Computers and Chemical Engineering 34 (2010) 802–811

Contents lists available at ScienceDirect

Computers and Chemical Engineering

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

Modelling and sensitivity analysis of ATAD

Jaime Rojas[a,*], Toshko Zhelev[a], Aarón David Bojarski[b]

[a] *Charles Parsons Initiative on Energy and Sustainable Environment, University of Limerick, National Technological Park, Plassey, Co. Limerick, Ireland*
[b] *Chemical Engineering Department, Universitat Politècnica de Catalunya, Av. Diagonal 647, E-08028 Barcelona, Spain*

ARTICLE INFO

Article history:
Received 30 July 2009
Received in revised form
26 November 2009
Accepted 29 November 2009
Available online 4 December 2009

Keywords:
Wastewater treatment
Autothermal thermophilic aerobic digestion
Energy efficiency
Plant capacity
Modelling
Sensitivity analysis

ABSTRACT

Several authors have pointed out the need to identify the optimum operating conditions (OCs) of autothermal thermophilic aerobic digestion (ATAD). This study proves the hypothesis that the OCs have the potential to substantially improve the energy efficiency and plant capacity of established ATAD systems. As ATAD is a semi-batch process, its energy efficiency has to be optimized via dynamic optimization (DO). This methodology requires an adequate mathematical model, and appropriate selection of optimization variables. The paper presents an improved mathematical ATAD model based on previous models found in the literature. A global sensitivity analysis (GSA) was performed in order to identify variables with significant influence upon energy efficiency and plant capacity, thus paving the way for the DO of ATAD systems. The results of the GSA show that reactor volume, reactor temperature, and aeration flowrate are significant variables, which is consistent with reported literature. The results of the GSA also show that both energy efficiency and plant capacity of ATAD systems can be substantially improved by altering reactor volume and OCs.

© 2009 Elsevier Ltd. All rights reserved.

1. Introduction

ATAD is an activated sludge process used in wastewater treatment with two goals: stabilization and pasteurization of the sludge. In this context, stabilization refers to the reduction of the volatile solids (*VS*) concentration of the sludge, while pasteurization refers to the elimination of pathogens through heat treatment. Comprehensive reviews on ATAD origin, design, and operation can be found in USEPA (1990), LaPara and Alleman (1999) and Layden, Kelly, Mavinic, Moles, and Barlet, (2007a, 2007b).

As the name indicates, ATAD is an aerobic sludge treatment at thermophilic temperatures (45–65 °C). If the reactors are well insulated, the reaction becomes autothermal or self-heated, which means that no external energy is required to maintain thermophilic temperatures.

The fundamental way how ATAD works can be described as follows: Sludge containing organic matter, thermophilic and mesophilic (some of whom are pathogens) biomass is aerated in a well insulated reactor. Thermophiles grow on the expense of oxygen and organic matter (or *VS*), thus contributing to sludge stabilization. During their digestion, the thermophiles release vast amounts of metabolic energy, thus reaching thermophilic temperatures inside the reactors. The high reactors' temperatures are lethal for pathogens, hence resulting in their elimination and, consequently, in sludge pasteurization.

Due to the high oxygen uptake rates (OURs) of thermophilic microorganisms, as high as 1000–2000 mg/l/h (LaPara & Alleman, 1999), ATAD has a relatively high energy requirement regarding the aeration of the reactors with 9–15 kWh/m^3 (USEPA, 1990). ATAD is, therefore, an energy intensive process. In this study, only the energy used for aeration is considered. The typical plant capacity of conventional ATAD plants is 30–40 m^3/day (USEPA, 1990).

Even though the development of ATAD technology started in the 1950s (LaPara & Alleman, 1999), its use remains nowadays relatively limited compared to other sludge treatments. Additionally, there are conflicting reports in current literature regarding the energy efficiency and cost effectiveness of ATAD technology which may have contributed to its limited use (Layden et al., 2007b).

1.1. Operating conditions

In the literature, a number of issues have been reported regarding the OCs of ATAD. Perhaps, the most notable refer to the aeration, operating temperature, sludge flowrate, and the organic matter concentration of the influent sludge.

The OURs of ATAD systems show strong variations along the reaction, being very high at the beginning when the readily biodegradable substrate is consumed and slowing down significantly thereafter. Despite these variations, conventional ATAD systems make use of invariable air supply regardless of the level

* Corresponding author.
E-mail address: Jaime.Rojas@ul.ie (J. Rojas).

0098-1354/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.compchemeng.2009.11.019

of bacterial activity. This has the disadvantage of insufficient oxygen delivery resulting in poor stabilization and odours (Layden et al., 2007a; Scisson, 2003). Juteau (2006) noted that if aeration is designed to satisfy the period of high OUR, it will be oversized for the rest of the time. Layden et al. (2007a) added that if air is supplied at a higher rate than is needed, evaporative latent heat loss will be the result, creating a heat loss in the high temperature reactors. The continuous and invariable aeration of the ATAD reactors may also lead to excessive energy consumption (Layden et al., 2007b). LaPara and Alleman (1999) concluded that further work is needed to determine the best way to accommodate the enormous OURs of ATAD systems. Hence, Staton, Alleman, Pressley, and Eloff (2001) suggested that these problems could be resolved by using variable speed aeration controlled through online monitoring of the oxidation reduction potential, thus matching oxygen supply and demand.

Conventional ATAD systems make use of poor temperature regulation sometimes requiring heating and cooling loops (Scisson, 2003). Furthermore, the daily loading of the reactors with cold raw sludge results in a thermal shock that significantly decreases reactors' temperatures. The use of heat integration could lead to smaller thermal shocks and lower operating cost, and it could even be necessary if sludge concentrations are not high enough to sustain thermophilic temperatures (USEPA, 1990). In spite of this, few plants make use of heat exchangers (Layden et al., 2007b). Pre-heating of the influent sludge using the heat from the effluent would reduce the thermal shock in the first stage reactor, and potentially result in shorter hydraulic retention time (HRT) (Layden et al., 2007b).

The sludge flowrate influences the sludge oxidation rate, with high frequencies leading to high rates due to small fluctuations of the process conditions (Ponti, Sonnleitner, & Fiechter, 1995a). Therefore, continuous operation could display the high degradation potential of ATAD systems (Ponti, Sonnleitner, & Fiechter, 1995b). Further advantages of continuous operation are avoidance of oxygen-limited conditions, thermal shock reduction, and increased realizable loads (Csikor, Mihaltz, Hanifa, Kovacs, & Dahab, 2002). But more importantly, the volume change frequency influences the specific energy requirements for the removal of defined organic matter quantities (Ponti et al., 1995b). Despite these experimental insights, conventional ATAD systems make use of one single volume change per day, thus not allowing a complete exploitation of the thermophiles' efficiency (Ponti et al., 1995a).

The organic matter concentration in the influent has been found to positively influence the stabilization process (Ponti et al., 1995a).

Given this background, several authors agree that more research is needed to identify the optimum OCs of ATAD systems (LaPara & Alleman, 1999; Layden et al., 2007a). However, there is no comprehensive study in the available literature where the previous OCs have been mathematically and systematically optimized for the purpose of minimizing the energy requirements of the system. The problem of minimizing the energy requirements of ATAD systems by altering the OCs requires the use of dynamic optimization (DO), the reason being that ATAD is a batch process which inherently is never at steady state. DO in turn requires a mathematical model of the reaction and the selection of optimization variables.

The aim of this paper is to present a mathematical ATAD model and to select promising (significant) optimization variables, thus paving the way for the dynamic optimization of ATAD systems.

This paper presents a mathematical model of the ATAD reaction that is based on two previous models found in the literature. The model consists of a mass and energy balance and it makes use of temperature-dependent kinetic parameters. In order to identify promising optimization variables, a global sensitivity analysis (GSA) was performed.

The results of the GSA show that there is a significant scope for improvement regarding the energy requirements and plant capacity of ATAD systems. Improvements in the energy requirements and plant capacity can be achieved by altering reactor volume and OCs. Depending on reactor volume and OCs either the pasteurization or stabilization process becomes the limiting factor of the reaction, while stabilization tends to be the limiting factor of ATAD in most cases. This insight had not been reported in the literature before. The variables with significant influence upon energy requirements, plant capacity, and stabilization and pasteurization time are reactor volume, reactor temperature, and the aeration flowrate. These findings are consistent with reported literature.

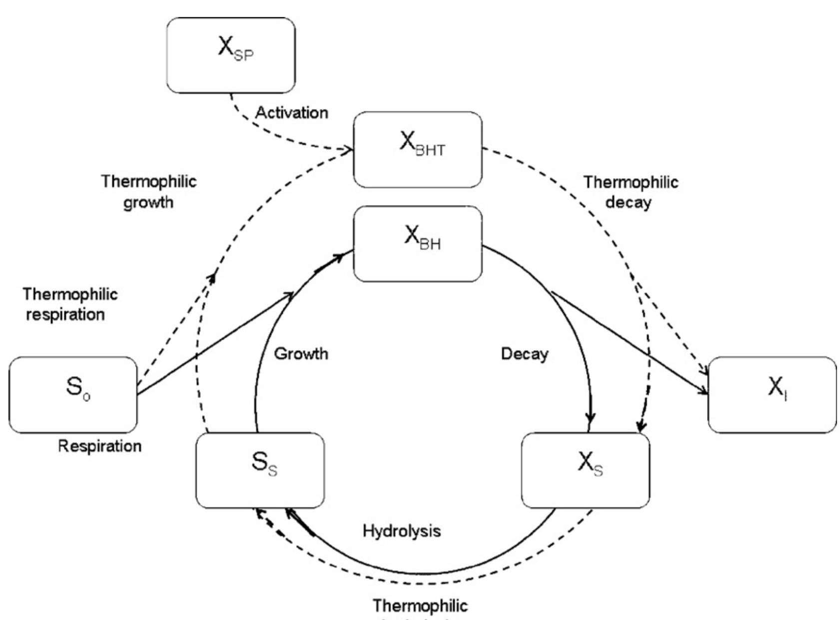

Fig. 1. Structure of extended ASM1 model at thermophilic temperatures adapted from Kovács et al. (2007).

دریافت فوری ← متن کامل مقاله

ISIArticles
مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات