastewater for the removal of a wide variety of contaminants, such as suspended solids, organic compounds, nutrients, pathogens, metals, and emerging contaminants [1–7]. Aside from its effectiveness in pollutant removal, it has also displayed cost efficiency in wastewater treatment [3,8,9].

Of the several removal mechanisms involved in the operation of CWs: sedimentation, filtration, volatilization, adsorption, plant uptake, and bacterial activity [10] with bacterial activity often playing the most important role in removing contaminants [11,12]. And though plant uptake is a minor contributory factor for contaminant removal [13], plants significantly improve bacterial activities [13–15] as its rhizosphere provides the area for microbes to grow, its root exudates provide nutrients that support microbial growth [11,12], and its roots supply oxygen needed by aerobic bacteria [16].

A number of studies have investigated the effect of plants in treating organic pollutants [17–19]. *Phragmites australis* significantly enhanced the capacity of a pilot scale horizontal subsurface flow CW in removing monochlorobenzene and perchloroethylene [17]. A significant difference was also observed in the performance of planted and unplanted CW in terms of nutrient removal [18]. However, despite the improved nutrient removal, no significant difference was found in organic matter removal between planted and unplanted CW. This is attributed to the sole or major dependence of organic compound degradation on the microbial systems in the soil [15].

Despite the number of studies dealing with benzene removal by CWs [20–24], little attention has been given to determining the efficacy of plant on treating benzene and the optimal hydraulic retention time (HRT) for benzene treatment by CWs. These specific concerns will be addressed in this study using a surface flow type CW and *Phragmites karka* as the vegetation. CW efficiency was analyzed at benzene levels of 66 and 45 mg L^{-1}.

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2. Materials and methods

The experimental set-up consists of two horizontal surface flow CWs. Containers with fiberglass walls and steel reinforcements measuring 1 m long, 0.6 m wide, and 0.8 m high were used. The solid media consist of local materials from Vietnam. The lower 0.1 m layer is made of gravel (2–3.15 mm grain size) and topped with soil (sand and silt) to a height of 0.3 m. The water level was maintained at a height of 0.1 m above the solid media.

One CW was planted with local common reed P. karka at a density of 0.44 rhizomes m^{-2} [25] while the other served as the control and contains only the solid media. P. karka was used since it is the type available locally and the potential to treat organic contaminant in Phragmites − planted CW has been described in literature [7,17,18,26,27]. The CW water is a BH medium [28] (containing 9in g L^{-1}) 0.2 MgSO$_4$·7H$_2$O, 0.02 CaCl$_2$, 1 KH$_2$PO$_4$, 1 K$_2$HPO$_4$, 1 NH$_4$NO$_3$, and 0.05 FeCl$_3$. The acclimation process involved spiking of the water with 100 mg L^{-1} of benzene weekly for 16 wk to encourage the growth of benzene-degrading bacteria.

Optimal HRT was determined by treating synthetic wastewater (66 mg L^{-1} of benzene in distilled water) in the CW. This concentration was employed in order to preclude inhibitory conditions that affect bacteria as observed at higher concentration and elicit improved contaminant biodegradation commonly observed at concentration lower than 100 mg L^{-1} [29,30]. Benzene removals in the effluent samples from the planted CW at four different HRTs (2, 4, 6, and 8 d) were determined. Optimal HRT is selected and used for the succeeding experiments.

In the actual experimental runs, both systems were fed with synthetic wastewater at the optimal HRT achieved above and at benzene concentrations of 66 mg L^{-1} and another concentration of 45 mg L^{-1} to provide comparison. Effluent samples were taken every day for 3–7 d. Fig. 1 shows a photograph of the actual set-up.

Each effluent sample underwent solvent extraction using hexane to extract benzene. A calibration curve was generated from the extraction and analysis of the standard solutions made by preparing several solutions of benzene at known concentrations. Analyses of actual effluent samples were done by Gas Chromatography with Flame Ionization Detector (GC-FID), and concentrations were determined by comparing with the calibration curve generated. Each of the steps is elaborated in the following paragraphs.

For benzene extraction, 4 mL hexane was added to 50 mL of the collected effluent. The solution was shaken at 120 rpm for 20 min at room temperature to enable effective extraction of the benzene to hexane. The solution is then allowed to stand undisturbed until two distinct layers were formed. One mL of the upper layer solution is suctioned by a syringe and transferred to vials. The samples were securely covered and stored at 4 °C to prevent volatilization of benzene.

The calibration curve was prepared through this procedure. Measured amounts of benzene were spiked in distilled water to achieve concentrations of 10–90 mg L^{-1}. Each of these solutions underwent benzene extraction process as described previously. Analysis with GC-FID gave peak areas that correlated with concentration. A calibration curve constructed from these six benzene levels was used as the basis for the computation of benzene concentrations of the effluent samples tested with the GC-FID method.

The GC used (7890A-Agilent, USA) was fitted with an Agilent HP-5MS 30 m × 0.25 mm × 0.25 µm capillary column and equipped with a FID (6890N-Agilent, USA). Oven, injector, and detector temperatures were 280, 300, and 280 °C respectively. Nitrogen gas was used as the carrier gas.

3. Results and discussion

3.1. Optimal HRT

Fig. 2 summarizes the results of the optimal HRT tests. It is apparent that the treatment efficiency increases with HRT. The same relation was observed in other studies as effluent concentrations increase with loading; however, increasing the HRT higher than 8 d does not result in a significant increase in efficiency anymore [31,32] and will require large-sized CWs. Thus, an HRT of 8 d was used in all test runs in this study.

3.2. Benzene removal efficiency

Fig. 3 shows the benzene removal efficiency with planted and unplanted CW at the feed benzene concentration of 66 mg L^{-1}. Results suggest that while planted CW achieved removals at an average of 48%, the unplanted CW resulted only to around 31% efficiency. This removal efficiency may be lower than that observed in literature [20–24] mainly due to the significantly lower benzene concentrations used in this study. This demonstrates a significant difference of 17% between the treatment efficiencies of the planted and unplanted CW.

The 17% increase in the benzene removal for the planted CW demonstrates that P. karka caused the significant enhancement in removal. This could be attributed to the capacity of plants to release
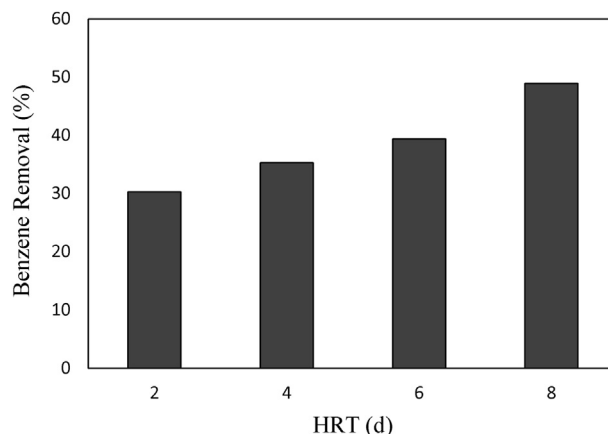

Fig. 1. Surface flow constructed wetland set-up.

Fig. 2. Benzene removal at various HRT.