Bioresource Technology 261 (2018) 412–419

Contents lists available at ScienceDirect

Bioresource Technology

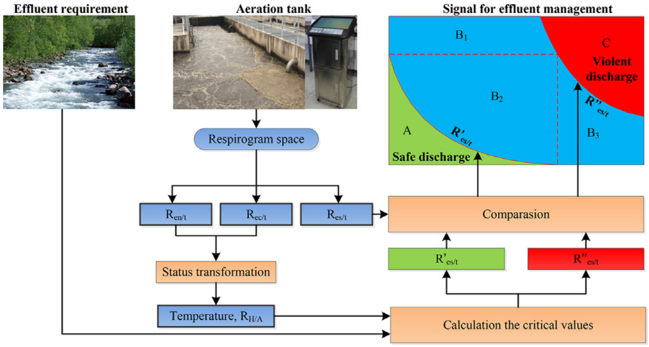
journal homepage: www.elsevier.com/locate/biortech

A simple respirogram-based approach for the management of effluent from an activated sludge system

Zhi-Hua Li[a,*], Yuan-Mo Zhu[a], Cheng-Jian Yang[a], Tian-Yu Zhang[b], Han-Qing Yu[c]

[a] School of Environmental and Municipal Engineering, Xi'an University of Architecture and Technology, Xi'an 710055, China
[b] Department of Mathematical Sciences, Montana State University, Bozeman, MT 59717-2400, USA
[c] CAS Key Laboratory of Urban Pollutant Conversion, Department of Chemistry, University of Science & Technology of China, Hefei 230026, China

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Activated sludge
Modeling
Respirogram
Oxygen uptake rate
Wastewater treatment plant management

ABSTRACT

Managing wastewater treatment plant (WWTP) based on respirometric analysis is a new and promising field. In this study, a multi-dimensional respirogram space was constructed, and an important index $R_{es/t}$ (ratio of in-situ respiration rate to maximum respiration rate) was derived as an alarm signal for the effluent quality control. A smaller $R_{es/t}$ value suggests better effluent. The critical $R'_{es/t}$ value used for determining whether the effluent meets the regulation depends on operational conditions, which were characterized by temperature and biomass ratio of heterotrophs to autotrophs. With given operational conditions, the critical $R'_{es/t}$ value can be calculated from the respirogram space and effluent conditions required by the discharge regulation, with no requirement for calibration of parameters or any additional measurements. Since it is simple, easy to use, and can be readily implemented online, this approach holds a great promise for applications.

1. Introduction

Adjustment of the operational conditions of a wastewater treatment plant (WWTP) is essential to its stable and optimal operation, and the feedback from effluent quality is the most frequently used strategy for in-time adjustment or optimization (Dalmau et al., 2015; Valverde-Pérez et al., 2016). Thus, predicting effluent quality is critical to WWTP management, and many mathematical models have been proposed to predict WWTP effluent quality. Among these models, activated sludge models (ASMs) have been widely used, ranging from effluent quality prediction to operation condition evaluation and simulation of treatment processes, and they make WWTP operation more precise (Van

---

[*] Corresponding author.
E-mail address: lizhihua@xauat.edu.cn (Z.-H. Li).

https://doi.org/10.1016/j.biortech.2018.03.134
Received 12 March 2018; Received in revised form 29 March 2018; Accepted 30 March 2018

Nomenclature

ASM	activated sludge model
b_A	autotrophic decay rate [d^{-1}], 0.12$^{\#}$
b_H	heterotrophic decay rate [d^{-1}], 0.62*
CAST	cyclic activated sludge system
COD	chemical oxygen demand
DO	dissolved oxygen [$mg\,L^{-1}$]
f_p	fraction of biomass leading to particulate products, 0.08*
f_s	fraction of COD contributed to respiration [%]
K_{NH}	ammonia half saturation coefficient for autotrophs growth [$mgN\,L^{-1}$], 1.00*
K_s	half-saturation parameter for heterotrophic biomass [$mgCOD\,L^{-1}$], 20*
MLSS	Mixed liquid suspended solids [$mg\,L^{-1}$]
OUR	oxygen uptake rate [$mgO_2\ (L\,min)^{-1}$]
OUR_s	in-situ respiration rate [$mgO_2\ (L\,min)^{-1}$]
OUR_q	quasi-endogenous respiration rate [$mgO_2\ (L\,min)^{-1}$]
OUR_e	endogenous respiration rate [$mgO_2\ (L\,min)^{-1}$]
OUR_n	nitrogen stimulated respiration rate [$mgO_2\ (L\,min)^{-1}$]
OUR_c	carbon source stimulated respiration rate [$mgO_2\ (L\,min)^{-1}$]
OUR_t	maximum respiration rate [$mgO_2\ (L\,min)^{-1}$]
PAOs	phosphate-accumulating organisms
PLC	programmable logic controller
$R_{es/t}$	relative to $\frac{OUR_s}{OUR_t}$
$R'_{es/t}$	the corresponding $R_{es/t}$ for safe boundary line
$R''_{es/t}$	the corresponding $R_{es/t}$ for violent boundary line
$R_{en/t}$	relative to $\frac{OUR_e+OUR_n}{OUR_t}$
$R_{ec/t}$	relative to $\frac{OUR_e+OUR_c}{OUR_t}$
$R_{H/A}$	relative to $\frac{X_H}{X_A}$
SCADA	supervisory control and data acquisition
$S_{i,j}$	normalized sensitivity coefficient
SS	readily biodegradable substrate [$mgCOD\,L^{-1}$]
TN	total nitrogen
TP	total phosphorus
WWTP	wastewater treatment plant
X_S	slowly biodegradable substrate [$mgCOD\,L^{-1}$]
Y_A	autotrophic yield coefficient [mg cell COD $(mgCOD)^{-1}$], 0.24*
Y_H	heterotrophic yield coefficient [mg cell COD $(mgCOD)^{-1}$], 0.67*
μ_A	maximum specific autotrophic growth rate [d^{-1}], 0.8*
μ_H	maximum specific heterotrophic growth rate [d^{-1}], 6.00*
*	these defaults which were used in the simplified version of ASM1 from Melcer (2004) (T = 20 °C).
#	this default which were used in the simplified version of ASM1 from Henze et al. (2000) (T = 20 °C)

Loosdrecht et al., 2015; Bahar and Ciggin, 2016). However, operating WWTP using ASMs is hard because of the complex and diverse nature of ASM components. Most of the parameters and kinetic coefficients in ASMs vary from case to case, the pre-application procedures, such as parameter calibration, sensitivity analysis and wastewater component estimation, are time-consuming and labor-intensive. These factors also introduce barriers against the wide applications of ASMs for full-scale wastewater treatment management. According to an international survey, approximately 35% of users still believe that the models do not solve their problems or achieve their goals (Hauduc et al., 2009).

The biological characteristics of sludge are the key factors governing effluent quality. Statistical models, e.g., neural networks and multivariant regressions, are also used to establish the relationships between the effluent quality and the operational factors (Dürrenmatt and Gujer, 2012; Hreiz et al., 2015; Foscoliano et al., 2016). These models combine water quality prediction and operation optimization and have been successfully applied in real-time monitoring of WWTPs. However, statistical models require a considerable amount of previously accumulated data for training and are usually trained on a case by case basis, thus cannot be easily applied to general cases. Consequently, these models cannot predicate conditions that, historically, rarely or never occurred (Dürrenmatt and Gujer, 2012; Xu et al., 2017).

Neither the biological mechanical models such as ASMs, nor the statistical models such as neural networks, can be easily used by operators in full-scale WWTPs. As a result, despite of great achievements in these models (Van Loosdrecht et al., 2015), operators still run the plants according to their prior experiential rules, at least in most plants in developing countries like China.

Respirograms have been widely applied for evaluating kinetic and stoichiometric characteristics of activated sludge (Ciggin and Orhon, 2014; Kor-Bicakci et al., 2015; Capodici et al., 2016; Mannina et al., 2016a). As one of the important indexes, oxygen uptake rate (OUR) is frequently used for describing the properties of activated sludge. OUR itself only provides limited information. For example, endogenous and exogenous respiration values could be used to identify an available substrate source (Jubany et al., 2009; Zamouche-Zerdazi et al., 2014), absence or presence of calcium-induced respiration could be used to evaluate the robustness of activated sludge (Li et al., 2018a) and the endogenous respiration itself also provides useful information (Friedrich and Takács, 2013). However, the combined usage of several OURs measured under different conditions as an entire set exhibits a great capability of elucidating the biological mechanisms behind observations. For instance, the ratio of endogenous and maximum respiration could well indicate the physiological status of activated sludge (Friedrich et al., 2015), and the recovery potential after shocking loading (Li et al., 2018b).

To further take advantage of such a combination, the new concept of multi-dimensional respirogram space was proposed in this work, aiming to provide an efficient management tool for WWTP operators for quick and easy determination of whether the effluent is qualified according to the local discharge regulations without complex parameter measurements.

2. Materials and methods

2.1. Conceptual rationale of the method

In summary, Sections 2.2 and 2.3 give the source of samples and experimental procedures for determining various respiration rates. Section 2.4 points out what information extracted from the respirogram space could be used to evaluate the effluent quality. Section 2.5 explains how to calculate the respirogram and transform the respirogram status to operational status using ASM1 model and proposes a respirogram-based method that can quickly and easily determine whether the effluent is qualified.

2.2. Source of the samples

Activated sludge and raw wastewater samples were taken from seven full-scale WWTPs in two provinces of northwestern China. The detailed information about these WWTPs is listed in Table 1.

2.3. Determination of the respirogram space

Respirogram space, composed of a series of OURs, was introduced in this work. The respiration rates were measured offline using automatic