Available online at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/jes

JES JOURNAL OF ENVIRONMENTAL SCIENCES www.jesc.ac.cn

Development of natural treatment system consisting of black soil and Kentucky bluegrass for the post-treatment of anaerobically digested strong wastewater

Xiaochen Chen[1,*], *Kensuke Fukushi*[2]

1. *Department of Urban Engineering, The University of Tokyo, Tokyo 113-8656, Japan*
2. *Integrated Research System for Sustainability Science, The University of Tokyo, Tokyo 113-8654, Japan*

ARTICLE INFO

Article history:
Received 13 February 2015
Revised 11 May 2015
Accepted 15 May 2015
Available online 23 October 2015

Keywords:
Natural treatment system
Black soil
Kentucky bluegrass
Strong wastewater
Soil column test

ABSTRACT

To develop a sound post-treatment process for anaerobically-digested strong wastewater, a novel natural treatment system comprising two units is put forward. The first unit, a trickling filter, provides for further reduction of biochemical oxygen demand and adjustable nitrification. The subsequent soil–plant unit aims at removing and recovering the nutrients nitrogen (N), phosphorus (P) and potassium (K). As a lab-scale feasibility study, a soil column test was conducted, in which black soil and valuable Kentucky bluegrass were integrated to treat artificial nutrient-enriched wastewater. After a long-term operation, the nitrification function was well established in the top layers, despite the need for an improved denitrification process prior to discharge. P and K were retained by the soil through distinct mechanisms. Since they either partially or totally remained in plant-available forms in the soil, indirect nutrient reuse could be achieved. As for Kentucky bluegrass, it displayed better growth status when receiving wastewater, with direct recovery of 8%, 6% and 14% of input N, P and K, respectively. Furthermore, the indispensable role of Kentucky bluegrass for better treatment performance was proved, as it enhanced the cell-specific nitrification potential of the soil nitrifying microorganisms inhabiting the rhizosphere. After further upgrade, the proposed system is expected to become a new solution for strong wastewater pollution.

Introduction

In rural communities, strong organic wastewater is produced from many sources, such as livestock farming (*i.e.*, animal excrement) and human excrement. This strong wastewater is usually of great concern, as without sound management it can lead to severe water pollution problems, such as eutrophication. Anaerobic digestion is generally considered the optimal treatment option, because it not only contributes to the decomposition of water-borne organic matters, but also generates biogas (methane) as a valuable energy source (Khanal, 2008). Nevertheless, the effluent of anaerobic digestion becomes another thorny problem. On the one hand, the organic pollutants could still exist in high concentration in this effluent (Park et al., 2010). On the other hand, the anaerobically-digested strong wastewater is typically characterized by a high content of nutrients, especially nitrogen (N), phosphorus (P) and potassium (K). Prior to discharge, post-treatment is still required, in order to avoid contamination of the receiving water bodies.

* *Corresponding author*. E-mail: chenxiaochen1984@gmail.com (Xiaochen Chen).

http://dx.doi.org/10.1016/j.jes.2015.05.030

Land-treatment of wastewater has been practiced for a long period of time, and could be a feasible strategy for dealing with strong wastewater (Hunt and Poach, 2001; Yang et al., 2007). However, most of the conventional land-treatment technologies can barely provide satisfactory performance. Water-borne biodegradable organic matter represented by biochemical oxygen demand (BOD), once in high concentration, is fatal to the land-treatment process. First, the consequent rapid growth of heterotrophs can result in soil blockage and prevent water penetration (Rice, 1974). Second, oxygen is likely to be in deficiency, due to the consumption by the flourishing heterotrophic microbes. As a result, the nitrification process performed by soil nitrifying microorganisms could be seriously suppressed. As for the anaerobically-digested strong wastewater, in which NH_3-N constitutes the vast majority of all forms of N (Park et al., 2010), this nitrification inhibition implies a failed N removal process. In addition, normal plants can hardly survive growing conditions like nutrient-enriched wastewater (Munns, 2002; Yang et al., 2007). In that case, therefore, neither direct nutrient recovery through plant absorption nor economic benefit from biomass production can be achieved by the land-treatment process.

Aiming at developing a sound post-treatment process for anaerobically-digested strong wastewater, a novel natural treatment system is proposed (Fig. 1). The wastewater flows through the two units of this system in sequence. The first unit is a trickling filter, an aerobic fixed-biofilm process. Moderately high influent temperature is the key to the good performance of this unit, as it keeps the biofilm in a robust condition to achieve better treatment efficiency and avoid clogging (Gray, 2010). The anaerobically-digested strong wastewater satisfies this requirement well, with a typical temperature of either 35°C (mesophilic) or 55°C (thermophilic) (Kim et al., 2002). Then a successful trickling filter unit benefits the following soil–plant unit from two aspects, *i.e.*, (1) further removal of BOD, so that soil clogging and inhibited nitrification will not occur in the soil–plant unit; and (2) adjustable nitrification function, which controls the ratio of NH_3-N to (NO_2^- + NO_3^-)-N in wastewater and may lead to their optimal ratio facilitating N removal and recovery in the soil–plant unit. Moreover, the plant is considered indispensable in this proposed system. For one thing, direct nutrient recovery and consequent market value from selling of plants are highly anticipated. For another, it is assumed that the growing plant can broadly enhance the soil microbial activity, especially the nitrification activity of soil nitrifiers, and hence bring about boosted nitrification efficiency. This 'stimulation on nitrification' hypothesis is based on our previous finding that alfalfa had a stimulating effect on the soil nitrifying microorganisms inhabiting not only the rhizosphere but also much deeper layers underground (Chen and Fukushi, 2014). As for the removal and recovery of P and K, retention by soil and absorption by plants could be the main routes.

A long-term lab-scale test was carried out as a feasibility study for use of this innovative natural treatment system as a post-treatment process for anaerobically-digested strong wastewater. With the main focus on its performance and mechanisms for the removal and recovery of major water-borne nutrients (*i.e.*, N, P and K), the superiority of this system over conventional land-treatment systems was expected to be demonstrated. In addition, the 'stimulation on nitrification' hypothesis was tested to verify the essential role of the plant, and identify the scope and scale of its impact. Furthermore, suggestions for future upgrade and scale-up of this system were discussed.

1. Materials and methods

1.1. Soil and plant

The soil used in this study was commercially-available black soil, which is rich in organic matter content and arguably one of the best types of soils in terms of fertility, arability and supporting microbial activity. The basic properties of black soil (Table S1) were measured according to standard methods (Lu, 2000; Pansu and Gautheyrou, 2006).

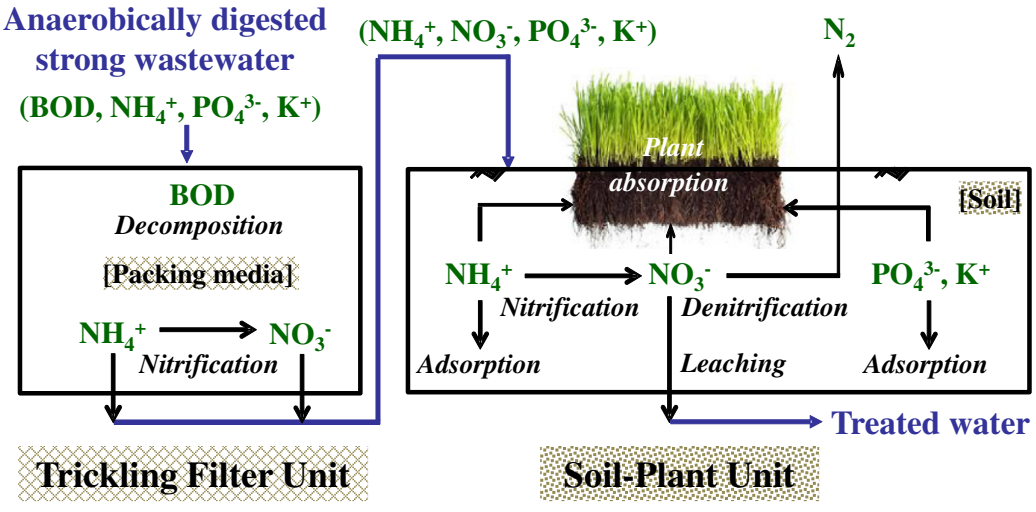

Fig. 1 – Schematic diagram of the proposed natural treatment system. Note that an impermeable layer should be installed surrounding the soil (of the soil–plant unit), for the sake of preventing secondary pollution to the adjacent environment.