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Design of a Reed Bed System for Treatment of Domestic Wastewater using Native Plants

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ABSTRACT
The reed bed system is one types of phytoremediation technology for removing pollutants from the environment. This technology provides an environmentally friendly approach to treating contamination with competitive cost, compared to the physico-chemical treatment. The design of reed bed system is highly important in order to achieve the highest pollutant removal efficiency. The design of reed bed system affects the natural oxygen transfer from the environment. The reed bed system was proven to have a good efficiency in removing Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solid (TSS), Total Dissolve Solid (TDS), Total Nitrogen (TN) and a number of bacteria. In addition to the oxygen transfer from the environment, the interaction among pollutant-plants-medium-microbes also plays a vital role in the removal of pollutant using the reed bed system. It was suggested that the future related research should accommodate the importance of several environmental conditions to the interaction between pollutant, plants, medium and microbes as well as the impact of those interactions on the pollutant removal efficiency.

Keywords: domestic wastewater, green technology, interactions, local plants, phytoremediation.

INTRODUCTION

Phytoremediation is one of the treatment technologies that utilize plants to remediate the pollutants in contaminated environments (Ismail et al., 2017; Purwanti et al., 2019). It improves the condition of environments following the removal of the contamination (Bolan et al., 2011). This technology is also considered to be low cost and environmentally friendly in terms of the real implantation (Kinidi and Salleh, 2017; Tien et al., 2018). The reed bed system is a man-made wetland planted with selected species of plants (reeds) which have a capability to take oxygen from the air and release it into the rhizosphere (Manios et al., 2002). As a result of this action, a very high population of micro-organisms is promoted and enhanced in the rhizosphere (Bolan et al., 2011; Safronova et al., 2006; Titah et al., 2018). The reed bed system is a combination of three interdependent key elements: the growing medium, the plants and the micro-organisms (Ismail et al., 2019; Manios et al., 2002; Zhang et al., 2013).

It is necessary to find the optimal reed bed design characteristics such as residence time in order to maximize the removal efficiency under the smallest-as-possible treatment area (Purwanti et al., 2018b). Understanding the behavior of reed beds treating wastewater is required to obtain the optimum condition for wastewater treatment processes. Typically, the domestic wastewater contains pathogens (bacteria), total solids (dissolve and suspended), nutrients (nitrogen and phosphorus), other organic pollutants and traces of heavy metals (Ahmad et al., 2016; Mtshali et al., 2014; Ning et al., 2017; Samer, 2015).

It was reported that up to 18% of rivers were polluted by organic compounds as the presence of high biochemical oxygen demand (BOD). Around 24% of rivers in Malaysia were also polluted by ammoniacal nitrogen (NH_3-N) originated from sewage that may include the livestock farming activities and domestic wastewater (Katayon et al., 2008; Ministry of Science Technology and the Environment Malaysia, 2003). These pollutants need to be brought down to permissible limits before the disposal of effluent by maximizing removal of pollutants from domestic wastewater (Manju et al., 1998; Tangahu et al., 2019; Titah et al., 2019). Hence, this paper was aimed at discussing about the design of reed bed system for treatment of domestic wastewater. Additionally, the paper also aimed at investigating the effectiveness of native plants in treating domestic wastewater. The result of this study may provide a general design of a phytoremediation reactor, especially using a reed bed system and provide an alternative technology for treating the domestic wastewater.

Design of Reed Bed System

Figure 1 presents a schematic diagram for the reed bed system, which was designed for the domestic wastewater treatments. It consisted of four lines; each line has three identical beds made of fiberglass columns of 2 m length, 1 m width and 1 m height. The type of medium used for this reed beds mostly consists of gravel of different size and sand. The gravel of different size was employed as a medium in the system with an alternative arrangement (10–15 mm, 3–5 mm (river sand) and 30–35 mm respectively) instead of the conventional medium arrangement to form multiple layers in the reed beds (Figure 2).

This bed system was designed to provide oxygen on the surfaces in which other organisms can grow and proliferate. The beds were planted with treatment plants which are highly suggested to be native plants already proven to have good capability in removing pollutants (Imron et al., 2019; Ismail et al., 2015; Purwanti et al., 2018b). Numerous flow systems inside the reed bed, including free flow, subsurface flow (horizontal or vertical flow) or combination of these, can be considered for application (Cossu et al., 2001; Mehraban et al., 2008) and the selection of appropriate flow diagram must consider the characteristic of the wastewater and the type of the used plants (Bolan et al., 2011; Shagol et al., 2011; Tangahu et al., 2011). The reed bed system must be operated in parallel during the operation period to overcome the maintenance time (Dodane et al., 2012).

The availability of oxygen in the reed bed matrix mostly is key factor restricting the removal rates of pollutants (Ahmad et al., 2017; Cossu et al., 2001; Darajeh et al., 2014). Therefore, employing good natural recirculation system may influence the performance of a reed bed by increasing the atmospheric oxygen exchange. Recirculation of wastewater may also be installed in order to enable better diffusion of oxygen from the air to maintain aerobic conditions and also enhance the pollutants-plants-microorganisms interaction (Al-Baldawi et al., 2018; Hasan et al., 2016; Hussain et al., 2018; Kumar and Gopal, 2015; Safronova et al., 2006).

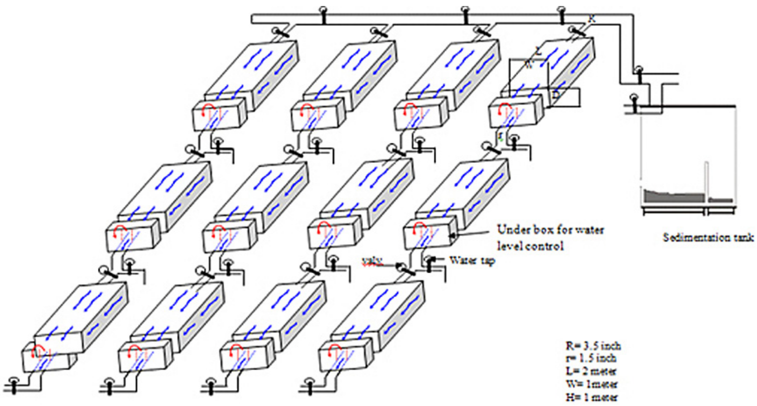

Figure 1. Schematic diagram for the reed bed system

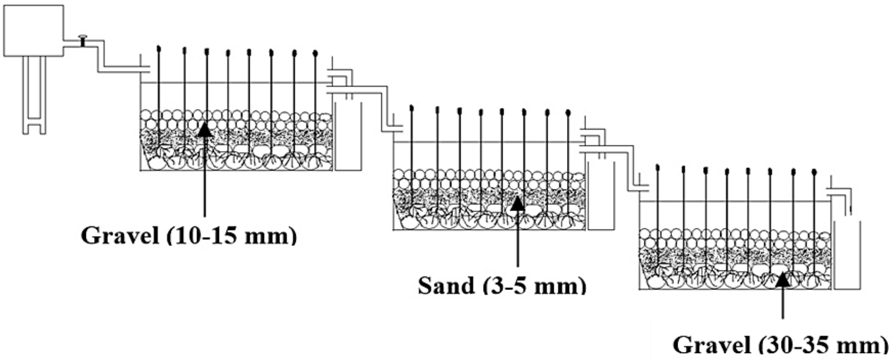

Figure 2. Medium arrangement in this reed bed system

Table 1. Performance of reed bed in treating wastewater

No	Reed bed system	Type of effluent	Plant species	Findings	Source
1	Constructed wetland system	Blackwater	*Vetiveria zizanioides* and *Typha angustifolia*	A reliable performance to reduce BOD and COD of blackwater up to the permissible value with 50% and 56% of total removal, respectively.	Wulandari et al. (2019)
2	Constructed wetland system	Food industry effluent	*Scirpus grossus* and *Typha angustifolia*	The complete treatment plant consisted of anaerobic baffled reactor and constructed wetland showed removal of COD, BOD and nutrient up to 99.71%, 99.76%, and 98.9%, respectively.	Purwanti et al. (2018b)
3	Continuous effluent recirculation system	High strength domestic wastewater	*Phragmites australis*	The system achieved total removal of 77% for COD, 78% for BOD_5, 66% for suspended solid, 62% for NH_4–N, and 38% for phosphorus, which mean that effluent recirculation can be considered to be applied to improve the removal efficiency of reed bed by enhancing interactions between wastewater, plants, and microorganisms either on surface of the medium or in the rhizosphere.	Zhao et al. (2004)
4	Conventional and alternative medium arrangement system	Farm wastewater	*Phragmites australis*	Considerable removal of COD and BOD_5 was obtained in both systems. The total removal percentages of COD reaching up to 74.79% and BOD_5 up to 67.71% in the anti-sized system. These removal efficiencies were slightly higher compared to the progressively-sized system which only reach 71.71% for COD and 66.71% for BOD_5.	Sun et al. (2007)
5	Recirculated system	Farm wastewater	*Cyperus flabelliforis*	Recirculation enhances oxygen transport by pumping and re-distributing the wastewater and increase its contact with air. The increasing contact between wastewater and air will enhance the respiration and activities of the aerobic microorganisms. It also increased the removal of total nitrogen from 71% to 85% and achieving final COD and TKN removal of 95% and 98%, respectively.	Kantawanichkul et al. (2001)
6	Sub-surface system	Domestic wastewater	*Typha latifolia*	Constant removal of NH_3-N, reaching the value up to more than 80%.	Manios et al. (2002)
7	Sub-surface system	Domestic wastewater	*Lepironia articulata*	A total removal of COD, TSS and total coliform up to 77%, 88%, and 99%, respectively, indicating that sub-surface system may also handle the high number of bacteria in wastewater.	Katayon et al. (2008)

Reed bed performance and selection of plants

The performance of reed bed in treating the domestic wastewater is remarkably good. The presented design might provide a better removal efficiency of some parameters in domestic wastewater by providing a better natural oxygen transfer. For additional reference, some studies mention the removal efficiency of the reed bed in treating wastewater, as tabulated oinn Table 1.

In addition to the reed bed system, the capability of the plants used is a non-separated contribution to the overall reed bed performance (Manios et al., 2002; Reed and Glick, 2005; Zhang et al., 2013). It is highly suggested that the involved plants should be native to the location, because it has a better adaptability to the surrounding environmental condition (Abdullah et al., 2020). Since this design will be applied in Malaysia, some Asian native plant species which had been proven to have a good capability in treating wastewater are summarized in Table 2.

Future research approaches

Further research in the reed bed topic may analyze the optimum environmental condition during the treatment period. The optimum environmental condition may include retention time (Koottatep and Polprasert, 1997), pH (Dakora and Phillips, 2002), temperature (Vlaev et al., 2011), and the flow system (Cossu et al., 2001; Yasmin et al., 2016). The analysis of the environmental condition is highly suggested to consider the interaction of plant-medium and also plant-microbes during the reed bed treatment. The highest removal of pollutant is considered to be obtained by achieving the optimum condition for medium-plant-microbes interaction.

CONCLUSIONS

Reed bed is proven to be highly reliable in treating wastewater, especially from the domestic source. A good reed bed design will give a better chance to

Table 2. Performance of the native Asian plants involved in reed bed system in treating wastewater

No	Plant species	Type of plant	Location	Summary	Source
1	*Azolla pinnata*	Aquatic	Malaysia	*A. pinnata* showing a very reliable removal of COD up to 100% from the pulp and paper industry with the initial concentration of 72.4 mg/L.	Ahmad et al. (2017)
2	*Chara vulgaris*	Aquatic	India	Maximum removal of Total Dissolve Solid, COD, BOD, and electro conductivity of 68%, 78%, 82% and 86%, respectively were obtained in the 10% of textile effluent concentration after 120 h of treatment using *C. vulgaris*.	Mahajan et al. (2019)
3	*Cyperus flabelliforis*	Terrestrial	Thailand	The involvement of C. *flabelliforis* under vertical recirculated vegetated bed showed a good removal efficiency of total nitrogen, COD and TKN up to 85%, 95% and 98%, respectively.	Kantawanichkul et al. (2001)
4	*Cyperus rotundus*	Terrestrial	Indonesia	*C. rotundus* having high tolerance to the BOD content in wastewater up to 7,500 mg/L. This species can grow well under high organic stress originated from industrial wastewater.	Purwanti et al. (2018a)
5	*Lemna minor*	Aquatic	Malaysia and Indonesia	*L. minor* showed a good capability in transferring oxygen to water, which result in a better pollutant oxidation and showing a removal efficiency of NH_4-N up to 91%.	Cossu et al. (2001)
6	*Lepironia articulata*	Terrestrial	Malaysia	Constructed wetlands planted with *L. articulata* successfully removed Total Suspended Solid (50.18–88.49%), COD (56.77–77.62%), Phosphorus (15.99–88.68%), NH_4^+ (27.50–96.34%), and total coliforms (99%). This plant also showed a capability in removing Total Coli up to 86%.	Katayon et al. (2008); Yasmin et al. (2016)
7	*Salvinia molesta*	Aquatic	Malaysia	This species showed a total removal of 100% COD from the wastewater of pulp and paper industry.	Ahmad et al. (2017)
8	*Scirpus grossus*	Terrestrial	Malaysia and Indonesia	Constructed wetland planted with *S. grossus* showed a good performance in removing nutrient and fecal coliform bacteria. This plant also showed good capability in tolerating high COD content wastewater up to 7,500 mg/L.	Purwanti et al. (2018a); Tanaka et al. (2006)

achieve higher removal efficiency of pollutants by providing higher natural oxygen exchange. The application of reed bed treatment was shown to have a capability in removing TSS, COD, BOD, Total Nitrogen, TKN and also bacteria. The performance of reed bed in removing pollutants cannot be separated from the capability of the involved plants species. The interaction between pollutant, medium, plants and also microbes plays an important role in treating wastewater using the reed bed system.

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