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Insight into effects of electro-dewatering pretreatment on nitrous oxide emission involved in related functional genes in sewage sludge composting

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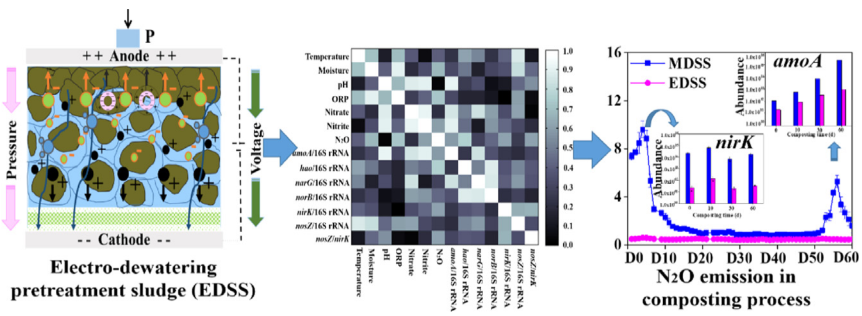
GRAPHICAL ABSTRACT



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ABSTRACT

Electro-dewatering (ED) pretreatment could improve sludge dewatering performance and remove heavy metal, but the effect of ED pretreatment on nitrous oxide (N_2O) emission and related functional genes in sludge composting process is still unknown, which was firstly investigated in this study. The results revealed that ED pretreatment changed the physicochemical characteristics of sludge and impacted N_2O related functional genes, resulting in the reduction of cumulative N_2O emission by 77.04% during 60 days composting. The higher pH and NH_4^+-N, but lower moisture, ORP and NO_2^--N emerged in the composting of ED sludge compared to mechanical dewatering (MD) sludge. Furthermore, ED pretreatment reduced *amoA*, *hao*, *narG*, *nirK* and *nosZ* in ED sludge on Day-10 and Day-60 of composting. It was found that *nirK* reduction was the major factor impacting N_2O generation in the initial composting of ED sludge, and the decline of *amoA* restricted N_2O production in the curing period.

1. Introduction

The output of municipal sewage sludge gradually increased with expansion and upgrade of wastewater treatment plants in China (Wang et al., 2018a,b,c). Sludge dewatering is mainly performed through mechanical techniques including gravitational settler, centrifuges, belt filter presses or plate and frame filter-presses. Inorganic (ferric or aluminium chloride) or organic (synthetic polyelectrolyte) flocculants are generally added in sludge prior to mechanical dewatering to facilitate the formation of flocculated particle networks and water removal. A plateau value 25% (wt% dry solids content) is the highest efficiency that can be reached through mechanical dewatering (Heij et al., 1996). The excessive moisture content of sludge increases transport and disposal cost, which accounts for 30–50% of operating costs in a wastewater treatment plant (Dursun, 2007). Therefore, it is imperative to develop new technology to remove more water from sludge.

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Electro-dewatering (ED) pretreatment is an effective technology that notably improves the separation of liquid and solids in sewage sludge. The ED pretreatment combines conventional mechanical dewatering with an electric field to accelerate the dewatering kinetics of sludge with low energy consumption (Mahmoud et al., 2016). Four typical electrokinetic phenomena (electrophoresis, electro-osmosis, electromigration and electrochemical reactions) exist in the ED process, which significantly change the physicochemical properties of sewage sludge (Mahmoud et al., 2010). Previous studies intensely investigated the optimization of ED process, suggesting that increasing voltage and pressure enhanced sludge dewatering efficiency, while the voltage was the only significant effect at 95% confidence level (Mahmoud et al., 2011). In addition, low salt content and acid pH promoted ED rate, but the presence of polyelectrolyte did not influence ED process (Citeau et al., 2011). However, to the best of our knowledge, there is almost no research concerning the posttreatment of ED sludge.

Sewage sludge treatment and disposal is imperative to avoid its potential risk to human health on account of the migration of pollutants to agricultural land and groundwater (Maulini-Duran et al., 2013; Wu et al., 2015). The composting is an economical and effective biotechnology for sludge stabilization that could inactivate pathogens and convert organic pollutants into humified product (Wang et al., 2014; Zhang et al., 2014). Unfortunately, composting process is an important source of nitrous oxide (N_2O) (Wang et al., 2018a,b,c). N_2O is an important greenhouse gas, and it has 298 times greater global warming potential than the equivalent mass of CO_2 (Forster et al., 2007). Total N_2O generation is increasing at the rate of 0.25% annually (Forster et al., 2007). N_2O emission probably results in stratospheric ozone depletion and causes a series of environmental problems (Li et al., 2016). Therefore, immediate action needs to be taken to reduce N_2O production in sludge composting.

Previous studies regarded the optimization of operation conditions (such as aeration rate, C/N ratio and bulking agent) as the primary approach to mitigate N_2O emission in composting process (Yang et al., 2013; Jiang et al., 2015; Jiang et al., 2011). It was reported that high aeration rate increased N_2O and NH_3 emission rate (Jiang et al., 2011). Intermittent aeration enhanced nitrification/denitrification alternation and produced more N_2O in curing stage compared to continuous aeration (Jiang et al., 2015). Biochar and zeolite are porous microstructure materials, and the N_2O emission rate significantly declined when biochar mixed with zeolite was added in composting matrix (Awasthi et al., 2016a,b). In addition, the N_2O emission rate was correlated to NO_x-N concentration (Wang et al., 2013). Sawdust possessed low NO_x-N and bulk density, which led to the lowest N_2O production among sawdust, cornstalks and spent mushroom substrate in kitchen composting (Yang et al., 2013). However, N_2O generation greatly depends on physicochemical characteristics of feedstock, thus these methods mentioned above could not radically inhibited N_2O generation in sludge composting. ED pretreatment provided an effective approach to significantly change the physical and chemical properties of sludge. Nonetheless, the effect of ED pretreatment on N_2O generation in sludge composting process is largely unknown.

N_2O generation is closely related to the metabolic function of microbial community in composting system. Biochar amendment decreased the abundances of *narG*, *norB* and *nirK*, but increased the abundance of *nosZ*, resulting in lower N_2O emission in curing phase (Wang et al., 2013). Significant positive correlation between N_2O emission and the abundances of *nirK* and *nosZ* was observed in biochar-amended composting (Li et al., 2016). In addition, intermittent aeration lessened N_2O emission through affecting the nitrification and denitrification genes in sludge bio-drying process (Zhang et al., 2017). However, microbial functional genes depend on the physical and chemical properties of sludge, consequently these methods could not radically change the abundances of nitrification and denitrification genes in the sludge.

In this study, the effect of ED pretreatment of sludge on N_2O emission in aerobic composting process was evaluated for the first time. Variations in the physicochemical characteristics of electro-dewatering sewage sludge (EDSS) and mechanical dewatering sewage sludge (MDSS) were detected, respectively. The abundances of the related functional genes (*amoA*, *hao*, *narG*, *nirK*, *norB* and *nosZ*) were determined through quantitative polymerase chain reaction (qPCR). The primary objectives of this study were to assess the effect of ED pretreatment on N_2O generation process, autotrophic nitrifying and denitrifying genes in composting process, and put forward a feasible strategy to mitigate N_2O emission in composting treatment based on present experimental results.

2. Materials and methods

2.1. Raw materials and experimental design

Two aerobic composting experiments of sewage sludge were conducted in lab-scale and monitored for 60 days. MDSS and EDSS were collected from the same urban municipal wastewater treatment plant in which the sludge was dewatered by MD and ED facility, respectively. The operating pressure and voltage of ED machine were 600 kPa and 30 V respectively. The initial moisture content, volatile solids (VS) content, pH and oxidation-reduction potential (ORP) of MDSS were 85.01%, 49.23%, 7.22 and −28 mV, respectively. The initial moisture content, VS content, pH and ORP of EDSS were 67.53%, 42.59%, 8.47 and 62 mV, respectively. Sawdust (2cm × 2 cm) purchased from a local farm was used as bulking agent to regulate the moisture and the bulk density of the feedstock.

8 kg of MDSS and EDSS mixed with 1.6 kg sawdust to form the initial composting materials for both treatments, respectively. The volume of composter was 40 L. Forced aeration through an air pump occurred in the present experiment, and the aeration rate maintained at 0.5 L/min. Both composting piles were turned and remixed manually every 10 days. Composting samples were collected from both treatments approximately every three days. The temperatures of both treatments and ambient were determined once a day using thermometers. The ORP of composting materials was detected in situ through a Chuandi FJA-5 ORP meter (Nanjing, China). The sludge was separated from the sawdust to analysis in order to avoid the effect of organic bulking agent on sample analysis.

2.2. Sample collection and physicochemical analysis

Five subsamples were removed randomly from the composting to yield one integrated sample. The integrated sample was divided into three parts. One part was used to detect the moisture content, VS content, pH, and the concentrations of NH_4^+-N, NO_2^--N and NO_3^--N. Another part was air-dried, ground, and passed through 0.075 mm sieve to measure C/N ratio and the concentration of dissolved organic carbon (DOC). The last part was stored at −80 °C for DNA extraction. Each parameter was measured in triplicate for the purpose of alleviating personal error.

Each composting sample was dried at 105 °C for 24 h to determine the moisture content based on the weight loss of the mixtures. Subsequently, the dry sample was burnt in a muffle furnace at 550 °C for 4 h and the VS content was measured according to the weight differences. 2 g of fresh samples were dissolved in 20 ml of distilled water to detect pH value. Fresh samples were extracted with 2.0 M KCl solution at the ratio of 1:10 (w/v) to determine the NH_4^+-N concentration using colorimetric method, and the concentrations of NO_2^--N and NO_3^--N using ion chromatography (DIONEX ICS-3000, USA). The residue passing through the sieve was extracted with distilled water at a ratio of 1:10 (w/v) to detect the concentration of DOC by a TOC analyzer (TOC-V_{CPN}, Shimadze).

Gas samples were collected from the reactors three times a day using syringes, and then were immediately injected into pre-evacuated