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A novel methodology to quantify nitrous oxide emissions from full-scale wastewater treatment systems with surface aerators

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ABSTRACT

The quantification of nitrous oxide (N_2O) emissions from open-surface wastewater treatment systems with surface aerators is difficult as emissions from the surface aerator zone cannot be easily captured by floating hoods. In this study, we propose and demonstrate a novel methodology to estimate N_2O emissions from such systems through determination of the N_2O transfer coefficient (k_La) induced by surface aerators based on oxygen balance for the entire system. The methodology is demonstrated through its application to a full-scale open oxidation ditch wastewater treatment plant with surface aerators. The estimated k_La profile based on a month-long measurement campaign for oxygen balance, intensive monitoring of dissolved N_2O profiles along the oxidation ditch over a period of four days, together with mathematical modelling, enabled to determine the N_2O emission factor from this treatment plant (0.52 ± 0.16%). Majority of the N_2O emission was found to occur in the surface aerator zone, which would be missed if the gas hood method was applied alone.

1. Introduction

Nitrous oxide (N_2O) is a significant greenhouse gas, with a global warming potential approximately 300-fold stronger than that of carbon dioxide (IPCC, 2001). It also reacts with ozone in the stratosphere leading to ozone layer depletion (Portmann et al., 2012). N_2O can be produced and directly emitted from wastewater treatment systems (Ahn et al., 2010). N_2O emissions can contribute substantially to the carbon footprint of wastewater treatment plants (WWTPs). It is estimated that an emission factor as low as 0.5% would lead to a greenhouse gas emission that is comparable to that of the indirect CO_2 emission due to energy consumption in conventional biological nutrient removal WWTPs (De Haas and Hartley, 2004). Therefore, reliable quantification of N_2O emissions from full-scale WWTPs is of importance.

Presently, the UN Climate Panel (IPCC) is using an oversimplified fixed emission factor as their current global climate tool to quantify N_2O emissions, without considering specific designs and operational conditions (IPCC, 2006). However, the N_2O emission data collected from WWTPs to date show a huge variation in the fraction of influent nitrogen load emitted as N_2O. By monitoring 12 WWTPs in the US, Ahn et al. (2010) reported emission factors in the range of 0.01–1.8%. Some other studies

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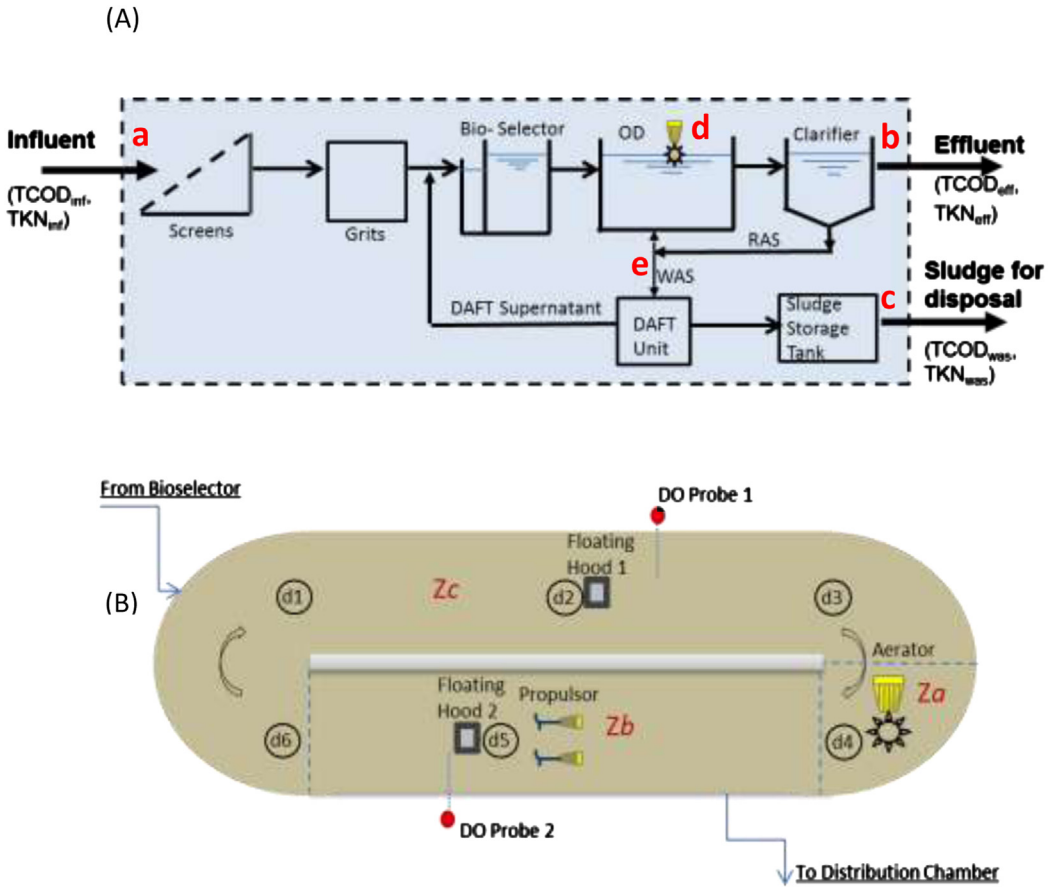

Fig. 1 – (A) A simplified flowchart of the WWTP studied with the long-term sampling/data collection locations (a-raw wastewater; b-effluent; c-disposed sludge; d-oxidation ditch; e-waste activated sludge) (B) Sampling locations in the oxidation ditch during intensive sampling period (d1-anoxic zone where the wastewater enters; d2-anoxic zone near floating hood 1; d3-anoxic zone before mixed liquor enters the aeration zone; d4-aeration zone with a surface aerator; d5-aerobic zone near the propulsor and floating hood 2; d6-anoxic zone, at the end of the ditch. The ditch is divided into three zones based on visual observation (Za – aerator zone, Zb – propulsor zone with noticeable turbulence on surface, Zc – non-turbulent zone).

revealed even higher (>10%) emission factors (Kampschreur et al., 2009; Foley et al., 2010). A high degree of temporal variability in N_2O emission has also been observed within the same WWTP (Ahn et al., 2010). These variabilities in measured emissions strongly contrast with the fixed emission factor method currently applied to estimate N_2O emissions from wastewater treatment (IPCC, 2001). Therefore, each WWTP needs to be assessed individually through either direct measurement of N_2O emission or reliable model-based estimation (Foley et al., 2011).

For the WWTPs that are fully covered, the N_2O emission rate can be calculated by measuring N_2O concentration in the gas phase, as well as the total gas flow rate. Using this method, Daelman et al. (2013) monitored N_2O emissions from a fully covered municipal WWTP in Netherlands for sixteen months, and observed that 2.8% incoming nitrogen was emitted as N_2O, which constituted three quarters of the carbon footprint of the plant.

However, most WWTPs are open-surface sludge systems. The floating chamber method is typically used for the quantification of N_2O in such systems (Law et al., 2012). N_2O flux is captured using a floating hood, a method adapted from gas emission measurement from soils. Recently, the online, continuous monitoring of N_2O with floating hoods enabled relatively accurate quantification of N_2O emissions from some open-surface activated sludge systems (Kampschreur et al., 2008; Joss et al., 2009; Ahn et al., 2010; Desloover et al., 2011).

An alternative method to quantify N_2O emissions is based on mass transfer estimation. In WWTPs, N_2O is produced in the liquid phase during nitrogen removal, which may be transferred into gas phase when N_2O is over-saturated. The rate of emission can be estimated using the volumetric mass transfer coefficient (k_La, d^{-1}) and the liquid phase N_2O concentration. Foley et al. (2010) estimated N_2O emissions from seven WWTPs in Australia with various process configurations using this method, with a reported N_2O emission factor from 0.6 to 25% of the denitrified nitrogen. However, k_La is related to many factors in a WWTP, including reactor geometry (particularly aerator immersion depth), aeration bubble size, diffuser layout and liquid viscosity, among others (Gillot et al., 2005). Therefore, the estimation of k_La for N_2O emission is very difficult in reality, especially considering the dynamic conditions and spatial variability in a wastewater treatment