A comparative study of removal efficiency of organic contaminant in landfill leachate contaminated groundwater under micro-nano-bubble and common bubble aeration

Mei Bai
Southeast University
Zhibin Liu (seulzb@seu.edu.cn)
Southeast University https://orcid.org/0000-0001-6602-1275
Liangtong Zhan
Zhejiang University
Zhu Liu
Southeast University
Zhanhuang Fan
Cecep Dadi (Hangzhou) Environmental Remediation Co., Ltd.

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Abstract

Landfill leachate contaminated groundwater is widespread all over the world. In order to study the organic contaminant removal efficiency of landfill leachate contaminated groundwater under oxygen micro-nano-bubble (MNB) aeration, a series of lab-scale experiments of oxygen MNB aeration as well as common bubble (CB) aeration were conducted. On the one hand, the difference of mass transfer, microbial activity enhancement and contaminant removal efficiency between MNB and CB aeration were estimated. On the other hand, the composition variations of dissolved organic matter (DOM) in groundwater treated by MNB or CB aeration were characterized by ultraviolet-visible (UV-VIS) absorption spectrum and fluorescence excitation-emission matrix (EEM). The test results showed that the oxygen utilization efficiency and volumetric oxygen transfer coefficient of MNB aeration were 10 and 50 times that of oxygen CB aeration, respectively. On the 30th day after MNB aeration, the dehydrogenase activity (DHA) of groundwater increased by 101.25%. Compared with CB aeration, the chemical oxygen demand (COD), 5-day biochemical oxygen demand (BOD_5) and ammonia nitrogen removal efficiency under MNB aeration increased by 29.72%, 13.43% and 138.59%, respectively. With the biodegradation effect of MNB aeration, a large number of protein-like and soluble microbial by-product substances were degraded, and humic and fulvic acid-like substances were degraded to a certain level. Oxygen MNB aeration played a chemical oxidation effect while enhancing the biodegradation of groundwater, and it was an energy-efficient landfill leachate contaminated groundwater treatment method.

1. Introduction

Sanitary landfilling is the most widely applied solid waste management method (Kaza et al., 2018). In landfills, waste, liquid present in the waste and percolated rain water interact and result in leachate. The leachate has high chemical oxygen demand (COD) content, high ammonium nitrogen content and lasting toxicological characteristics (Alslaibi et al., 2011; Li et al., 2014; Regadio et al., 2012; Yang et al., 2013). When the liners of landfill failed, the leakage of leachate often leads to the contamination of groundwater and soil. Landfills are considered to be important sources of groundwater contamination. The major groundwater contaminants from landfill include ammonia, organic matter, such as COD, heavy metals and so on (Alslaibi et al., 2011; Milosevic et al., 2012; Regadio et al., 2012; Smahi et al., 2013; Tian et al., 2005). These contaminants pose great threat to human health.

Over the last few decades, a variety of different physical, chemical and biological technologies have already been used to remove or degrade contaminants from groundwater(Grover et al., 2011; Zhang and Zhou, 2008). In situ bioremediation is one of the most widely used groundwater remediation techniques (Azubuike et al., 2016). it is an eco-friendly and low cost approach. Specifically, in situ bioremediation is achieved by providing substrates to stimulate the growth of native microbial species at first, and then the microorganisms transform contaminants into less harmful daughter products (Albers et al., 2015). Aeration is the most common method to stimulate microbial growth. However, traditional aeration consumes more than 50% of the total energy requirement in wastewater treatment plants (Belloir et al., 2015). Sander et al.(2017), Xiao and Xu (2020) found that fine bubbles aeration could save approximately 20% operating cost than conventional aeration. As a kind of fine bubbles, micro-nano-bubbles (MNB) has sm all diameter (with a diameter of 200 nm-50 μm), large specific surface area and low rising velocity in liquid, and it persists for long periods and significantly improves gas solubility (Feng et al., 2020; Hu and Xia, 2018). With the superior mass transfer characteristics, MNB has received continuous attention in the fields of aeration(Ye et al., 2019; Zhang and Guiraud, 2017).

Some studies about contaminant removal efficiency under MNB aeration have shown satisfactory performance. As a pretreatment technique, MNB has been shown to be highly beneficial for downsizing the water/wastewater treatment plants and improving the quality of product water (Kazuyuki et al., 2010; Kazuyuki et al., 2009). In aerobic biofilm system, air nanobubble aeration accelerated the growth of the biofilm and achieved better removal efficiency of COD and ammonia nitrogen. The dehydrogenase activity was as maximum as six times higher than that of traditional aeration (Xiao and Xu, 2020). In membrane bioreactor, oxygen MNB markedly enhanced the removal efficiency of contaminants compared with conventional air aeration, and the pure oxygen provided a high dissolved oxygen condition which would influence the biomass activity by affecting the enzymatic activities (Zhuang et al., 2016). Due to the characteristic of high mass transfer efficiency (Bai et al., 2021; Xiao and Xu, 2020), the strong of bubble migration (Kristen et al., 1993; Li et al., 2014) and high pollutant degradation efficiency, MNB aeration has become a promising measure for wastewater remediation.

As mentioned above, groundwater contamination resulting from the landfill leachate is widespread. However, little investigation has been done about treatment of landfill leachate contaminated groundwater by MNB aeration. Different from industrial pollution sites, there are compound contaminants such as organic matter, inorganic salt and heavy metal in solid waste landfill site. For landfill leachate contaminated groundwater, the main contaminants, such as COD, ammonia nitrogen and heavy metal, are degradable and transformable, and their concentrations fluctuate greatly in time and space. Therefore, it is very important to study the contaminant removal efficiency on landfill leachate contaminated groundwater under MNB aeration and its mechanism.

The objective of the present work was to evaluate the effect of oxygen MNB aeration on the organic contaminant removal and composition variation of landfill leachate contaminated groundwater. Furthermore, the difference between oxygen MNB and common bubble (CB) aeration was investigated. Specifically, the groundwater samples were treated by oxygen MNB or CB aeration at first, respectively. The mass transfer efficiency of MNB and CB aeration were estimated by the dissolved oxygen (DO) value variations during aeration. Then, according to the concentration variation of COD, 5-day biochemical oxygen demand (BOD_5), ammonia nitrogen and dehydrogenase in groundwater samples before and after MNB or CB aeration, the contaminant removal and microbial activity enhancement efficiency of MNB aeration on landfill leachate contaminated groundwater were evaluated. After that, the composition variation of dissolved organic matter (DOM) in groundwater before and after MNB or CB aeration were characterized by ultraviolet-visible (UV-VIS) absorption spectrum and fluorescence excitation-emission matrix (EEM). At last, the energy consumption of MNB and CB aeration were estimated.

2. Material And Methods

2.1. Material

Landfill leachate was collected from Woqishan Landfill (Wenzhou, Zhejiang province, China). The collected leachate was stored in a brown glass reagent bottle in refrigerator at 4 ℃. The landfill leachate was diluted 20 times with distilled water, and it was taken as the synthetic landfill leachate contaminated groundwater sample. Raw groundwater in this study is referred to as the synthetic landfill leachate contaminated groundwater. The average composition of the synthetic landfill leachate contaminated groundwater was given as follows: pH, 8.8; total dissolved solids (TDS), 1.23 ppt; COD, 320 mg/L; BOD_5, 91 mg/L; ammonia nitrogen, 123.15 mg/L; total nitrogen (TN), 249 mg/L. All the chemical reagents used in the work were of analytical grade.

2.2. Experiment methods

The schematic of the experimental apparatus is shown in Fig. 1. MNB and CB column were consisted of a plexiglass cylinder with inner diameter of 260 mm and a height of 650 mm. There was 20 L landfill leachate contaminated groundwater in MNB and CB column, respectively. Pressurized dissolution type MNB generator (XZCP-K-1.1, Yunnan Xiazhichun Environmental Protection Technology Co., Ltd, China) was used for MNB aeration. The method of MNB aeration was described in previous literature(Bai et al., 2021). CB was generated by the tube with a diameter of 3 mm. During the MNB and CB aeration, oxygen was injected at a rate of 1.8 L/min and the DO concentration in MNB and CB column were recorded by DO meter (YSI ProSolo). The MNB and CB aeration lasted for 5 minutes. Once the aeration was finished, the groundwater samples containing oxygen MNB and CB were sealed in brown glass reagent bottles and were stored at 20 ℃ in an incubator (Boxun, XPS-250B-Z). On the 3rd, 5th, 10th, 15th, 20th and 30th day after aeration, the groundwater samples were analyzed.

2.3. Analysis

COD and ammonia nitrogen were measured colorimetrically (COD: 20-1500 mg/L range, HACH, Loveland, CO, USA; ammonia nitrogen: 0.4-50 mg/L range, HACH, Loveland, CO, USA). BOD_5 was determined by the dilution and seeding method(SEPA, 2002). All analytical measurements were done at least in triplicate, and the standard deviation was found to be below 5% in all cases.

The molecular electronic absorption spectra was obtained using the UV-VIS Spectrophotometer (Shimadzu, UV3600) in quartz cuvettes (3 mL and 1 cm optical path). UV-VIS absorbance spectra was conducted under an wavelength range of 200-600 nm at 1 nm intervals. Fluorescence excitation-emission matrix (EEM) analysis was made with a fluorescence spectrometer (Edinburgh Instruments, FS5) under the excitation (Ex) wavelength 230-550 nm at 5 nm increments across an emission (Em) wavelength 250-650 nm at 1 nm intervals. UV-VIS absorbance and EEM analysis were made with groundwater samples diluted 1:20.

The dehydrogenase activity (DHA) is a group of enzymes involved in the redox reaction in cellular respiration using organic matter as the substrate and plays a crucial role in cell energy metabolism. Analysis of DHA is a common test for the quantification of microbial activity. In this study, the triphenyl tetrazolium chloride (TTC)-DHA test was used to compare differences in the microbial activity of the groundwater before and after MNB or CB aeration, respectively. The test of DHA was done according to the research work of Wang et al. (2017).

3. Results And Discussion

3.1. Contaminant removal efficiency

Figure 2 showed that the concentration of COD, BOD_5 and ammonia nitrogen in groundwater all decreased after MNB and CB aeration. The COD concentration in groundwater treated by MNB aeration was higher than that in groundwater treated by CB aeration within 10 days after aeration and decreased continuously thereafter, and it was less than treated by CB aeration eventually. Specifically, on the 30th day after aeration, the COD removal efficiency was 50.94% under MNB aeration and it was 39.27% under CB aeration. The BOD_5 concentration in groundwater treated by both MNB and CB aeration were almost the same within 10 days. However, value of BOD_5 concentration in groundwater treated by MNB aeration was gradually became less than that in groundwater treated by CB aeration with time. On the 30th day after aeration, BOD_5 removal efficiency was 94.91% by MNB aeration, while 83.67% of BOD_5 was removed by CB aeration. The ammonia nitrogen concentration decreased during the initial 5 days after MNB and CB aeration and increased continuously thereafter. On the 3rd day after aeration, 16.77% and 22.05% of ammonia nitrogen were removed by MNB and CB aeration, respectively. However, on the 30th day, the ammonia nitrogen removal efficiency decreased to 12.55% under MNB aeration, and it decreased to 5.26% under CB aeration. The main reason of the decrease in ammonia nitrogen removal efficiency was that organic nitrogen was transformed into ammonia nitrogen in the process of ammoniation. In addition, it can be concluded that the MNB aeration had better ammonia nitrogen removal efficiency than CB aeration. As a whole, MNB aeration showed relatively better performance. Compared with CB aeration, the COD, BOD_5 and ammonia nitrogen removal efficiency under MNB aeration increased by 29.72%, 13.43% and 138.59% on the 30th day after aeration, respectively.

It is notable that MNB aeration could significantly improve COD, BOD_5 and ammonia nitrogen removal efficiency. An important reason for this phenomenon was probably owing to the improved biomass activity by the higher oxygen transfer efficiency of MNB aeration. Fig. 3 (a) shows the DO variations in groundwater during MNB and CB aeration. The DO value, with the initial value of 4.7 mg/L, increased gradually with time. During MNB aeration, the DO increased to the maximum value of 39.27 mg/L rapidly within 100 s, and afterward it kept the same value. However, it increased continuously during the whole process of CB aeration and reached 8.36 mg/L at the end.

As shown in Fig. 3 (b), the DO peak value of groundwater during MNB aeration was greater than that during CB aeration, although the same amount oxygen was injected. If the dissolved phase of oxygen is regarded as the effective use of oxygen, the oxygen utilization efficiency can be calculated by the following equation:

$$R = \frac{\left(m - P_{DO} \times V\right)}{m} \times 100\% \quad (1)$$

where, R is oxygen utilization efficiency, %; m is oxygen input mass, mg; P_{DO} is the peak value of DO, mg/L; and the V is the volume of groundwater sample, L. As shown in Fig. 3 (b), oxygen utilization efficiency of MNB aeration was 10 times that of CB aeration. The fast increase rate of DO, the great DO peak value and the higher oxygen utilization efficiency in groundwater during MNB aeration resulted from high mass transfer efficiency of MNB. In order to investigate the mass transfer efficiency of MNB and CB aeration, the volumetric oxygen transfer coefficient (k_La) of MNB and CB were calculated by the following equation(Bai et al., 2021):

$$\frac{dC^*}{dt} = k_La\left(C_s^* - C^*\right) \quad (2)$$

where, k_La is the volumetric mass-transfer coefficient, 1/s; C^* is DO concentration at time t, g/m^3; and C_s^* is DO concentration at saturation, g/m^3. The k_La values of MNB and CB are shown in Fig. 3 (b). The k_La of MNB was 50 times that of CB. The reason for this phenomenon was that small bubble size of MNB led to the increase of gas-liquid interfacial area per unit gas volume. The great k_La of MNB was speculated to be the main reason for the improved contaminant removal performance.

DHA is the representation of the oxidative dehydrogenation process responding to oxygen supplementation, so it is commonly used for evaluating the activities of aerobic microorganisms in activated sludge (He et al., 2007; Zou et al., 2009). In this research, DHA of groundwater before and after aeration were investigated to reveal the influence of MNB and CB aeration on the microbial activity of groundwater. Fig. 4 shows the variations of DHA of groundwater before and after MNB or CB aeration. The DHA of all the groundwater samples increased gradually with time. From the 20th to 30th day after aeration, it increased sharply with the accumulation of activated microorganisms. And it in groundwater treated by MNB aeration was 101.25% higher than raw groundwater. In addition, The DHA in groundwater treated by MNB aeration was always higher than that in groundwater treated by CB aeration. The reason was that DO concentration of groundwater treated by MNB aeration was considerably high (39.27 mg/L), which provided sufficient electron donor during the metabolic process and significantly accelerated the enzymatic activity(Zhuang et al., 2016). In addition, high microbial activity in groundwater treated by MNB aeration was the reason of high COD, BOD_5 and ammonia nitrogen removal efficiency under MNB aeration.

3.2. Characterization of DOM before and after oxidation

3.2.1 UV-VIS absorbance spectra of groundwater

The UV-VIS absorbance spectra (200-600 nm) of groundwater before and after MNB or CB aeration are presented in Fig. 5. The DOM in landfill leachate contaminated groundwater was complex, so there was no obvious absorption peak in UV-VIS absorbance spectra of groundwater. Fig. 5 showed that the absorption of raw groundwater in the ultraviolet region (wavelength <290 nm) was strong, and then it decreased sharply after MNB and CB aeration. According to research work of Chen et al.(2019), the absorption in the wavelength below 250 nm indicates the presence of conjugated unsaturated bonds, and it in range of 250-290 nm suggests the existence of heterocyclic aromatic hydrocarbon. Thus, it can be concluded that the aromatic organic matters in groundwater were degraded or decomposed into small molecular substances by MNB and CB aeration, and the UV- quenching polar functional groups were destructed during these treatments.

The UV-VIS absorbance spectra of groundwater before and after aeration are further analyzed, and the results are shown in Fig. 6. The ration of E250/E365 correlates strongly with the averaged molecular weight of organic matter, and the ration of E300/E400 represents the humification, aromaticity and molecular weight of organic matter(Artingera et al., 2000; Peuravuori and Pihlaja, 1997). In this research the values of E250/E365 and E300/E400 decreased from 9.2 to 2.8 and from 4.5 to 2.2 on the 30th day after MNB or CB aeration, respectively. The phenomenon revealed that the molecular structure degree and condensation degree of organic matter in groundwater increased after MNB and CB aeration. In addition, the specific absorbance of E254, E280 and S239-400 can be used to explain the degradation pathway of DOM in groundwater(Gregory et al., 1997; Guo et al., 2011; Kavurmaci and Bekbolet, 2014). E254 is a distinctive feature of electronic spectra of aromatic compound. E280 represents the relative hydrophobic size of organic matter. Likewise, S239-400 characterizes the change in benzene compound. As seen in Fig. 6(b), the values of E254, E280 and S239-400 decreased with time after MNB and CB aeration, suggesting that the aromatic C=C structure was broken. Therefore, MNB and CB aeration reduced the aromaticity and hydrophobicity of organic matter, and reduced the concentration of organic matter in groundwater. Seen from Fig. 6(a) and (b), on the 30th day after aeration, the values of E250/E365, E300/E400, E254, E280 and S239-400 of groundwater treated by MNB aeration were lower than that of groundwater treated by CB aeration, which indicated that organic matter in groundwater treated by MNB aeration was more hydrophobic and had a more complex structure degree and a greater aromaticity. That is to say, more biodegradable organic matter in groundwater was degraded and transformed into organic matter with complex structure by MNB aeration.

3.2.2 EEM of groundwater

As shown in Fig. 7, the fluorescent components in groundwater before and after oxygen MNB or CB aeration were analyzed by EEM. The fluorescence EEM spectra can be divided into five unique Ex/Em regions that represent different DOM types, based on the quantification analysis of Chen et al.(2003): Region I at Ex/Em of 220-250 nm/250-330 nm and region II at Ex/Em of 220-250 nm/330-380 nm. The region I and II are associated with protein-like substances. Hudson et al.(2008) found that the substances in region I and II are related to microbial activity and can be formed by microbial activity. In addition, compared with humic acid-like substances, the protein-like substances have a simple structure and are more likely to be used by microorganisms as an energy source or a material for synthesizing other substances. Region III at Ex/Em of 220-250 nm/380-650 nm, and it is identified as fulvic acid-like substances. According to Jouraiphy et al.(Jouraiphy et al., 2008), fulvic acid-like substances could only be degraded to a certain level. Region IV at Ex/Em of 250-550nm/250-380 nm, and it is referred to soluble microbial by-product substances which are accessible and easily biodegradable compound, such as fatty acids(Sun et al., 2016). Region V at Ex/Em of 250-550 nm/380-650 nm, it is ascribed as humic acid-like substances which are hard biodegradable (Heo et al., 2015; Sun et al., 2016). The humic acid-like substances are derived from the biodegradation of organic matter.

As shown in Fig. 7, for raw groundwater, fluorescence mainly appeared in regions of ▯, ▯, ▯ and ▯, and the region V had the highest fluorescence intensities. This meant there were protein-like, fulvic acid-like, soluble microbial by-product and humic acid-like substances in landfill leachate contaminated groundwater. After MNB and CB aeration, the fluorescence intensities of groundwater sample in five region all increased, and then decreased with time. And on the 30th day after MNB or CB aeration, the fluorescence intensities of groundwater samples were all far less than that of raw groundwater. The result was consistent with the decrease of COD and BOD_5 concentration. Therefore, the content of DOM in groundwater was decreased by MNB and CB aeration.

To obtain more details on the transformation of DOM components of groundwater after MNB or CB aeration, EEM spectra were analyzed using the fluorescence regional integration(Chen et al., 2003) and the results are shown in Fig. 8(a). The area sum of five regions decreased. This trend confirmed that MNB or CB aeration could reduce DOM content in groundwater again. Specifically, on the 30th day after aeration, the area of region ▯ and ▯ both decreased, and they in groundwater treated by MNB aeration were less than them in groundwater treated by CB aeration. The results revealed that a large number of protein-like substances were degraded after MNB and CB aeration, and MNB aeration degraded protein-like substances more effectively than CB aeration. There were two possible reasons for this phenomenon. On the one hand, the groundwater treated by MNB aeration had a stronger microbial degradation effect. On the other hand, the MNB aeration had an oxidizing effect while enhancing the biodegradation of groundwater. A part of aromatic protein-like substances with good structural stability were eliminated by the oxidizing effect of MNB aeration. As seen in Fig. 8(a), the decrease of soluble microbial by-product substances (region ▯) was observed in both groundwater treated by MNB and CB aeration, while MNB aeration achieved higher removal efficiency of such components. The difference was attributed to the fact that the groundwater treated by MNB aeration has higher microbial activity (Fig. 4). In addition, it can be noticed from Fig. 8(a) that there were still soluble microbial by-product substances in groundwater on the 30th day after MNB aeration. That is, the groundwater after MNB aeration can be further treated by biodegradation, such as further oxygen MNB aeration. Although region ▯ and V were related with fulvic acid-like substances and humic acid-like substances, which were reported to be non-biodegradable compounds, they were found to be degraded to a certain extent in groundwater treated by MNB and CB aeration. This phenomenon was consistent with research result of Derrien et al.(2019) that humic and fulvic acid-like substances could only be degraded to a certain level by biodegradation. Because the reason might be that there were some specific types of microbial enrichment in groundwater treated by MNB and CB aeration. MNB aeration also showed higher removal efficiency of such components. The above results clearly showed that MNB aeration promoted the degradation of DOM in landfill leachate contaminated groundwater.

As discussed above, the content of DOM in groundwater decreased after MNB or CB aeration processes. And the content changes were different for different kinds of DOM. Fig. 8(b) shows relative excitation-emission area volume of □-□ regions in groundwater on the 30th day after MNB or CB aeration. As a whole, after MNB or CB aeration, the relative content of the biodegradable substances (region □, □ and □) decreased, while it increased for non-biodegradable substances (region □ and □). It indicated that some soluble microbial by-product or protein-like substances were transformed to humic acid-like substances during the biodegradation process. Or, little fulvic and humic acid-like substances were degraded. Compared with DOM in groundwater treated by CB aeration, there were more humic acid-like substances and less protein-like substances in groundwater treated by MNB aeration. The result showed that MNB played a more effective role in biodegradation. As discussed in sub-section 3.1, groundwater treated by MNB aeration had higher microbial activity than groundwater treated by CB aeration. And it was reported that the soluble microbial-by product substances resulted from microbes during substrate metabolism (Li et al., 2013). So, the relative content of soluble microbial by-product substances in groundwater treated MNB aeration was more than that in in groundwater treated by CB aeration, and its value was relatively high (Fig. 8(b)). Furthermore, soluble microbial by-product substances were biodegradable compounds. Thus, the groundwater treated by MNB aeration could be further treated by biodegradation.

3.3 Energy consumption

Based on the experimental condition, the preliminary energy consumption in MNB and CB aeration were estimated based on the same DO value of 8.37 mg/L. In this study, the CB aeration was achieved by directly injecting oxygen into groundwater from the oxygen bottle, so there was no electricity consumption during the procedure. As shown in Fig. 3(a), in order to obtain the DO value of 8.37 mg/L, oxygen MNB and CB aeration lasted for 8 seconds and 5 minutes, respectively. The electricity and oxygen consumptions of MNB aeration were 8.8 kW and 0.24 L, while they were 0 kW and 9 L in MNB aeration. Although the electricity consumption of MNB aeration was more than that of CB aeration, the oxygen consumption of MNB aeration was much less than that of CB aeration. So, it can be concluded that MNB aeration was a more energy-efficient landfill leachate contaminated groundwater treatment method.

4. Conclusions

Organic contaminant removal of oxygen MNB aeration from landfill leachate contaminated groundwater was studied by comparing with oxygen CB aeration. At first, the mass transfer efficiency of MNB and CB aeration were estimated. Secondly, the contaminant removal and microbial activity enhancement effect of the two kinds of aeration on landfill leachate contaminated groundwater were evaluated. At last, the composition variations of DOM in groundwater before and after aeration were characterized. Based on the test results, the following conclusions can be drawn:

The maximum DO value, oxygen utilization efficiency and k_La in groundwater treated by oxygen MNB aeration were 39.27 mg/L, 5.32% and 0.264 1/s, they were 4.8, 10 and 50 times that in groundwater treated by oxygen CB aeration, respectively. In addition, the DHA of groundwater increased by 101.25% by oxygen MNB aeration. Oxygen MNB aeration could effectively remove organic contaminants in landfill leachate contaminated groundwater. On the 30th day after MNB aeration, the COD, BOD_5 and ammonia nitrogen removal efficiency were 50.94%, 94.91% and 12.55%, and they were increased by 29.72%, 13.43% and 138.59% compared with CB aeration, respectively.

MNB aeration destructed the UV-quenching polar functional groups, and made the aromatic organic matters in groundwater degraded or decomposed into small molecular substances. DOM in groundwater treated by MNB aeration was more hydrophobic and had a more complex structure degree. The content of DOM in groundwater decreased sharply after oxygen MNB aeration. With the biodegradation effect of MNB aeration, a large number of protein-like and soluble microbial by-product substances were degraded, and humic as well as fulvic acid-like substances were degraded to a certain level. The groundwater treated by MNB aeration can be further treated by biodegradation. Oxygen MNB aeration had an oxidizing effect while enhancing biodegradation of groundwater contaminants. It is proved to be an energy-efficient landfill leachate contaminated groundwater treatment method.

Declarations

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Author contribution Mei Bai: conceptualization, data curation, writing-original draft. Zhibin Liu: conceptualization, writing-review & editing, supervision, funding acquisition. Liangtong Zhan: funding acquisition, project administration. Zhu Liu: data curation. Zhanhuang Fan: funding acquisition, project administration.

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Data availability The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

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Figures

Figure 1

Schematic diagram of the experimental apparatus.

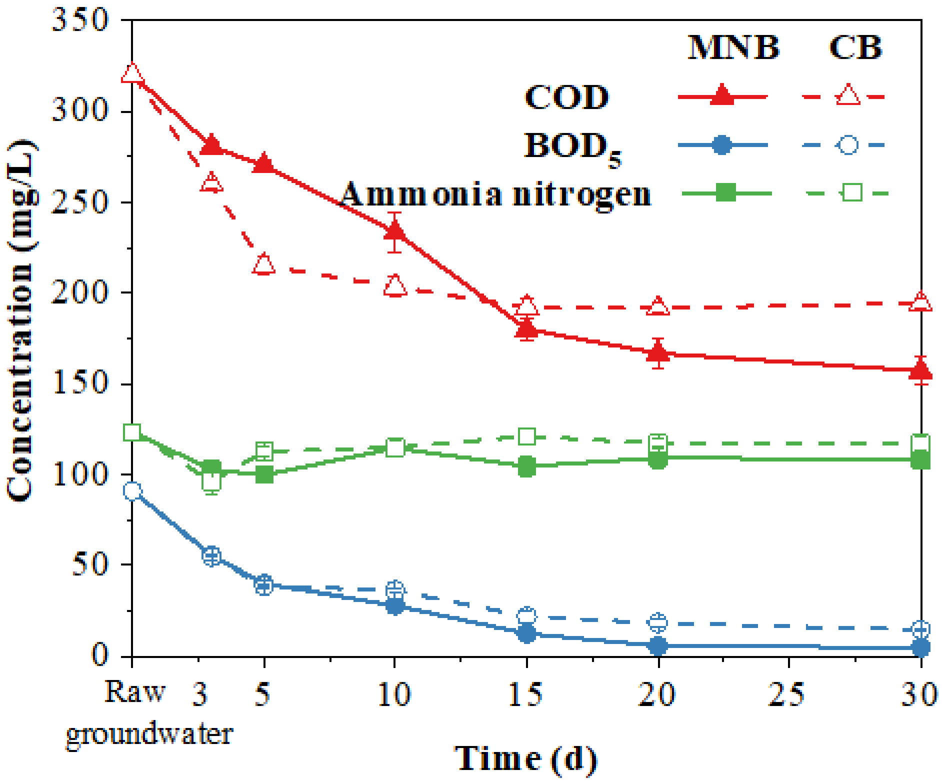

Figure 2

Variations of COD, BOD_5 and ammonia nitrogen concentration of groundwater treated by MNB and CB aeration.

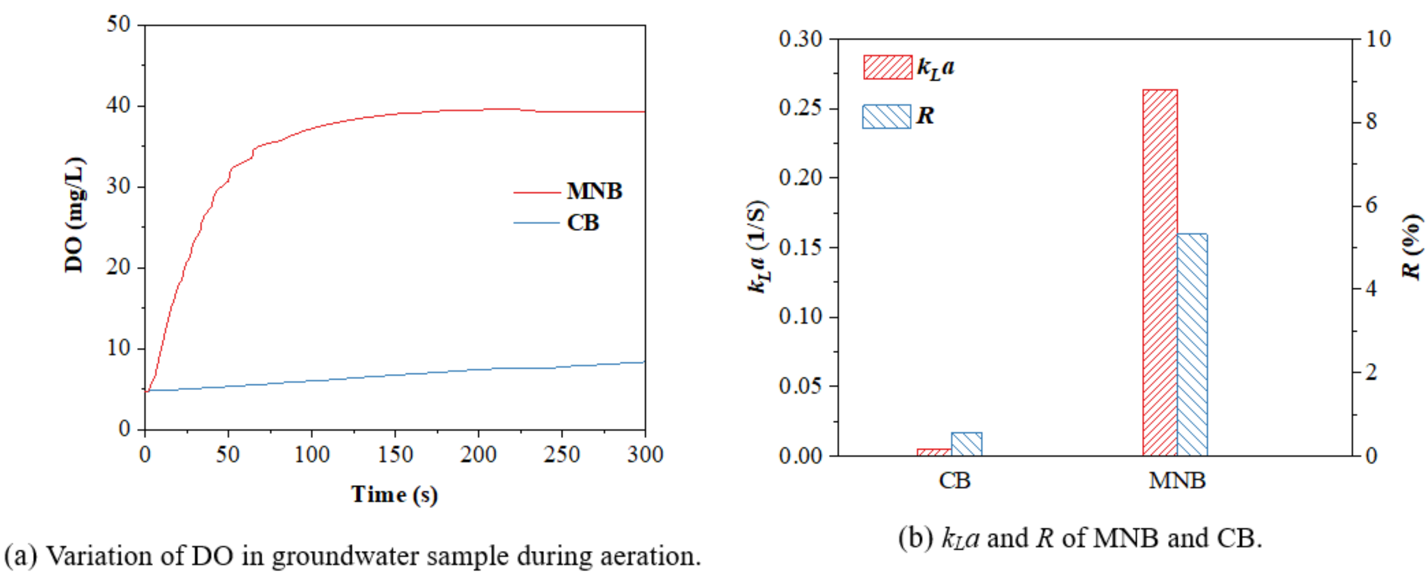

Figure 3

Mass transfer efficiency of MNB and CB.

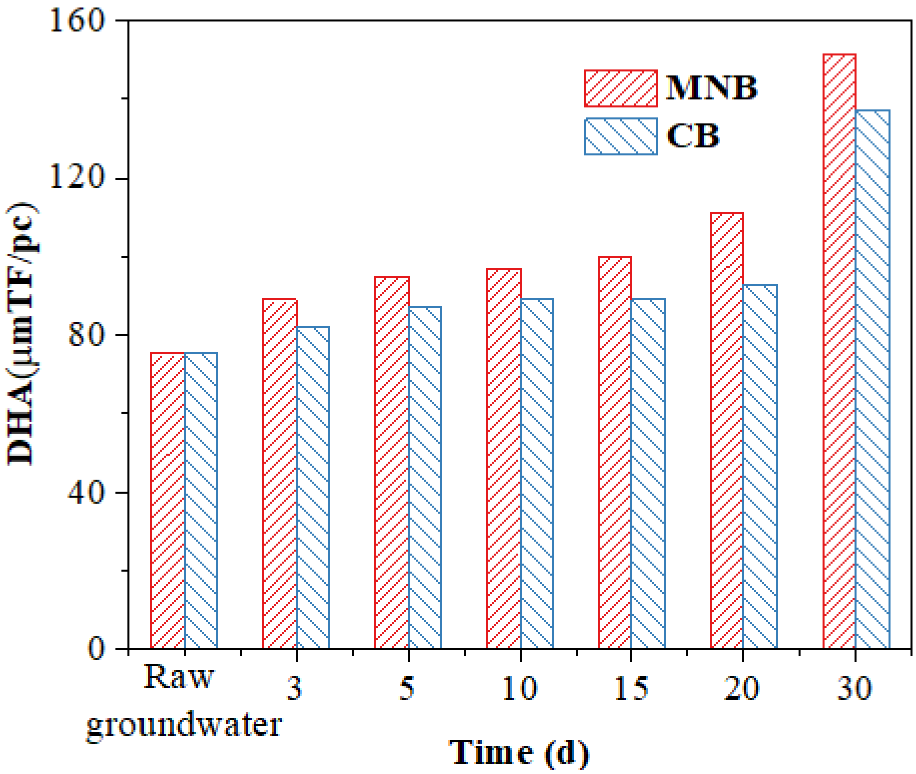

Figure 4

Dehydrogenase activity (DHA) of groundwater before and after MNB or CB aeration.

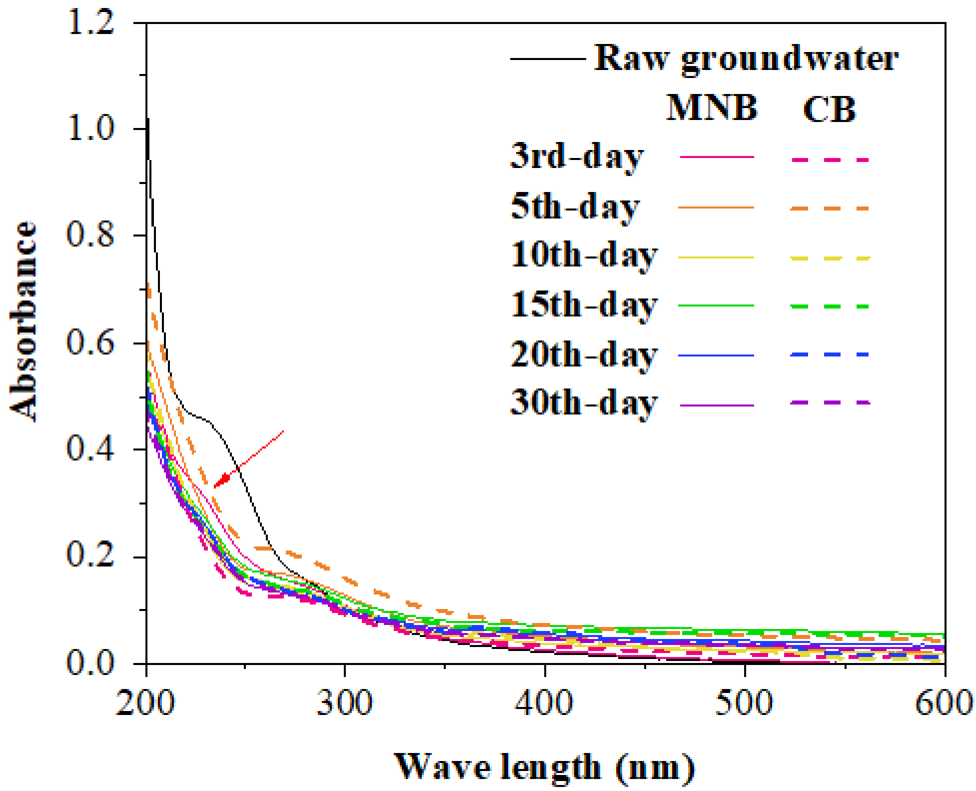

Figure 5

UV-VIS absorbance spectra of groundwater before and after MNB or CB aeration.

Figure 6

The changes of UV-VIS absorbance spectra parameters of groundwater before and after MNB or CB aeration.

Figure 7

EEM images of DOM in groundwater before and after MNB or CB aeration.

Figure 8

Excitation-emission area volumes of □-□ regions in different groundwater samples.