International Biodeterioration & Biodegradation 119 (2017) 377–386

Contents lists available at ScienceDirect

International Biodeterioration & Biodegradation

journal homepage: www.elsevier.com/locate/ibiod

Surplus sludge treatment in two sludge treatment beds under subtropical condition in China

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ARTICLE INFO

Article history:
Received 21 July 2016
Received in revised form
2 November 2016
Accepted 3 November 2016
Available online 10 November 2016

Keywords:
Bioavailability
Heavy metals
Sludge dewatering
Sludge stabilization
Sludge treatment beds

ABSTRACT

Sludge treatment bed has been used for sludge dewatering and stablilization due to the low operating and maintenance costs. However, there are still limiting information of this technology compare to conventional technologies, and very few information on using this technology in developing countries. In the present study, two sludge treatment beds were investigated under seven sludge loading rates and feeding frequencies under subtropical condition in China. The results showed that plants play an important role for sludge dewatering and stablilization. The best loading rate and feeding frequency for sludge dewatering and stablilization was 10L/4d in the planted system, with TS (total solid) and VS (volatile solid)/TS contents were 29% and 25%, respectively. The best pollutants removal efficiencies in leachate was observed at 12L/4d in the planted system, which were 99.8%, 91.1%, 98.6%, and 91.5% for COD (chemical oxygen demand), NH_4^+-N, TN (total nitrogen), and TP (total phosphorus), respectively. Heavy metals concentrations in the leachate were below the Chinese integrated wastewater discharge standard. In the accumulated sludge, TN + TP + TK (total potassium) > 30 g/kg which fulfill the standard of Chinese sludge for agriculture reuse. The bioavailability of Cu, Ni, Cr, Fe, and Pb was low thanks to the high proportion in residual state and oxidation state. However, Cd needs to be considered before the treated sludge can be applied for agriculture in China.

1. Introduction

Sludge is an inevitable by-product from wastewater treatment plant. Annual sludge production has increased significantly in China (about 30 million tons with water content of 80%) due to dramatic improvement in wastewater treatment capacity (Dai, 2012). The problem of sludge is wide spread in China as the sludge treatment facilities are ten times lower than the wastewater treatment facilities. The main reason behind this is the lack of investment on sludge treatment facilities as the sludge treatment facilities are mostly applied in large wastewater treatment plants with daily capacity more than 15,000 m^3, resulting in 56% sludge without appropriate treatment (Xu, 2010). Therefore, other options for sludge treatment especially for the small scale wastewater treatment plants are crucial in China.

Sludge dewatering and stabilization are most important steps in sludge treatment (Uggetti et al., 2011). In case of sludge dewatering there is potential decrease in sludge volume resulting in increased total solids (TS). However, about 51–65% TS are volatile organic compounds (Uggetti et al., 2012a). Therefore, it is important to stabilized the sludge to prevent the secondary pollution in sludge disposal process. Conventional sludge treatment methods mainly include the sludge thickening, drying, composting, anaerobic digestion, aerobic nitrification etc. (Uggetti et al., 2010). These conventional approaches are normally fast and effective, but the drawback is high costs and energy consumption. So these expensive options of sludge treatment can not be adopted by small scale wastewater treatment plants due to lack of capital (Kengne et al., 2014). Therefore, cheap and low energy requiring sludge treatment facilities are in high demand especially in small towns in China.

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http://dx.doi.org/10.1016/j.ibiod.2016.11.005
0964-8305/

Sludge treatment wetlands (STWs) is a cheap, sustainable and eco-friendly/environment-friendly sludge treatment technology. It has advantages of low energy consumption, low operating and maintenance costs, and better environmental compatibility (Uggetti et al., 2009a, 2009b; Nielsen, 2015). It has been successfully used in Europe since the 1980s (Uggetti et al., 2010). In the STWs, sludge dewatering is mainly done through penetration, evaporation, and transpiration (Sun et al., 2013). The stability of sludge in STWs is due to plants and microbial interactions (Cui et al., 2012). Currently, STWs have been widely used in Denmark, United Kingdom, Germany, Italy, Brazil and other countries for treating sludge produced by small scale wastewater treatment systems (Edwards et al., 2001; Nielsen et al., 2014; Calderon-Vallejo et al., 2015; Nielsen and Bruun, 2015; Peruzzi et al., 2015). In 2006, nearly 30% of the sewage sludge in Denmark was treated by STWs, which are around 200 in the whole country (Edwards et al., 2001). STWs are also widely used in the United States, about 50% of the rural sewage treatment system are using STWs to treat their produced sludge (Nielsen, 2005). In the Mediterranean region, such as Italy, France, and Spain have also many full scale STWs to treat sludge (Uggetti et al., 2009a). Conversely, only few information on STWs application in developing countries, such as pilot scale STWs were established in Asia region of Palestine and the northeast region of China (Nassar et al., 2006; Cui et al., 2008).

At present, there is no standard configuration and design criteria for STWs, and there is no standard recommended strategy for loading and resting periods for sludge treatment in STWs. Very few information on surface loading rates or loading patterns is available (Vincent et al., 2012; Sonko et al., 2015; Magri et al., 2016). The relatively more land area required by STWs compare with conventional sludge treatment technologies limiting the use of this technology especially when land cost is high. Moreover, the climate condition is also an important factor limiting the application of this technology.

In the Mediterranean region (Italy, France, Spain) where the hot and dry summer is especially suitable for the sludge treatment in STWs, most studies on STWs showed excellent results (Edwards et al., 2001; Uggetti et al., 2009a). Also in temperate maritime climate like Denmark, with humid, overcast mild and windy winter and cool summers, also showed good performance of STWs (Nielsen et al., 2014). Nowadays, there are still only a few STWs systems in northeast region of China, where the climate is known to be temperate in monsoon temperate continental with high temperature in summer (from the coast to inland humidity decline), and cold and dry in winter. To our knowledge, there is not a single report on treatment performance of STWs system in the middle and lower reaches of Yangtze River, such as Wuhan, which has the subtropical humid monsoon climate.

Therefore, the objectives of this study were (1) to evaluate the effects of plants on the effectiveness of STWs; (2) to testify different sludge loading rate and feeding frequency in STWs; (3) to assess the potential of treated sludge for agricultural application based on the analysis of nutrients, pathogens and heavy metals (both total amount and their speciation). Overall, to provide an alternative approach on sludge treatment for small scale wastewater treatment plant under subtropical condition in China.

2. Material and methods

2.1. Experiment setup

Two sludge treatment beds (STBs) were installed at the campus of Huazhong Agricultural University, Wuhan, China. The site has a subtropical humid monsoon climate, long and high temperature in summer (around 135 days and average temperature of 29.3 °C). The dimensions of each STB were 100 × 20 × 60 cm (Length × Width × Height), a schematic diagram of the laboratory scale STB was shown in Supplementary Material Fig. S1. Each STB was filled with gravel size of 8–16 mm in the bottom layer and 4–8 mm in the upper layer with the height of 15 cm for both layers, the rest 30 cm was left for sludge accumulation. The porosity of each STB was 0.42. One STB was planted with *Canna indica*, while the other STB was unplanted. Surplus sludge from local wastewater treatment plant was fed into the STBs from the top with seven different loading rates and feeding frequency: A: 12L/3d, B: 8L/6d, C: 8L/4d, D: 10L/4d, E: 12L/4d, F: 12L/3d, G: 10L/3d. The sludge lading rates were 70.8, 18.3, 19.6, 27.3, 36.8, 36.5, 28.0 kg TS/m^2/year, respectively. The average sludge loading rate was 32 kg TS/m^2/year. The main characteristics of the feeded sludge were summarized in Table 1. Plants (*C. indica*) were selected from the nature ponds in the campus, and 10 plants (50 plants/m^2) were planted in the planted STB at the beginning of the experiment. The STBs were protected from rain, the mean air temperature and humidity were monitored during the experiment and are given in Supplementary Material Fig. S2.

2.2. Sample analysis

In order to calculate removal efficiency in comparison with input loads, all water in the STB was drained and quantified before new feeding. The calculation of water loss was described elsewhere (Chen et al., 2016). The sludge water content (WC) were estimated by drying the sludge samples in an oven at a temperature around 105 °C for 24 h, and cooling down in desiccator containing active desiccants, and weighed with an accurate balance of 0.0001 g before and after heating. Draining water volume was record before each feeding to calculate the evapotranspiration of each period. The draining water samples were collected from the effluent of the STBs every feeding period. Draining water and sludge samples were taken from each STB, and were analyzed for pH, redox, COD (chemical oxygen demand), TN (total nitrogen), ammonia (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), TP (total phosphorus), Alkaline-N (alkali-hydrolyzable nitrogen), Olsen-P (rapidly-available phosphorus), Olsen-K (rapidly-available potassium), DHA (dehydrogenase activity) and heavy metals: copper (Cu), manganese (Mn), nickel (Ni), zinc (Zn), chromium (Cr), iron (Fe), cadmium (Cd), plumbum (Pb). Total solids (TS) and volatile solids (VS) were analyzed from the accumulated sludge to evaluate the dewatering

Table 1
Characteristics of the raw surplus sludge (mean, SD), n = 62.

Parameters	Unit	Mean	SD
pH	–	6.6–7.0	
Redox	mV	−317–−50	
TS	%	0.7	0.3
VS	%	0.3	0.1
WC	%	99.4	0.3
COD	mg/L	7235	2541
NH_4^+-N	mg/L	65	27
NO_3-N	mg/L	5.1	2.5
NO_2^--N	mg/L	0.04	0.03
TN	mg/L	389	230
TP	mg/L	147	33
Cu	mg/L	0.5	0.4
Mn	mg/L	1.4	1.2
Ni	mg/L	0.2	0.1
Zn	mg/L	2.0	1.4
Cr	mg/L	0.2	0.1
Fe	mg/L	53	28
Cd	mg/L	0.03	0.02
Pb	mg/L	0.5	0.2