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Waste Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

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

Effect of low aeration rate on simultaneous nitrification and denitrification in an intermittent aeration aged refuse bioreactor treating leachate

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ARTICLE INFO

Article history:
Received 3 October 2016
Revised 30 December 2016
Accepted 30 December 2016
Available online xxxx

Keywords:
Aged refuse bioreactor
Simultaneous nitrification and denitrification
Aeration rate
Leachate

ABSTRACT

Three intermittent aeration aged refuse bioreactors (ARBs), A, B, and C, with aeration rates of 670, 1340, and 2010 L/m^3 aged refuse·d in stage 1, and 670, 503, and 335 L/m^3 aged refuse·d in stage 2 were constructed to evaluate the effect of low aeration rate on leachate treatment by simultaneous nitrification and denitrification (SND). Results show that SND can be achieved and improved by reasonably adjusting the aeration rate of the ARB. In stage 1, the average chemical oxygen demand (COD) removal rates of ARBs A, B, and C were 91%, 92%, and 93%, respectively. The ammonia nitrogen (NH_4^+-N) removal rate of the three ARBs approached 100%. The total nitrogen (TN) average removal rates were 68%, 59%, and 57%. The average SND efficiency values were 73%, 66%, and 65%. In stage 2, the COD removal rates of ARBs A, B, and C decreased from the original values of 85%, 92%, and 93% to 84%, 81%, and 80%. The NH_4^+-N removal rate decreased from above 99% to 90%–92% in ARB B and from above 99% to 87%–91% in ARB C. The TN removal rates of ARBs B and C increased to 59% and 53% on day 15 from the initial values of 49% and 43% and were maintained at 49%–61% and 50%–60%. The SND efficiency of ARBs B and C improved, and the average values were 68% and 70% after day 15. These values were higher than the 66% of ARB A during the same period. Comprehensively considering the COD, NH_4^+-N, TN removal rate, and SND efficiency, the optimal aeration rate of 670 L/m^3 aged refuse·d is therefore suggested in this study.

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1. Introduction

Leachate from municipal solid waste landfill is characterized by high chemical oxygen demand (COD) and ammonia nitrogen (NH_4^+-N), and can pollute water body and environment without strict treatment before discharge (Kjeldsen et al., 2002; Price et al., 2003). Therefore, leachate treatment is an important task in refuse landfill management (Zhao et al., 2002).

Traditional leachate treatment processes mainly include two categories: biological process, physical–chemical method (Li et al., 2010). Physical–chemical methods such as air stripping, flocculation/precipitation, coagulation, membrane technologies, and chemical oxidation, etc., are simple in process, easy to operate, and insensitive to temperature change. However, high initial investment of plant equipment, energy requirements, frequent use of chemical additives and burdensome daily maintenance limit their universal application (Wiszniowski et al., 2006; Xie et al., 2010). Therefore, physical–chemical methods are mostly used as pre-treatment to improve the biodegradability or as post-treatment to meet stricter discharge standard (Li et al., 2009).

Unlike the physicochemical methods, the biologic processes are much efficient and inexpensive to treat the leachate. The most often applied biologic treatment methods include upflow anaerobic sludge blanket, activated sludge, membrane bioreactor, and bioreactor technique, etc. In 2002, Zhao et al. (2002) initiated an innovative process for leachate treatment using a aged refuse bioreactor. The aged refuse bioreactor process has several advantages: better treatment effect, simpler technological flow, easier maintenance, no excess sludge production, lower capital investment and operating cost (Zhao et al., 2002; Shi, 2005; Sun et al., 2014b). Generally, investment cost of leachate in the aged refuse bioreactor process is about $1450–2150 per ton. Operation cost of leachate is about $0.58–0.72 per ton. Such as, a demonstration project of the leachate treatment capacity of 50 t/d, the capital cost is about $1900 per ton of leachate, and the operating cost is about

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http://dx.doi.org/10.1016/j.wasman.2016.12.042
0956-053X/© 2016 Published by Elsevier Ltd.

Please cite this article in press as: Sun, X., et al. Effect of low aeration rate on simultaneous nitrification and denitrification in an intermittent aeration aged refuse bioreactor treating leachate. Waste Management (2017), http://dx.doi.org/10.1016/j.wasman.2016.12.042

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\$0.73 per ton of leachate (Shi, 2005). Laboratory results show that the initial COD, biochemical oxygen demand, and NH_4^+-N reduce from 3000–7000, 540–1500, and 500–800 mg/L to lower than 100–350, 10–200, and 10–25 mg/L (Zhao et al., 2002). In a 100 m^3 leachate/day demonstration aged refuse bioreactor, when the leachate with initial COD, BOD_5, and NH_4^+-N concentrations were 986–4128 mg/L, 264–959 mg/L, and 538–1583 mg/L, respectively. The corresponding concentrations in the effluent were reduced to below 300–400 mg/L, 2–12 mg/L, and 10–20 mg/L, respectively (Li et al., 2010).

But the total nitrogen (TN) removal is difficult. The TN removal is 20%–30% in one-stage bioreactor (Zhao et al., 2002), 49%–63% in two-stage field-scale bioreactor (Li et al., 2010), and 58%–73% in three-stage field-scale bioreactor (Li et al., 2009), indicating a relatively poor denitrification capacity. The reason is that mature landfill leachate contains high concentrations of ammonia and low-biodegradable organic carbon (Xie et al., 2010a). Therefore, enhancing the TN removal efficiency by reducing the requirements for oxygen and carbon substrate is the key to biological processes (Xie et al., 2013).

The simultaneous nitrification and denitrification (SND) phenomenon is observed in aged refuse bioreactors (Han et al., 2011). One of the primary factors affecting SND is the dissolved oxygen (DO) concentrations (Pochana and Keller, 1999). In low DO concentrations, diffusion limitations create anoxic zones within floc particles thereby facilitating SND (Holakoo et al., 2007; de Silva et al., 1998; Nagaoka, 1999). Therefore, SND can be feasible in a single aged refuse reactor by controlling the oxygen level to create anoxic circumstance.

In this context, the intermittent aeration aged refuse bioreactors were constructed in the study. The study involved two operation periods with different aeration rates. The main objective of the research was to investigate the influence of different aeration rates on the efficiency of TN removal by SND, and determines the optimum aeration rate for the occurrence of SND to enhance the TN removal efficiency in a single aged refuse reactor. Based on the idea of "Waste Control by Waste", the intention of the study is to aerate the aged refuse bioreactor operated at a landfill facility to treat the collected leachate, also pave the way for aged refuse comprehensive utilization.

2. Materials and methods

2.1. Experimental setup

The schematic of the experimental apparatus is shown in Fig. 1. Three ARBs were constructed to treat leachate, and all were made of polyvinyl chloride columns with an inner diameter of 39 cm and a height of 100 cm. A perforated pipe with a diameter of 25 mm and an open ratio of 1.0% was located vertically in the center of each bioreactor. The pipe was connected to a diaphragm air pump and sealed in the top, thereby avoiding the short circuit of airflow. The aeration rate was adjusted by a gas flowmeter. Each bioreactor was loaded from bottom to top with 100 mm of gravel (30–50 mm in diameter) and 50 mm of small gravel (approximately 10 mm in diameter), followed by 600 mm of aged refuse (4–10 mm in diameter) topped with 100 mm of the gravel layer (approximately 10 mm in diameter).

2.2. Aged refuse and leachate

The 10 year-old aged refuse and leachate were obtained from the Chongkou Sanitary Landfill in Guilin, located in the southwest China. At least 1000 kg of aged refuse was excavated and naturally dried in a laboratory. The non-biodegradable materials, such as stones, metals, glass, and plastic bags, were removed. Fine fraction resembled soil, with diameters of 4–10 mm, was selected because this refuse is an ideal bioreactor material (Sun et al., 2014a). The characteristics of the aged refuse and leachate are described in Tables 1 and 2.

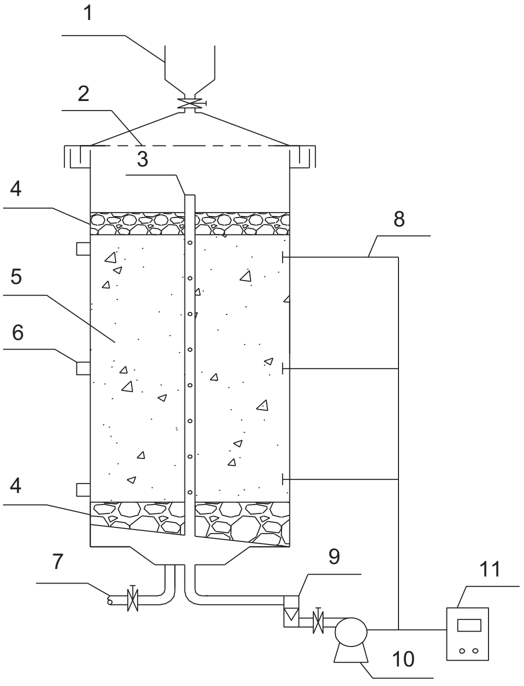

Fig. 1. Schematic diagram of the aged refuse reactor. (1) Leachate injection port; (2) liquid distributor; (3) perforated pipe; (4) gravel layer; (5) aged refuse layer; (6) solid sampling port; (7) leachate sampling port; (8) temperature probe; (9) gas flowmeter; (10) diaphragm air pump; (11) control cabinet.

2.3. Experimental operations

Intermittent aeration pattern was used in the ARBs. The aeration period lasted from 12:00 to 20:00. Based on the aeration rate, the experimental operation included two stages. Stage 1 covers the period from days 1 to 54. Stage 2 covers days 57–113. In stage 1, the aeration rates of bioreactors A, B, and C were 670, 1340, and 2010 L/m^3 aged refuse·d, respectively. In stage 2, the aeration rates of bioreactors A, B, and C were regulated to 670, 503, and 335 L/m^3 aged refuse·d, respectively. During the two stages, the initial leachate was injected into each reactor at 12:00 every day, with a hydraulic loading rate of 20 L/m^3, and the effluent was discharged directly. The experiment was operated at room temperature fluctuating from 21 °C to 31 °C.

2.4. Experimental analysis

Leachate of approximately 50 mL was sampled for analysis at three-day intervals. The samples were stored below 4 °C in glass bottles. The leachate samples were filtered using a qualitative filter paper, and the filtered samples were measured in triplicate. The COD, NH_4^+-N, NO_3^--N, NO_2^--N, and TN of the leachate samples were analyzed according to the standard methods set by the State Environmental Protection Administration of China (2008). COD was measured by the potassium dichromate volumetric method. NH_4^+-N was measured by Nessler's reagent spectrophotometric method. NO_3^--N was measured by the ultraviolet spectrophotometric method. NO_2^--N was measured by the spectrophotometric method. The TN of the leachate samples was filtered by a

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