Science of the Total Environment 466–467 (2014) 616–624

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Balancing effluent quality, economic cost and greenhouse gas emissions during the evaluation of (plant-wide) control/operational strategies in WWTPs

Xavier Flores-Alsina [a,b], Magnus Arnell [a,c], Youri Amerlinck [d], Lluís Corominas [e], Krist V. Gernaey [b], Lisha Guo [f], Erik Lindblom [a,g], Ingmar Nopens [d], Jose Porro [d,h], Andy Shaw [i,j], Laura Snip [b], Peter A. Vanrolleghem [f], Ulf Jeppsson [a,*]

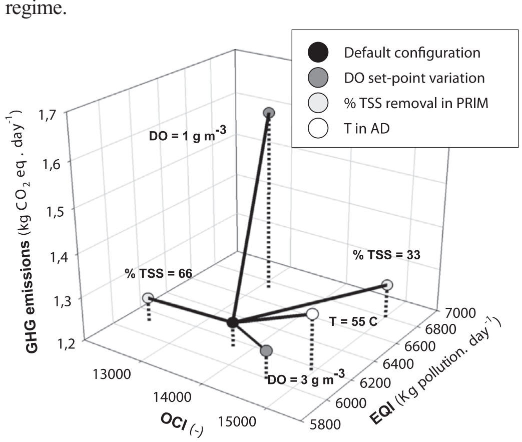
[a] Division of Industrial Electrical Engineering and Automation (IEA), Department of Measurement Technology and Industrial Electrical Engineering (MIE), Lund University, Box 118, SE-221 00 Lund, Sweden
[b] Center for Process Engineering and Technology (PROCESS), Department of Chemical and Biochemical Engineering, Technical University of Denmark, Building 229, DK-2800 Kgs. Lyngby, Denmark
[c] CIT Urban Water Management, Gjuterigatan 1D, SE-582 73 Linköping, Sweden
[d] BIOMATH, Department of Mathematical Modelling, Statistics and Bioinformatics, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium
[e] ICRA, Catalan Institute for Water Research, Scientific and Technological Park of the University of Girona, H_2O Building, Emili Grahit 101, 17003 Girona, Spain
[f] ModelEAU, Département de génie civil et de génie des eaux, Université Laval, 1065 Avenue de la Médecine, Québec G1V 0A6, QC, Canada
[g] Sweco Environment, Gjörwellsgatan 22, SE-100 26 Stockholm, Sweden
[h] Laboratory of Chemical and Environmental Engineering (LEQUiA), University of Girona, Faculty of Sciences, Campus Montilivi s/n, 17071, Girona, Spain
[i] Black & Veatch, 8400, Ward Parkaway, Kansas City, MO 64114, USA
[j] Illinois Institute of Technology, 3300 South Federal Street, Chicago, IL 60616, USA

HIGHLIGHTS

- A 3-D graphical representation shows the interactions among effluent quality, operational cost and GHG emissions during the evaluation of operational/control strategies in WWTP.
- The study points out the importance of taking into account the existing interactions among the water and sludge line.
- The potentially undesirable effects of local energy optimization (aeration/biogas) are highlighted when calculating the total plant's overall global warming potential.

GRAPHICAL ABSTRACT

The 3-D representation of effluent quality (EQI), operational cost (OCI) and greenhouse gas emissions (GHG) during the evaluation of several (plant-wide) control/operational strategies: (1) modification of the DO set point, (2) modification of the primary clarifier TSS removal efficiency and (3) modification of the anaerobic digester temperature regime.



* Corresponding author at: Division of Industrial Electrical Engineering and Automation (IEA), Department of Measurement Technology and Industrial Electrical Engineering (MIE), Lund University, Box 118, SE-221 00 Lund, Sweden. Tel.: +46 46 222 92 87.
E-mail address: ulf.jeppsson@iea.lth.se (U. Jeppsson).

0048-9697/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.scitotenv.2013.07.046

A R T I C L E I N F O

Article history:
Received 2 April 2013
Received in revised form 2 July 2013
Accepted 13 July 2013
Available online xxxx

Editor: Simon Pollard

Keywords:
Benchmarking
Global warming
Model-based evaluation
Multi-criteria decision making
Process control
Sustainability

A B S T R A C T

The objective of this paper was to show the potential additional insight that result from adding greenhouse gas (GHG) emissions to plant performance evaluation criteria, such as effluent quality (EQI) and operational cost (OCI) indices, when evaluating (plant-wide) control/operational strategies in wastewater treatment plants (WWTPs). The proposed GHG evaluation is based on a set of comprehensive dynamic models that estimate the most significant potential on-site and off-site sources of CO_2, CH_4 and N_2O. The study calculates and discusses the changes in EQI, OCI and the emission of GHGs as a consequence of varying the following four process variables: (i) the set point of aeration control in the activated sludge section; (ii) the removal efficiency of total suspended solids (TSS) in the primary clarifier; (iii) the temperature in the anaerobic digester; and (iv) the control of the flow of anaerobic digester supernatants coming from sludge treatment. Based upon the assumptions built into the model structures, simulation results highlight the potential undesirable effects of increased GHG production when carrying out local energy optimization of the aeration system in the activated sludge section and energy recovery from the AD. Although off-site CO_2 emissions may decrease, the effect is counterbalanced by increased N_2O emissions, especially since N_2O has a 300-fold stronger greenhouse effect than CO_2. The reported results emphasize the importance and usefulness of using multiple evaluation criteria to compare and evaluate (plant-wide) control strategies in a WWTP for more informed operational decision making.

© 2013 Elsevier B.V. All rights reserved.

1. Introduction

The main focus in assessing the operation of wastewater treatment plants has historically been the effluent water quality under constraints of technical feasibility and cost. This certainly still holds, but the discussions on sustainability in general and the issue of climate change due to greenhouse gas (GHG) emissions in particular (Foley et al., 2011; Law et al., 2012; Rodriguez-Garcia et al., 2012) have widened the scope for the utilities. An increasing interest in GHG emissions calls for novel approaches to evaluate the performance of control and operational strategies in order to include additional performance indicators related to GHG emissions.

Aside from evaluating control and operational strategies (Nopens et al., 2010) before full-scale implementation (Ayesa et al., 2006), dynamic activated sludge models (ASM) (Henze et al., 2000) have been widely used for multiple purposes in wastewater engineering such as benchmarking (Gernaey et al., 2013), diagnosis (Olsson, 2012; Rodriguez-Roda et al., 2002), design (Rieger et al., 2012; Flores et al., 2007), teaching (Hug et al., 2009) and optimization (Rivas et al., 2008). Based on new knowledge on the chemical and biochemical mechanisms of GHG production, recent efforts have been made to capture the production and emissions of CO_2, CH_4 and N_2O and integrate these processes in the traditional ASM models (Batstone et al., 2002; Hiatt and Grady, 2008; Ni et al., 2013; Mampaey et al., 2013; Guo and Vanrolleghem, 2013).

Nevertheless, there are few studies discussing the additional benefit of adding a new dimension related to GHG production and emission to the traditional effluent quality and operational cost indices within the performance evaluation procedures (Flores-Alsina et al., 2011; Corominas et al., 2012; Guo et al., 2012). In this paper, an extended version of the International Water Association (IWA) Benchmark Simulation Model No. 2 (BSM2), i.e., BSM2G, is used for all simulations to demonstrate the benefit of adding this additional GHG emissions dimension.

A novelty of this paper includes the evaluation of plant-wide control/operational strategies through an integrated GHG modeling approach, representing the major pathways known to contribute significantly the plant-wide carbon footprint. These strategies involve changes related to the following process variables: (i) the dissolved oxygen (DO) set point of the aeration system in the activated sludge section; (ii) the removal efficiency of the total suspended solids (TSS) in the primary clarifier; (iii) the temperature in the anaerobic digester (AD); and (iv) the control of the flow of anaerobic digester supernatants from sludge treatment. Further, the authors in this paper consider the main interactions between the water and the sludge line. Finally, changes in effluent quality index (EQI), operational cost index (OCI) and CO_2, CH_4 and N_2O emissions are analyzed by means of a 3-D representation and thoroughly discussed. As a side effect, synergies and trade-offs between local energy optimization and the overall GHG production is studied in detail.

2. Methods

2.1. Wastewater treatment plants under study

The WWTP under study (BSM2G) has the same layout as the IWA BSM2 platform proposed by Nopens et al. (2010). The plant is treating an influent flow rate of 20,648 $m^3 \cdot day^{-1}$ and a total COD and N load of 12,240 and 1140 $kg \cdot day^{-1}$, respectively. Influent characteristics are generated following the principles stated in Gernaey et al. (2011). The activated sludge (AS) unit is a modified Ludzack-Ettinger configuration consisting of 5 tanks in series. Tanks 1 (ANOX1) and 2 (ANOX2) are anoxic (total volume = 3000 m^3), while tanks 3 (AER1), 4 (AER2) and 5 (AER3) are aerobic (total volume = 9000 m^3). AER3 and ANOX1 are linked by means of an internal recycle with the purpose of nitrate recycle for pre-denitrification. The BSM2G plant further contains a primary (PRIM) (900 m^3) and a secondary (SEC) clarifier (6000 m^3), a sludge thickener (THK), an anaerobic digester (AD) (3400 m^3), a storage tank (ST) (160 m^3) and a dewatering unit (DW). Additional information about the plant design and operational conditions can be found in Flores-Alsina et al. (2011).

The biological process model used in the study is described in detail in Guo and Vanrolleghem (2013). From the original set of models of BSM2, the Activated Sludge Model No. 1 (ASM1) (Henze et al., 2000) has been expanded with the principles proposed by Hiatt and Grady (2008) and Mampaey et al. (2013). The Hiatt and Grady model incorporates two nitrifying populations: ammonia oxidizing bacteria (AOB) and nitrite oxidizing bacteria (NOB) using free ammonia (NH_3) and free nitrous acid (FNA) as nitrogen substrate, respectively. The model also considers sequential reduction of nitrate (NO_3^-) to nitrogen gas (N_2) via nitrite (NO_2^-), nitric oxide (NO) and nitrous oxide (N_2O) using individual reaction-specific parameters. Additionally, the ideas summarized in Mampaey et al. (2013) are used to consider NO and N_2O formation from the nitrification pathway assuming ammonia (NH_3) as the electron donor. To account for seasonal variability, liquid–gas saturation constants, kinetic parameters, transfer coefficients and equilibrium reactions are temperature dependent. Stripping equations for the gases were implemented as in Foley et al. (2011). The interfaces presented in Nopens et al. (2009) have been modified to link the modified activated sludge model and the anaerobic digestion model (Batstone et al., 2002), by considering COD, N and charge balances for all oxidized nitrogen compounds. Further information about the GHG models and parameter values can be found in Corominas et al. (2012) and Guo et al. (2012).

Download English Version:

https://daneshyari.com/en/article/6332322

Download Persian Version:

https://daneshyari.com/article/6332322

Daneshyari.com