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Pilot-scale multi-level biological contact oxidation system on the treatment of high concentration poultry manure wastewater

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ABSTRACT

A pilot-scale (5 m^3/d) study was applied for the treatment of a high-strength poultry manure wastewater by using a multi-level biological contact oxidation tanks system with novel carriers. Firstly, four kinds of carriers including porous block carriers, sponge globoid carriers, fiber ball carriers, and suspend plastic carriers were compared at lab-scale experiment to choose the best performed carriers for the further application in pilot scale experiment. Then, the performance of the pollutants elimination during the whole pilot-scale reactor as well as the contribution efficiency of each tank under different influent pollutants loads were investigated. Finally, the biomass evaluation on the carriers and the mechanism of nitrogen removal were also explored. The conclusion showed that the effluent quality could satisfy the discharge standard of pollutants for livestock and poultry breeding industry (GB 18596-2001) when the influent organic load was less than 3.64 kg COD_{cr}/(m^3 d) during the pilot-scale system placed with the porous block carriers. The contact oxidation tank I dominated the average contribution efficiency of COD_{cr} (89.2%), ammonia (69.6%), and the total nitrogen (57.3%) during the three-level biological contact oxidation tanks. The step-feed operational model was suggested to further increase the pollutants removal capacity of the following Tank II and Tank III. The oxygen-deficient environment of the biofilm and the proper three-dimensional spiral structure of the carriers were suitable for the happening of the simultaneous nitrification and denitrification occurred in the pilot-scale aerobic reactor.

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1. Introduction

With the ever-increasing level of living standard, the production of poultry and livestock have been extensively grown during the present century, which has produce large amounts of animal wastes and wastewater in both developed and developing countries (Yetilmezsoy and Sapci-Zengin, 2009; Rajagopal and Massé, 2016). In China, the chemical oxygen demands (COD) and total nitrogen of the poultry and livestock wastewater accounts for 96% and 38% of that in total agricultural wastewater, respectively. A promising process called anaerobic co-digestion (Misi and Forster, 2001) or co-composting (Petric et al., 2009) with other wastes could partially and effectively dispose both the solid and liquid fraction of manure (Zhang et al., 2014; Khoufi et al., 2015). However, there are still large amounts of liquid fraction of the manure considered as one kind of serious polluted effluent, which need to be properly handled, especially in the developing countries where the small-scale poultry farms dominated. The poultry manure wastewater is primarily from the manure dispose and fowlery cleaning, which was characterized by high concentration pollutants of organic matters and ammonia. The COD of chicken manure wastewater always reached over 10,000 mg/L. What is more, the wastewater usually varied much in concentration and volume during different seasons or management process.

The poultry manure wastewater are always purified by the anaerobic processes, which are considered to be an efficient technique for the treatment of the high-strength wastewater (Sakar et al., 2009). Meanwhile, various kinds of reactors have been explored for the pretreatment of poultry manure wastewater.

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Whereafter, the anaerobically pre-treated poultry manure wastewater have been further disposed by a lot of treatment method, such as, aerobic/anoxic process (Li et al., 2016), electrocoagulation (Yetilmezsoy et al., 2009), Fenton's oxidation (Yetilmezsoy and Sakar, 2008). Biological processes are suitable for the treatment of poultry manure wastewater due to their higher removal efficiency and lower cost. For the anaerobic techniques, the demand of high-level maintenance might restrict their forward application in the small-scale poultry farms (Atuanya, 2002; Yetilmezsoy, 2012). Dissimilarly, the aerobic biological processes, such as biological contact oxidation process, are widely used for the treatment of industrial wastewater (Kalyuzhnyi et al., 2002; Ma et al., 2009; Pan et al., 2017). The biological contact oxidation process was first brought forward at the end of 19th century (Waring, 1895). Of the system, the pollutants in the wastewater was purified and removed in respect of the thorough contact of the biofilm, which was attached on the carriers and formed when the aerated wastewater flow through the carriers during aerobic reactor. Based on its principle, the biological contact oxidation process is characterized by high efficiency, simple operation and low cost. Presently, the multi-level biological contact oxidation tank, especially derived with novel carriers, has been also explored to further improve the removal efficiency of pollutants in wastewater, which was desired to work out the previous touch questions including the biofilm clogging of carriers, frequently replaced carriers, and the elimination efficiency of nitrogen (Li et al., 2015; Zheng et al., 2015a, b; Zhu et al., 2017). However, there is no literature to report the performance of the multi-level biological contact oxidation tank technique for the treatment of poultry manure wastewater.

In the current study, a pilot-scale study was carried out to treat the high-strength poultry manure wastewater by using multi-level biological contact oxidation reactor placed with novel carriers. Firstly, the performance of four carriers was investigated and evaluated at lab-scale experiment to choose the best performed carriers, which would be placed into the pilot-scale reactors. Then, based on the optimized carriers, the performance of whole pilot-scale system and the contribution of each stage of the pilot-scale multi-level biological contact oxidation reactor under different influent wastewater loads were explored. Finally, the evaluation of the biofilm of the carriers and the carriers themselves were also applied to try to explain the mechanism of nitrogen removal during the pilot-scale systems.

2. Methodology

2.1. Wastewater

The wastewater including chicken manure wastewater and chicken slaughter wastewater was taken from a chicken breeding plant in Tongzhou district, Beijing, China, where the mixed wastewater was settled in respect of different influent pollutants loads. During the lab-scale experiment, the concentration of COD_{cr} and ammonia of the mixed wastewater was 1000–1200 mg/L and 100–110 mg/L, respectively. During the pilot-scale experiment, the concentration of COD_{cr}, ammonia, total nitrogen, total phosphate, suspended sludge (SS), and the BOD_5 of the mixed wastewater varied form 1082 to 3655 mg/L, 129 to 387 mg/L, 188 to 408 mg/L, 25 to 93 mg/L, 48 to 132 mg/L, and 617 to 1499 mg/L, respectively. The biodegradability and the pH of the mixed wastewater (shown as BOD_5/COD_{cr}) was about 0.45 and 7.0 to 8.0. This wastewater is characterized by high concentration of organic materials and suspended solid.

2.2. Experimental setup and procedure

2.2.1. Lab-scale experiment

The lab-scale experiment with four kinds of carriers in each 2 L beaker was applied to choose the best performed carriers, of which will be selected as the filling carriers of the pilot-scale reactors. The physical and chemical properties of the four carriers are shown in Table 1, where included one novel porous block carriers, two fixed carriers (sponge globoid carriers and fiber ball carriers), and one suspended plastic carriers. The dewatering sludge used in the current study was taken from a municipal wastewater treatment plant in Beijing, China. The sludge activation was recovered under the conditions including pH of 7.0–8.0, hydraulic retention time (HRT) of 24 h, and the dissolved oxygen (DO) concentration of above 4.0 mg/L. With the feed of same volume of prepared mixed wastewater in four beakers (with no carriers), the sludge flocs of each beaker increased apparently and their color gradually turned to brown after two days operation, where the concentration of SS and sludge settling ratio varied from 4.0 to 4.5 g/L and around 25% respectively. The results revealed that the sludge of each beaker could be applied for the following biofilm culturing. Then, the four kinds of carriers were respectively placed into the lab-scale setups (Fig. 1a). The lab-scale experiment was carried out under semi-continuous batch mode at the normal temperature (20–23 °C) and low temperature (12–17 °C) with a pH of 7.0–8.0, HRT of 12 h, DO concentration of above 2.0 mg/L, and no recycle device. Additionally, the filling ratio of the four kinds of carriers, defined as the value of the bulk volume of the carriers divided by the efficient volume of the reactor, are 13.70%, 13.40%, 13.45%, and 13.50% respectively (shown in Table 1).

2.2.2. Pilot-scale experiment

The pilot-scale experimental setup of 5 m^3/d, called a multi-level biological contact oxidation tank, consisted a three-stage contact oxidation reactors, which was provided by Shanghai Best Environmental Technology Corporation, China. The efficient volumes of each stage along the wastew-

Table 1
The physical and chemical properties of the four kinds of carriers during the lab-scale experiment.

Carrier	Porous block carriers	Sponge globoid carriers	Fiber ball carriers	Suspended plastic carriers
Single size (mm)	76*60*60	Φ80	Φ30–40	Φ10*H10
Number of the carriers (n)	1	1	12	86
Total bulk volume of the carriers (L(carriers))	0.274	0.268	0.269	0.270
Filling ratio of the carriers (L(carriers)/L(reactor))	13.70%	13.40%	13.45%	13.50%
Bulk volume density (kg/m^3)	50	24	1380	160
Specific surface area (m^2/m^3)	150	800	3000	>500
Void ratio (%)	96	>97	96	>95
Photos				

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