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Environmental impact analysis of nitrogen cross-media metabolism: A case study of municipal solid waste treatment system in China

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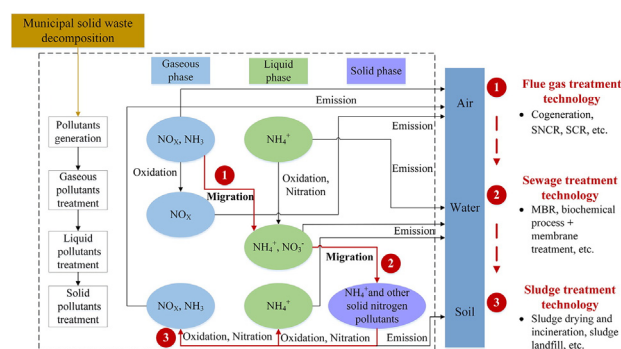
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HIGHLIGHTS

- Analysis framework for cross-media metabolism of nitrogen was developed for municipal solid waste treatment system (MSWTS).
- Critical technological processes were identified for the environmental impacts sensitivity analysis.
- Application of anaerobic digestion should be encouraged for its high removal efficiency of nitrogen.
- Incineration processes are easier to affect the environment in terms of nitrogen metabolism.
- Shift of management mode from single environmental medium control to ecosystem quality improvement is essential.

GRAPHICAL ABSTRACT



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ABSTRACT

Municipal Solid Waste Treatment System (MSWTS) contributes a lot to urban metabolism optimization and pollution control of nitrogen. An analysis framework for cross-media metabolism of nitrogen was developed for MSWTS to study the systematic effects of nitrogen metabolism in MSWTS on ecosystem quality. Then cross-media distribution of pollutants was calculated in landfill, composting, incineration and anaerobic digestion, respectively. Sixty three percent to 82% of the original inputs ended up in the natural environment using the former three technologies (landfill, composting and incineration), which was attributed to cross-media migration. Anaerobic digestion should be highlighted due to its overall desirable removal efficiency. Critical processes related to nitrogen cross-media migration were identified to analyze the overall environmental impacts sensitivities. Positive effects emerged in liquid-solid interface migration of nitrogen through sewage collection and treatment technology processes, while the incineration flue gas treatment witnessed negative effects in gas-liquid interface migration. Overall, the environmental impact sensitivity levels of nitrogen cross-media migration under critical processes were as follows: incineration > landfill > composting > anaerobic digestion. Therefore, the environment is most sensitively affected by incineration and its processes. The present study is of great significance to optimize environmental management by shifting the management mode from single environmental medium quality control to systematic ecosystem quality improvement.

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1. Introduction

Nitrogen has been studied increasingly in the urban ecosystem metabolism process and necessities of human production and daily life activities since the industrial revolution (Erisman et al., 2008). Environmental pollution and ecosystem degradation through man-made nitrogen emissions are becoming eminent (Erisman et al., 2013), despite contributions of artificial active nitrogen. Due to intricate paths and various chemical varieties, nitrogen metabolism processes become more difficult to be predicted with the disruption of human activities in the urban ecosystem (Gruber and Galloway, 2008; Galloway et al., 2008; Gu et al., 2009). Therefore, it has become an imperative task in the 21st century to optimize the nitrogen utilization and reduce the adverse effects of active nitrogen on human and the whole ecosystem quality (Galloway et al., 2013).

The Municipal Solid Waste Treatment System (MSWTS), an indispensable part of urban ecosystem, contributes a lot to the metabolism shift optimization and pollution control of nitrogen (Chen et al., 2010; Chung and Lo, 2008; Zhang et al., 2010). The MSWTS reduces direct nitrogen pollutant emissions into some single environmental medium (water, air or soil) to a great extent. However, new pollutants will actually be generated by consequential physiochemical processes, such as nitrification, de-nitrification and redox, etc. (Philip et al., 2002). Therefore, the MSWTS is not efficient to remove the nitrogen pollutants entirely due to the cross-media migration of nitrogen.

Currently, landfill (Rong et al., 2017; Fei et al., 2016; Mahar et al., 2016), composting (Jara-Samaniego et al., 2017; Rasapoor et al., 2016), incineration (Hong et al., 2017; Tao et al., 2017) and anaerobic digestion (Jain et al., 2015; Dennehy et al., 2017) are commonly used for MSW treatment. Pollutant disposal technologies are usually used simultaneously to reduce pollutant emission, such as electricity generation by landfill gas, leachate treatment, incineration flue gas, etc. (Korai et al., 2017). They play an important role in the cross-media migration of nitrogen pollutants. For example, to purify flue gas (NO_x involved) given by oxidation reaction and recover energy, technologies such as cogeneration, SCR and SNCR are used with incineration to lock gaseous pollutants in liquid absorbent and reduce the nitrogen emissions into the atmosphere (Van Caneghem et al., 2016; Yari et al., 2016). Nevertheless, large amounts of NO_x and NH_4 in the produced wastewater from the liquid absorbent and cogeneration process can cause water eutrophication if the wastewater is not processed before introduced into the natural water bodies. In addition, research has also shown that a fairly (large/small) part of pollutants (e.g., NO_x , NH_3 and the like), which are supposed to be eliminated by sewage treatment facilities, eventually end up in solid sludge and cause soil acidification in the environment (Zhang, 2014).

Recently, a series of studies have been carried out on urban nitrogen metabolism simulation, multimedia pollutant migration model and environmental impact assessment for waste treatment process. However, there is no systematic framework analyzing both the integrated impact of multimedia pollutant migration in urban nitrogen metabolism processes and the quality improvement of the whole ecosystem. Various nitrogen flow processes occurring at the whole or part of a city level were studied with regard to urban nitrogen metabolism analysis (Baker et al., 2001; Faerge et al., 2001; Savanick et al., 2007; Forkes, 2007; Gu et al., 2012). The concept of multimedia environment model is emerging to quantitatively depict the migration and transformation of pollutants among multiple environmental media and develop efficient approaches for pollution control (Armitage et al., 2009; Csiszar et al., 2013; Zheng et al., 2014). In addition, since 1990s, research aiming at environmental impact assessment of solid waste, especially life cycle assessments for different collection and treatment systems, has sprung up remarkably and provided systematic methodology and multidimensional assessment tools for some MSWTS (Iriarte et al., 2009; Arena et al., 2003; Hong et al., 2006; Jorgensen, 2004; Pasqualino et al., 2011; Renzoni and Germain, 2007).

Although nitrogen metabolism and its corresponding environmental impact assessment in urban ecosystem are being highlighted by researchers, systematic analysis based on multimedia nitrogen migration, aiming at quality improvement of the whole natural ecosystem, hasn't been studied. In addition, research has rarely studied the cross-media migration of nitrogen pollutants in MSWTS or the impact of the phenomenon on the whole environment. This present study, with the MSWTS as a case, intends to 1) illustrate the latent nitrogen migration process, 2) discriminate the critical technology causing primary cross-media migration, 3) evaluate the overall environmental effect by different migration forms. Technical policies and suggestions are proposed to provide the application and concept of collaborative multimedia optimization for the current pollution control mode of a single medium in the environmental.

2. Methodology

2.1. Analysis framework for cross-media metabolism

Four treatment technologies (landfill, incineration, composting and anaerobic digestion) have been chosen as the research targets, combined with the current main disposal technologies for municipal solid waste (MSW). Various treatment processes, material flows and conversion modules are involved in the technologies, among which latent migration and transformation of pollutants also exist. Moreover, flux exchanges commonly occur between technologies, technological processes and natural environment (hydrosphere, atmosphere and soil). Fig. 1 presents the analysis framework for cross-media metabolism in MSWTS, based on which generation, transformation and emission of nitrogen are traced and analyzed among different technologies, technological processes and environmental media.

Table 1 shows the technological processes involved in the four technologies of MSWTS.

2.2. Cross-media migration rate and sensitivity analysis of technology popularity to migration

Some proper indicators are essential to identify critical technological processes affecting cross-media migration quantitatively. The indicators could represent the relationship between popularization of technologies and migration degree. Popularity rate P of technological processes and migration rate T are adopted in the paper. In addition, migration coefficient R_i is employed to indicate the sensitivity of process i to cross-media migration. Eq. (1) and Eq. (2) show the calculation processes of parameters above.

$$R_i = T_i / \Delta P_i \quad (1)$$

$$T_i = \left(\frac{y + \Delta y}{x + \Delta x} - \frac{y}{x} \right) / \frac{y}{x} \quad (2)$$

X is nitrogen emissions from phase A and y is emissions from phase B. Δx and Δy are the emission variations of phase A and B respectively when P_i , the popularity rate of technology i , has some change of ΔP_i .

2.3. Environmental impact assessment model

Environmental impact of nitrogen pollutants emissions in cross-media migration model shall be evaluated to determine their overall effects under the objective of multimedia control. Life Cycle Impact Assessment (LCIA) was employed (Nabavi-Pelesaraei et al., 2017; Toniolo et al., 2017), with reference to criterion of ISO14042 and specified procedures (classification, characterization, impact categories, preferences, evaluation, etc.) (Fig. 2).

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