Bioresource Technology 203 (2016) 32–41

Contents lists available at ScienceDirect

Bioresource Technology

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

Activated sludge mass reduction and biodegradability of the endogenous residues by digestion under different aerobic to anaerobic conditions: Comparison and modeling

C.G. Martínez-García [a], C. Fall [a,*], M.T. Olguín [b]

[a] Centro Interamericano de Recursos del Agua (CIRA), Universidad Autónoma del Estado de México (UAEM), Apdo postal 367, Toluca C.P. 50091, Mexico
[b] Instituto Nacional de Investigaciones Nucleares (ININ), México, Departamento de Química, La Marquesa Ocoyoacac, Mexico

HIGHLIGHTS

- Modeling and comparing digestion rates in seven different aeration conditions.
- A model-sludge with only 2 fractions (the heterotrophs and its residues) was used.
- The endogenous residues biodegradation constant was estimated (0.001–0.004 d^{-1}).
- Sludge reduction was faster in the 12 h–12 h (ON/OFF) intermittently aerated digester.
- Nitrif-denitrification activity and acid pH could be clues of the best performances.

ARTICLE INFO

Article history:
Received 16 September 2015
Received in revised form 28 November 2015
Accepted 9 December 2015
Available online 17 December 2015

Keywords:
Digestion
Endogenous residues
Intermittent aeration
Modeling
Sludge minimization

ABSTRACT

This study was performed to identify suitable conditions for the in-situ reduction of excess sludge production by intercalated digesters in recycle-activated sludge (RAS) flow. The objective was to compare and model biological sludge mass reduction and the biodegradation of endogenous residues (X_P) by digestion under hypoxic, aerobic, anaerobic, and five intermittent-aeration conditions. A mathematical model based on the heterotrophic endogenous decay constant (b_H) and including the biodegradation of X_P was used to fit the long-term data from the digesters to identify and estimate the parameters. Both the b_H constant (0.02–0.05 d^{-1}) and the endogenous residue biodegradation constant (b_P, 0.001–0.004 d^{-1}) were determined across the different mediums. The digesters with intermittent aeration cycles of 12 h–12 h and 5 min–3 h (ON/OFF) were the fastest, compared to the aerobic reactor. The study provides a basis for rating RAS-digester volumes to avoid the accumulation of X_P in aeration tanks.

1. Introduction

The year 2014 was the centenary of the activated sludge process (AS), from the time that early developers in England presented a seminal work (1914) that leaded to its worldwide adoption. Currently, the activated sludge process is one of the most widely used methods for the treatment of wastewater from medium to large populations (Jenkins and Wanner, 2014). The production of large quantities of excess sludge, however, remains a tricky problem for the AS process. This is why there is continuing interest in developing processes that produce lower amounts of residuals (Khursheed and Kazmi, 2011; Huang and Goel, 2015). Instead of generating a large volume of sludge before stabilizing it off-line, new proposals seek to reduce solids from the source (i.e., in water-treatment lines) (Ramakrishna et al., 2005). Examples of this strategy are provided by modified activated sludge processes known as OSA (oxic-settling-anaerobic) and Cannibal™ (Saby et al., 2003; Troiani et al., 2011; Zhou et al., 2015). The Cannibal process is a sludge reduction technology that is commercialized in USA since about 15 years; a typical facility of this king is the Moringa (California) wastewater treatment plant (WWTP) (Labelle et al., 2015). Many full-scale OSA processes are also known across the world (Troiani et al., 2011). However, despite several full-scale plants, the mechanisms of these processes remain not fully understood.

In the OSA process, as in the Cannibal process, a digester known as an exchange tank (ET) is inserted into the sludge recirculation line of a treatment plant. The biomass alternates between the aerobic conditions of the aeration tank and the ET environment

---

* Corresponding author. Tel.: +52 722 2965550.
E-mail address: c-fa-ll@hotmail.com (C. Fall).

http://dx.doi.org/10.1016/j.biortech.2015.12.015
0960-8524/

(anaerobic, anoxic or hypoxic). This process results in sludge production that is reduced by more than 50% (Saby et al., 2003; Liu and Tay, 2001; Semblante et al., 2014; Labelle et al., 2015). The mechanisms responsible for reducing sludge yield were attributed to alterations of cellular metabolic uncoupling (i.e., more carbon going to the gas phase), lysis and cryptic growth, endogenous decay, biological floc destruction, and predation on bacteria by higher organisms such as protozoa, metazoa, rotifers and nematodes (Semblante et al., 2014). In many studies, the oxidation–reduction potential (ORP) across the reactors was identified as a key factor for sludge reduction; however, the mechanisms behind the process of mass loss are still not fully understood (Zhou et al., 2015). Mass reduction was attributed also (Park et al., 2006; Ramdani et al., 2012) to the possibility of hydrolyzing and biodegrading endogenous residues (X_P), which were formerly assumed to be inert in current activated sludge models (ASM, Henze et al., 2000). The biodegrability hypothesis was taken into account in the most recent version of the Biowin software package (Envirosim, 2014), which now features an option to include X_P degradation in its activated sludge model. No value has yet been suggested for the kinetic constants related to this process. Kinetic data are essential for reactor sizing and for WWTP simulations. Even for the well accepted ASM models (Henze et al., 2000), there is a knowledge gap about the range of variation of some of its kinetic constants, supporting the need for more research on the parameters.

It was suggested that the endogenous residues from the biomass decay (X_P) could be biodegraded further, following a first-order kinetic reaction with a decay constant k_P. Many studies have been published about the OSA and Cannibal processes (Saby et al., 2003; Troiani et al., 2011; Labelle et al., 2015); those studies have shown a beneficial reduction in sludge, but only a few of them have evaluated the potential biodegradability rate of the endogenous residues. A few authors have found the value of k_P somewhere between 0.005 and 0.012 d^{-1} under anaerobic and full or intermittent aeration (2 h per day, Ramdani et al., 2010, 2012; Park et al., 2006). No investigation has compared the k_P values in more than two types of environments simultaneously. However, it is important to know the order of magnitude of the degradation rate of X_P and, therefore, the best environment for the ET. This piece of information is essential when modeling is used to design or to simulate sludge-minimization processes based on the principle of the degradability of X_P (Sperandio et al., 2013; Fall et al., 2015).

Decay of the heterotrophic fraction X_H will also contribute to sludge diminution. A first-order decay rate process (Eq. (1)) is used not only in the dynamic activated sludge models (ASMs, Henze et al., 2000), but also in the traditional models of aerobic and anaerobic digestion processes (Metcalf and Eddy, 2003). A fraction of the dead biomass ($fp = 0.2$) remains as “inert” organic residuals, which are known as the endogenous residues X_P.

$$dX_H/dt = b_H X_H \tag{1}$$

X_H is the active biomass concentration (mg/L); b_H is the endogenous heterotrophic decay constant (d^{-1}), which is known to be lower in anaerobic (compared to aerobic) digestion (Metcalf and Eddy, 2003). Therefore, it would be appropriate to evaluate the variation of both the constant b_H and the parameter b_P in digestion environments with intermittent aeration (Troiani et al., 2011) compared to fully aerobic or anaerobic media.

Another important aspect that should be emphasized when comparing the values of the constants is the need to be certain that the parameters have been correctly estimated (identifiability issues) (Reichert, 1998). A high coefficient of correlation (R^2) from mathematical regressions is insufficient to justify the representativeness of a constant. It is imperative to test either the identifiability or the uniqueness of the estimated parameter sets (Sin et al., 2005). AQUASIM is modeling software that is known to perform this task very well (Reichert, 1998; Fall and Loaiza-Navia, 2007). When parameters are not identifiable with a given set of data, the fit may be perfect, but the estimated values and their comparison are no longer valid.

The objective of the study was the comparison and modeling of biological excess-sludge mass reduction and the potential biodegradation of X_P by digestion under aerobic, anaerobic, hypoxic and five intermittent-aeration conditions. The overall removal of volatile suspended solids (VSS), along with the first-order rate constants (b_H and b_P) of the models, were estimated and compared under different sludge-treatment conditions.

2. Methods

2.1. Cultivation of model sludge

The sludge used in the digestion experiments was cultivated in the laboratory from an acetate-based synthetic substrate (Table 1). Consequently, the composition of the bio-solid was simple, consisting of only two fractions: the heterotrophic biomass X_H and its decay endogenous products X_P (Martínez-García et al., 2014; Ramdani et al., 2010). The model sludge was produced from an activated-sludge system with two 30-liter sequential batch reactors (SBR) operated in parallel, based on a solid retention time (SRT) of 15 days and a hydraulic residence time (HRT) of 1.5 days. The chemical oxygen demand (COD) of the inflow was 500 mg/L (Table 1), and the COD/N/P ratio was approximately 100/4/2. The operation cycle of the SBRs included an anaerobic phase of 1 h after the feed, followed by an aerobic phase for the rest of the day. The non-aerated selector function was used as a strategy to overcome some bulking problems that had initially appeared.

2.2. Model sludge-digestion runs under different environments

The previously concentrated mixed-liquor purge from the SBRs was used to initiate the batch-digestion tests. Seven different types of digestion environments were evaluated: a fully anaerobic environment, a fully aerobic environment, a hypoxic environment, and four intermittent aeration conditions. The practice of intermittent aeration presents several advantages, such as lower energy expenditure, the ability to nitrify and denitrify within the same mixed-batch reactor, and the ability to subject the biomass to cycles of reducing and oxidizing environments. Wide-mouth 1.7-L glass Mason jars with hermetic lids equipped with magnetic mixers were used as digesters. The lids were perforated to connect the hoses used for sampling, aerating, and/or evacuating the produced gases. Each digester was batch-operated and fed once at the beginning of the experiment with concentrated sludge from the SBRs and then monitored over several months.

For the anaerobic system, a hydraulic seal was used to prevent the admission of environmental oxygen and to allow the gases

Table 1
Composition of the synthetic wastewater utilized to produce the sludge.

Major components	mg/L	Minor components	mg/L
CH_3COONa (500 mg/L COD)	641	H_3BO_3	0.045
NH_4Cl (28 mg N/L)	107	$ZnSO_4{\cdot}7H_2O$	0.036
KH_2PO_4 (2.7 mg P/L)	12	$MnCl_2{\cdot}4H_2O$	0.036
KCl	36	$CuSO_4{\cdot}5H_2O$	0.009
$FeCl_3{\cdot}6H_2O$	5	KI	0.054
$MgSO_4{\cdot}7H_2O$	90	$Na_2MoO_4{\cdot}2H_2O$	0.018
$CaCl_2{\cdot}2H_2O$	14	$CoCl_2{\cdot}6H_2O$	0.045
Yeast extract	1		
EDTA	1		