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Methane correction factors for estimating emissions from aerobic wastewater treatment facilities based on field data in Mexico and on literature review

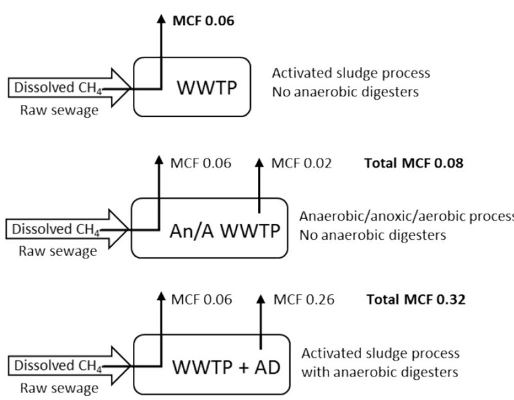
A. Noyola [a,*], M.G. Paredes [a], L.P. Güereca [a], L.T. Molina [b], M. Zavala [b]

[a] Instituto de Ingeniería, Universidad Nacional Autónoma de México, Av. Universidad 3000, 04510 México D.F., Mexico
[b] Molina Center for Energy and the Environment, 3252 Holiday Ct, Suite 223, La Jolla 92037, USA

HIGHLIGHTS

- Some methane correction factors (MCF) in IPCC tier 1 methodology should be revised.
- Exogenous influent dissolved CH_4 invalidates the assumption of a CH_4-neutral facility.
- 0.06 MCF for well-managed centralized aerobic WWTP is proposed (intertropical areas).
- Biological nutrient removal should be added in the IPCC guidelines with a 0.08 MCF.
- Aerobic WWTP + anaerobic digester should be added as an integrated process (MCF 0.32).

GRAPHICAL ABSTRACT



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ABSTRACT

Wastewater treatment (WWT) may be an important source of methane (CH_4), a greenhouse gas with significant global warming potential. Sources of CH_4 emissions from WWT facilities can be found in the water and in the sludge process lines. Among the methodologies for estimating CH_4 emissions inventories from WWT, the more adopted are the guidelines of the Intergovernmental Panel on Climate Change (IPCC), which recommends default emission factors (Tier 1) depending on WWT systems. Recent published results show that well managed treatment facilities may emit CH_4, due to dissolved CH_4 in the influent wastewater; in addition, biological nutrient removal also will produce this gas in the anaerobic (or anoxic) steps. However, none of these elements is considered in the current IPCC guidelines. The aim of this work is to propose modified (and new) methane correction factors (MCF) regarding the current Tier 1 IPCC guidelines for CH_4 emissions from aerobic treatment systems, with and without anaerobic sludge digesters, focusing on intertropical countries. The modifications are supported on in situ assessment of fugitive CH_4 emissions in two facilities in Mexico and on relevant literature data. In the case of well-managed centralized aerobic treatment plant, a MCF of 0.06 (instead of the current 0.0) is proposed, considering that the assumption of a CH_4-neutral treatment facility, as established in the IPCC methodology, is not supported. Similarly, a MCF of 0.08 is proposed for biological nutrient removal processes, being a new entry in the guidelines. Finally, a one-step straightforward calculation is proposed for centralized

* Corresponding author.
E-mail address: noyola@pumas.ii.unam.mx (A. Noyola).

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aerobic treatment plants with anaerobic digesters that avoids confusion when selecting the appropriate default MCF based on the Tier 1 IPCC guidelines.

1. Introduction

Wastewater treatment is a major component in today's systems for environmental pollution control, public health protection and water reclamation. However, in some cases, depending on the selected technology and on operational practices, wastewater treatment plants (WWTP) may be an important source of greenhouse gases (GHG), either linked to the consumption of fossil fuel-produced electricity (indirect CO_2 emissions) or to the in situ production of methane (CH_4) and nitrous oxide (N_2O). Methane, a relevant short-lived climate forcer (SLCF), has a significant contribution to climate change, as expressed by its global warming potential (GWP), considering that, over a 100-year time frame, it is 34 times more effective at trapping heat in the atmosphere than carbon dioxide (CO_2) (Myhre et al., 2013). For this reason, it is highly relevant to quantify CH_4 emissions from WWTP on a more precise basis, in order to evaluate different scenarios and establish appropriate mitigation strategies for the water sector (Flores-Alsina et al., 2011).

Sources of CH_4 emissions can be found in both, water and sludge, process lines in WWTP. In conventional aerobic processes, the first is assumed as not important, unless the treatment facility is poorly operated. However, there is now enough data that support significant CH_4 emissions from the preliminary steps and from the aerobic tanks in conventional, well managed treatment facilities, tracing these emissions to the CH_4 dissolved in the influent wastewater (Daelman et al., 2012; Masuda et al., 2015; Short et al., 2017, among others). In addition, when the sludge produced during wastewater treatment (as an unavoidable waste product) is digested in anaerobic reactors, it becomes an important source of methane emissions (Hospido et al., 2005; Wang et al., 2011; Yoshida et al., 2014a, among others). The waste sludge represents between 20 and 40% of the influent organic matter, depending on process variants and organic loads, with a typical biogas composition in the interval of 60 to 65% for CH_4 and 35 to 40% for CO_2 (Metcalf and Eddy, 2003).

In the majority of large-scale treatment facilities, the produced biogas is used in co-generation systems to produce heat and electricity, thus reducing the embedded fossil-fuel conventional energy and, at the same time, avoiding CH_4 emissions to the atmosphere, minimizing the carbon footprint of the wastewater subsector (Hobson, 1999; Chynoweth et al., 2001; Güereca-Hernández et al., 2015). However, fugitive (unintended) emissions of CH_4 may be produced as leaks in the anaerobic digesters due to inefficiencies in biogas capture and flaring systems. It has been reported that these fugitive emissions represent between 2 and 10% of the total methane emissions and a loss of potential energy and heat (Flesch et al., 2011; Dumont et al., 2013; Yoshida et al., 2014b). Higher leakage values may be encountered resulting in many cases due to poor operation and maintenance practices (Yoshida et al., 2014b).

CH_4 fugitive emissions from anaerobic processes are often difficult to quantify due to the diffusive nature of the emissions combined with large temporal variation and a challenging physical distribution of the process units (Delre et al., 2014). Atmospheric tracer release approach for quantifying methane fugitive emissions from wastewater treatment systems has been used both with static downwind collection of air with subsequent analysis in the laboratory, and as a mobile, direct measurement method using one or more trace gases (Scheutz et al., 2011; Mønster et al., 2014; Yver Kwok et al., 2015; Delre et al., 2017). The tracer method has minimal disturbances and straightforward data analysis that may be used to estimate emission rate of individually targeted sources or integrated emissions from a given facility; however, disadvantages such as potential high cost, interference from neighboring sources, the need of relatively flat topography and dependence on meteorological conditions can potentially limit its applicability (Soltani-Ahmadi, 2000).

In order to estimate CH_4 emissions from WWTP in national GHG inventories, the Intergovernmental Panel on Climate Change (IPCC) recommends using default emission factors (Tier 1) when limited data is available (such as Mexico and most developing countries). However, these estimates can be highly uncertain, owing mainly to the lack of reliable information about the operation of the treatment process and the local environmental conditions. Mexico, as most of the emerging economies, does not have locally measured methane emission factors from WWTP and consequently, accurate emission estimates is missing. At present, the reliability of the national emission estimations based on the Tier 1, IPCC Guidelines for wastewater treatment and discharge (Vol. 5, Chapter 6; IPCC (Intergovernmental Panel on Climate Change), 2006a) are limited to some extent, due to different aspects: CH_4 emissions from closed sewer systems and those resulting from WWTP from dissolved CH_4 in the influent are not considered; it is not clear how to deal, under Tier 1, with the aerobic treatment systems complemented with anaerobic sludge digesters. Also, the anaerobic-aerobic process for nutrient removal should be recognized as a new treatment system entry. These items are discussed in the paper.

The aim of this work is to propose adjustments to the current Tier 1 IPCC Guidelines for CH_4 emissions from aerobic treatment systems, with and without anaerobic sludge digesters, with emphasis in intertropical countries. The proposed changes are supported on in situ assessment of fugitive CH_4 emissions in two activated sludge treatment facilities in Mexico and on relevant literature data. Moreover, to the best of our knowledge, this is the first time that the tracer ratio technique is used in a developing country for determining CH_4 emissions from WWT facilities.

2. Methodology

Methane emissions measurements were carried out in two municipal wastewater reclamation treatment plants: "Dulces Nombres" in Monterrey (MTY) and "Cerro de la Estrella" in Mexico City (CMX). The MTY facility (5500 L/s; influent chemical oxygen demand (COD) 1116 mg/L; influent biochemical oxygen demand (BOD) 322 mg/L; BOD removal efficiency 97%) is located in the state of Nuevo León, México (25°44′19″N. 100°4′6″W). The CMX treatment plant (2300 L/s; influent COD 370 mg/L; BOD 180 mg/L; BOD removal efficiency of 85%), is located in Mexico City (19°20′12″N. 99°4′42″W). Both WWTP are based on a conventional activated sludge process arrangement (preliminary treatment, primary settling, secondary treatment, effluent disinfection) but they apply different sludge management practices. In the MTY facility, the excess sludge (primary and secondary: 117,300 kg/d total solids (TS) with 0.64 volatile fraction) is anaerobically treated in 5 mesophilic (32 °C) digesters (12,300 m^3 volume each one) with 31% volatile solids (VS) removal; the produced biogas (39,608 ± 1642 N-m^3/d, 66% CH_4) is burned in flares, without energy recovery. In the CMX facility, the sludge is discharged (raw, untreated) back to the municipal sewer system.

In the particular case of CMX facility, additional information was obtained from an unpublished internal report on dissolved CH_4 measurements and estimation of CH_4 emissions by means of a static chamber array (Supplementary Material).