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Treatment performances of a manganese ore constructed wetland for lignite-derived water

Chunhui Zhang*, Ke Ning, Yuanjie Guo, Jun Chen, Chen Liang, Xiaodong Zhang, Ruitong Wang, Lingxiao Guo

School of Chemical & Environmental Engineering, China University of Mining & Technology (Beijing), Room 202, Environmental Protection Building, No. Ding 11 Xueyuan Road, Beijing 100083, China
Tel./Fax: +861062331025; email: truemanjung@163.com

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ABSTRACT

To reclaim the lignite-derived created during the dehydration procedure of lignite as cooling water; a laboratory-scale horizontal subsurface flow constructed wetland was designed to treat this lignite-derived water in this research. In laboratory-scale wetlands, manganese ore constructed wetland was proven to be a feasible treatment technology for lignite-derived water reclamation. Comparing with lignite constructed wetland, manganese ore wetland showed better removal for all target pollutants including Fe, Mn, Chemical oxygen demand (COD), turbidity, and NH_3–N. The removal efficiencies of COD, turbidity, and NH_3–N increased accordingly with the increase of hydraulic retention time from 2 to 5 d inside both wetlands. With the hydraulic residence times at 5 d, the COD, turbidity, NH_3–N Fe, and Mn removal efficiencies were up to 76.2, 95.0, 84.8, 64.3, and 93.0% in the manganese ore case, respectively. After the treatment of manganese ore constructed wetland the COD, turbidity, ammonia nitrogen, Fe, and Mn concentrations can supply the requirement of national standard of reclaimed water quality (GB/T 19923-2005).

Keywords: Lignite-derived water; Manganese ore; Lignite; Constructed wetland; Wastewater reuse

1. Introduction

The moisture content of lignite in China is 30–50%, which is a major factor affecting the thermal efficiency of power generation. To remove the moisture of lignite, the lignite dehydration procedure must be processed. Approximately 85% of lignite moisture, which is called lignite-derived water, can be extruded in the dewatering procedure of lignite [1]. Most of lignite deposit regions in China are located in water shortage areas. The lignite-derived water should be a significant additional water resource [2]. Some previous studies on the water quality of lignite-derived water indicated that the concentrations of contaminants in lignite-derived water generally exceeded the guideline levels for most potential uses [3]. Therefore, lignite-derived water must be required to undergo some treatment processes prior to reuse. In Australia, the lignite-derived water produced by mechanical thermal expression process was treated by a combined anaerobic digestion and chemical method [4].

*Corresponding author.

In this research, a kind of horizontal subsurface flow constructed wetland was designed to remove impurities of the lignite-derived water. As an advanced treatment wastewater technology constructed wetland is characterized by low capital and operational cost, easy maintenance, versatility, and resistance to load shock [5]. Constructed wetland is widely applied to the removal of suspended solids, organics, and heavy metals [6]. Substratum is the core component of constructed wetland, which is not only responsible for the degradation of many pollutants but also functions as supporter and nutrient source to plants of constructed wetland. The selection of substratum can target at the removal of a specific pollutant. For example, gravel is normally the priority when aiming at the removal of organics while steel slag is often used for phosphorus removal [7,8].

In this research, a manganese ore constructed wetland is proposed to polish the lignite-derived water.

The aim is to examine its removal efficiency for iron, manganese, and organics in lignite-derived water reclamation. It is known to all that manganese ore is a favorable medium for its high adsorption capacity of iron and manganese [9–11]. Braeckevelt et al. applied a constructed wetland with lignite substratum for remediation of monochlorobenzene in contaminated groundwater [12]. Owing to the conveniently obtained of materials, the lignite was used as a kind of substratum in constructed wetland as a comparison with manganese ore. The aim of the present study is to examine the removal efficiency of a kind of horizontal subsurface flow constructed wetland to treat the lignite-derived water. The scope of the research was to document the investigation and removal of iron, manganese, and organics in lignite-derived water.

2. Materials and methods

2.1. Configuration of laboratory-scale constructed wetlands

Fig. 1 shows a schematic of the experimental layout of laboratoty-scale manganese ore constructed wetland and lignite constructed wetland. Each of these two horizontal subsurface flow constructed wetland was confined inside a PVC tank, which is 2 m long, 0.5 m wide and 0.6 m high. The substratum layer is 50 cm deep, composed of either 6–8 mm manganese ore or 5–30 mm lignite without any soil on the surface. The manganese ore (MnO_2: 38.6%; Density: 3.56 g/cm^3) was purchased from Henan Filter Co. Ltd, China. The lignite (total moisture content: 31%; carbon content: 66.56%; and density: 1.33 g/cm^3) was taken from Baori, Inner Mongolia, China. Reed planting density was set at 16–20 plants per square meter, spacing of plants was 20–25 cm. Gravels were arranged at influent and effluent areas to guarantee the even distribution of water. In order to facilitate sampling and analysis, the passing tubes were installed at starting edge, ending edge, and 1/4, 2/4, 3/4 of the middle in constructed wetland.

2.2. Characteristics of lignite-derived water

The lignite-derived water is expressed by temperature and by pressure imposed on the lignite during the quality upgrading process. Its characteristics were summarized in Table 1. Although the lignite-derived water quality conformed to “Integrated wastewater discharge standard” (GB 8978-1996) [13], it was still below the requirement of national standard of reclaimed water quality (GB/T 19923-2005) [14], regarding Fe, Mn, COD_{Cr}, turbidity, and NH_3–N.

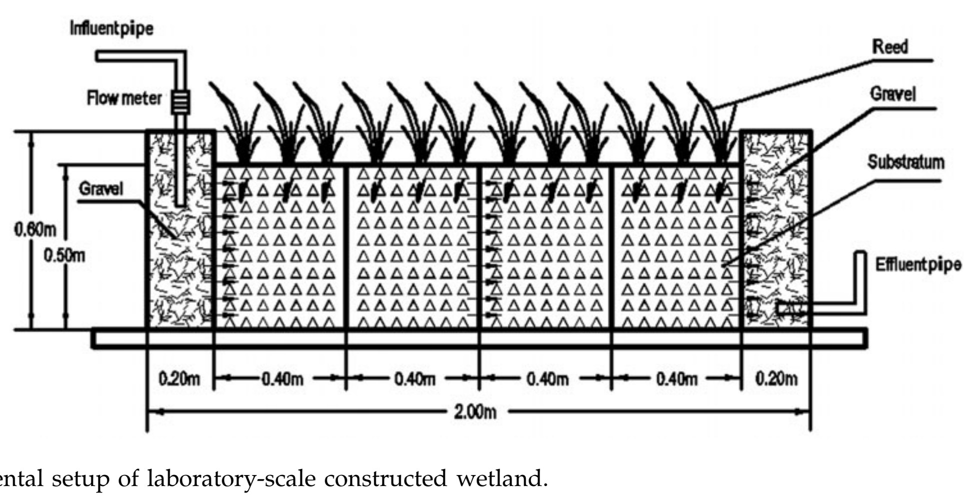

Fig. 1. Experimental setup of laboratory-scale constructed wetland.

Table 1
Characteristics of lignite-derived water

Parameter	pH		Turbidity (NTU)		Fe (mg/L)		Mn (mg/L)		COD_{Cr} (mg/L)		NH_3–N (mg/L)	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Concentration	6.5–7.2	6.7	10.6–17.5	14.6	0.23–0.36	0.28	0.45–0.64	0.51	138.3–205.6	182.5	16.0–20.2	18.0
Reclaimed water quality as cooling water (GB/T 19923-2005)	6.5–9		5		0.3		0.1		60		10	

2.3. Analytical reagents and methods

All reagents used in analysis were obtained from Beijing Chemical Reagent Company (Beijing, China) and conformed to the purity requirements of analytic grade. The lignite-derived water was analyzed for various parameters according to standard methods of China [15]. COD_{Cr} was determined using potassium dichromate titration method. Ammonia nitrogen test was performed using colorimetry method, turbidity was measured by a 2100P Portable Turbidimeter (Hach, USA), and the pH value was measured by a Shanghai Leici PHS-3D brand pH-meter. Fe and Mn were measured by spectrophotometry method.

3. Results and discussion

3.1. Removal of COD, turbidity, and ammonia nitrogen

In both the wetland systems under various hydraulic retention times, Table 2 summarized the removal of COD, turbidity, and ammonia nitrogen.

It can be seen that constructed wetland treatment improved the quality of lignite-derived water significantly. In the manganese ore case the COD, turbidity, and NH_3–N removal efficiencies were 62.8–76.2, 81.8–95.0 and 79.2–84.8%, respectively. While for lignite substratum the COD, turbidity, and NH_3–N removal efficiencies were 53.9–65.5, 74.2–93.3, and 80.8–85.5%. In general, manganese ore wetland exhibited a slightly better performance than lignite. This difference may be ascribed to the different size of manganese ore and lignite. According to the research of Xu et al. [10], the smaller size of substratum used in wetland owns a much larger specific surface area for filtration and biofilm development, which can achieve better removal of turbidity and organics. With regard to the influence of hydraulic retention time, both wetlands showed similar variation trend. Overall, the removal efficiencies of COD, turbidity, and NH_3–N increased accordingly with the increase of hydraulic retention time. The absorption and degradation of matrix, microorganism, and plants in the wetland are the main approaches to remove the pollutants. When the hydraulic residence time is short, the absorption of pollutants does not reach the adsorption equilibrium and the degradation of pollutants needs certain action time. Therefore, the pollutants are taken out of the system when not completely degraded, resulting in low removal efficiency. Whereas, long hydraulic residence times cause the running costs of constructed wetlands. In our study, the optimal hydraulic residence time is set at 5 days.

3.2. Removal of iron and manganese

Figs. 2 and 3 show the removal efficiencies of Fe and Mn in both constructed wetlands with the hydraulic residence times at 5 days.

With the Fe influent concentration varying from 0.23–0.36 mg/L and Mn influent concentration varying from 0.45–0.59 mg/L, it can be seen that in the manganese ore case the Fe and Mn concentrations can be reduced to 0.09–0.15 and 0.04–0.08 mg/L, respectively. While for lignite substratum, the Fe and Mn concentrations can be reduced to 0.14–0.19 and 0.06–0.13 mg/L, respectively. Similarly, manganese ore wetland showed better and stable removal efficiencies of Fe and Mn than lignite wetland.

3.3. Discussion

In the present study, the treated lignite-derived water is to be used as boiler makeup water. Under high temperature and pressure, most of the organic pollutants in boiler water should bring about hydrolysis. Acidic substances will be produced after organic pollutants hydrolysis. These acidic substances should cause a decrease in the pH value of the boiler water. Corrosion hazards should happen for the above reason. Therefore, the removal of the organic pollutants

Table 2
Removal efficiency of COD, turbidity, and ammonia nitrogen in manganese ore and lignite at various HRT

Substratum	HRT (d)	COD			Turbidity			Ammonia nitrogen		
		Influent (mg/L)	Effluent (mg/L)	Removal (%)	Influent (mg/L)	Effluent (mg/L)	Removal (%)	Influent (mg/L)	Effluent (mg/L)	Removal (%)
Manganese ore	5	165.5 ± 12.3	43.1 ± 5.8	76.2	12.6 ± 6.4	0.55 ± 0.21	95.0	17.4 ± 4.8	2.91 ± 1.55	84.8
	4	170.2 ± 14.5	50.6 ± 7.4	70.5	11.4 ± 5.8	0.73 ± 0.19	93.6	18.0 ± 4.3	3.55 ± 1.48	81.5
	3	161.6 ± 11.7	56.8 ± 8.2	66.4	13.0 ± 6.5	1.45 ± 0.25	87.2	15.5 ± 3.7	2.69 ± 1.21	83.9
	2	153.7 ± 10.9	58.9 ± 6.5	62.8	12.2 ± 7.1	2.06 ± 0.23	81.8	14.3 ± 5.5	2.88 ± 0.85	79.2
Lignite	5	165.5 ± 12.3	57.4 ± 8.8	65.5	12.6 ± 6.4	0.79 ± 0.15	93.3	17.4 ± 4.8	2.60 ± 0.64	85.5
	4	170.2 ± 14.5	65.2 ± 9.3	61.2	11.4 ± 5.8	1.37 ± 0.22	86.9	18.0 ± 4.3	2.95 ± 0.72	84.0
	3	161.6 ± 11.7	67.5 ± 8.1	58.6	13.0 ± 6.5	2.16 ± 0.14	82.1	15.5 ± 3.7	2.71 ± 0.49	82.6
	2	153.7 ± 10.9	73.3 ± 10.2	53.9	12.2 ± 7.1	3.05 ± 0.58	74.2	14.3 ± 5.5	2.84 ± 0.57	80.8

Note: All values were reported as mean ± standard deviation.

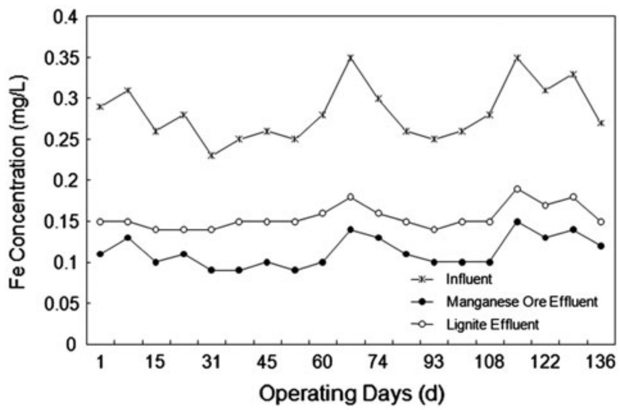

Fig. 2. Fe concentration variation in manganese ore and lignite constructed wetlands.

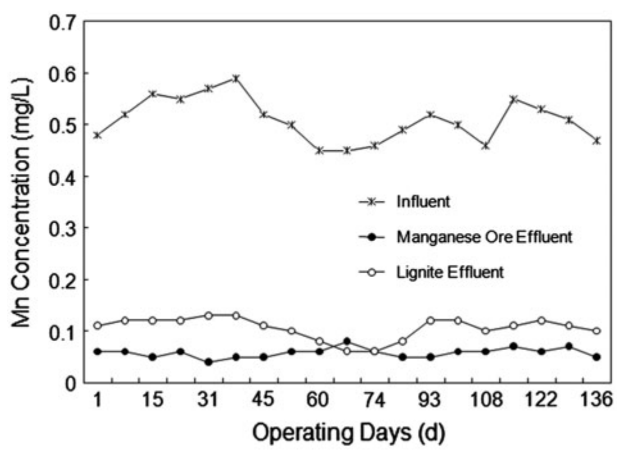

Fig. 3. Mn concentration variation in manganese ore and lignite constructed wetlands.

in the boiler water is very necessary [16]. In previous studies, Aslam et al. applied vertical flow constructed wetlands with compost-filled and gravel-filled media to treat refinery wastewater [17]. The COD influent of refinery wastewater was 165–347 mg/L. After the constructed wetland treatment, the removal efficiencies for the compost and gravel wetlands of COD were 45–78 and 33–61%, respectively. To reclaim treated steel wastewater as cooling water, manganese ore and gravel constructed wetlands were proposed by Xu et al. [10]. Their research results show that the manganese ore constructed wetland removals for COD, turbidity, ammonia–nitrogen, and total phosphorus were 55, 90, 67, and 93%, respectively, superior to the corresponding removals in the gravel wetland (31, 86, 58, and 78%, respectively). Generally, our research results are consistent with the former archives [18,19].

Base on our research, we can see that Fe and Mn are common constituents in lignite-derived water, similar to coal mine drainage. In particular, Butler et al. found that Fe concentration in lignite-derived water produced from mechanical thermal expression processing was 15–55 mg/L, which was much higher compared with the corresponding Fe concentration in lignite-derived water of our research [3]. The difference of water quality, especially for Fe concentration, is mainly due to the different areas of lignite origin. When the boiler water contains Fe or Mn, the metal fouling will be formed in the metal heating surface. Due to the difference in potential between the metal surface and fouling, portion corrosion of the metal will start up, which will cause metal perforated or burst. It is very important for removal of Fe or Mn in boiler water [20]. According to the precious researches, Goulet and Pick evaluated a surface flow wetland for remediation of Fe and Mn in wastewater. The results indicate that the Fe and Mn concentration in wastewater can be removed 11 and 40%, respectively [21]. Vymazal and Švehla pointed out that constructed wetlands were an effective treatment method for the removal of Fe and Mn, because Fe and Mn were predominantly entering the constructed wetlands with the wastewater [11]. In this study, the manganese ore wetland achieved much better removal efficiencies for organic pollutants, Fe and Mn than lignite wetland. This strongly suggested the important role of manganese ore as a good substratum for removing organic pollutants, Fe and Mn inside the constructed wetland.

4. Conclusions

A large amount of lignite-derived water is derived during the dehydration procedure of lignite. The concentration of Fe, Mn, COD_{Cr}, turbiditym and NH_3–N of the lignite-derived water is below the requirement of national standard of reclaimed water quality (GB/T 19923-2005). In this study, a laboratory-scale horizontal subsurface flow constructed wetland is developed to treat lignite-derived water. Manganese ore constructed wetland was proven to be a feasible treatment technology for lignite-derived water reclamation. Comparing to lignite constructed wetland, manganese ore wetland showed better removal for all target pollutants, including Fe, Mn, COD_{Cr}, turbidity, and NH_3–N. The removal efficiencies of COD, turbidity, and NH_3–N increased accordingly with the increase of hydraulic retention time from 2 to 5 d inside both wetlands. With the hydraulic residence times at 5 d, the COD, turbidity, NH_3–N Fe, and Mn removal efficiencies were up to 76.2, 95.0, 84.8, 64.3, and 93.0% in the manganese ore case, respectively. After the treatment of manganese ore constructed wetland, the COD, turbidity, ammonia nitrogen, Fe, and Mn concentrations can supply the requirement of national standard of reclaimed water quality (GB/T 19923-2005).

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