WATER RESEARCH 47 (2013) 5245–5256

Available online at www.sciencedirect.com

SciVerse ScienceDirect

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

# Investigation of the impacts of thermal pretreatment on waste activated sludge and development of a pretreatment model

Gillian Burger*, Wayne Parker

Department of Civil and Environmental Engineering, University of Waterloo, 200 University Avenue West, Waterloo, Ontario N2L 3G1, Canada

ARTICLE INFO

Article history:
Received 23 February 2013
Received in revised form
24 May 2013
Accepted 2 June 2013
Available online 15 June 2013

Keywords:
Waste activated sludge
Pretreatment
High-pressure thermal hydrolysis
Aerobic digestion
Modeling

ABSTRACT

This study investigated the impacts of high pressure thermal hydrolysis (HPTH) pretreatment on the distribution of chemical oxygen demand (COD) species in waste activated sludge (WAS). In the first phase of the project, WAS from a synthetically-fed biological reactor (BR) was fed to an aerobic digester (AD). In the second phase, WAS from the BR was pretreated by HPTH at 150 °C and 3 bars for 30 min prior to being fed to the AD. A range of physical, biochemical and biological properties were regularly measured in each process stream in both phases. The COD of the BR WAS consisted of storage products ($X_{STO}$), active heterotrophs ($X_H$) and endogenous decay products ($X_E$). Pretreatment did not increase the extent to which the BR WAS was aerobically digested and hence it was concluded that the unbiodegradable COD fraction, i.e. $X_E$, was unchanged by pretreatment. However, pretreatment did increase the rate of degradation as it converted 36% of $X_H$ to readily biodegradable COD ($S_B$) and the remaining $X_H$ to slowly biodegradable COD ($X_B$). Furthermore, $X_{STO}$ was fully converted to $S_B$ by pretreatment. Although pretreatment did not change the VSS concentration in the downstream aerobic digester, it did decrease the ISS concentration by 46 ± 11%. This reduced the total mass of solids produced by the digester by 21 ± 8%. A COD-based HPTH pretreatment model was developed and calibrated. When this model was integrated into BioWin 3.1®, it was able to accurately simulate both the steady state performance of the overall system employed in this study as well as dynamic respirometry results.



## 1. Introduction

WAS pretreatment technologies are typically evaluated in terms of the associated improvement in biogas and sludge production during digestion and post-digestion dewaterability. However, WAS properties, and hence the impact of pretreatment on WAS properties, are dependent upon the raw wastewater composition and configuration of the wastewater treatment plant (WWTP). A generally accepted means of characterizing and comparing the impact of pretreatment processes on these responses does not exist. A few research groups have presented approaches for modeling WAS pretreatment technologies (Lei et al., 2010; Phothilangka et al., 2008; Frigon and Isazadeh, 2010; Musser, 2009). However, in these studies, assumptions about the WAS COD fractionation were required because of the complex nature of the biomass.

* Corresponding author. Tel.: +1 289 237 5337; fax: +1 905 481 2610.
E-mail addresses: gstaples@uwaterloo.ca, gstapl@gmail.com (G. Burger).
0043-1354/$ – see front matter 
http://dx.doi.org/10.1016/j.watres.2013.06.005

**List of abbreviations and symbols**

| | |
|---|---|
| AD | Aerobic digester |
| ASM | Activated sludge model |
| $b_h$ | Aerobic endogenous decay rate of heterotrophic biomass |
| BCOD | Biodegradable chemical oxygen demand |
| BR | Biological reactor |
| COD | Chemical oxygen demand |
| DO | Dissolved oxygen |
| f | Endogenous residue fraction |
| ffCOD | Filtered and flocculated chemical oxygen demand |
| $f_s$ | Fraction of active heterotrophs converted to readily biodegradable substrate by pretreatment |
| $f_{STO}$ | Fraction of total chemical oxygen demand attributed to intracellular storage products |
| HPTH | High pressure thermal hydrolysis |
| HRT | Hydraulic retention time |
| ISS | Inorganic suspended solids |
| $k_d\_X_H$ | Rate constant for conversion of heterotrophic biomass by pretreatment |
| $k_d\_X_{STO}$ | Rate constant for conversion of storage products by pretreatment |
| $NH_3$ | Ammonia |
| $NO_3$ | Nitrate |
| NOUR | Nitrogenous oxygen uptake rate |
| $\Sigma OU$ | Cumulative oxygen uptake |
| $\Sigma OU_E$ | Cumulative oxygen uptake attributed to endogenous respiration |
| $\Sigma OU_S$ | Cumulative oxygen uptake attributed to substrate utilization |
| ON | Organic nitrogen |
| OUR | Oxygen uptake rate |
| XCOD | Particulate chemical oxygen demand |
| PON | Particulate organic nitrogen |
| PT | Pretreatment |
| SCOD | Soluble chemical oxygen demand |
| $S_U$ | Soluble unbiodegradable organics |
| SMPs | Soluble microbial products |
| SON | Soluble organic nitrogen |
| SRT | Sludge retention time |
| SS | Suspended solids |
| $S_B$ | Soluble readily biodegradable substrate |
| STKN | Soluble total Kjeldahl nitrogen |
| TCOD | Total chemical oxygen demand |
| TKN | Total Kjeldahl nitrogen |
| TSS | Total suspended solids |
| VFA | Volatile fatty acid |
| VSS | Volatile suspended solids |
| WAS | Waste activated sludge |
| WW | Wastewater |
| WWTP | Wastewater treatment plant |
| $X_E$ | Endogenous residue |
| $X_H$ | Active heterotrophic biomass |
| $X_B$ | Particulate slowly biodegradable substrate |
| $X_{STO}$ | Intracellular storage products in heterotrophic organisms |
| $X_I$ | Particulate unbiodegradable organics |
| $Y_H$ | Aerobic heterotrophic yield |
| $\mu_{max}$ | Monod maximum specific growth rate |

Some COD components of activated sludge are not readily isolated. For example, endogenous decay products ($X_E$) cannot be distinguished from other types of unbiodegradable particulate COD ($X_I$) when both are present in wastewater. Ramdani et al. (2010) have shown that the COD fractionation of activated sludge is simplified to active biomass ($X_H$) and $X_E$ when the system is fed with a synthetic soluble biodegradable substrate such as acetate. The COD concentration of these two components can be accurately measured using respirometric methods. Correctly fractionating the raw WAS would allow the pretreated WAS to be characterized more accurately.

The pretreatment models proposed by Musser (2009) and Frigon and Isazadeh (2010) were rate-based. It is proposed that pretreatment models may be simplified to stoichiometric COD transformations, without compromising the robustness of the simulations. Furthermore, these existing pretreatment models were based on ozonation and sonication hence there is a need to develop an accurate model for the HPTH pretreatment process.

HPTH pretreatment is becoming one of the most popular and promising WAS pretreatment techniques (Wilson and Novak, 2009). Full-scale installations of this type have been successfully used prior to anaerobic digestion for more than a decade (Tattersall et al., 2011). HPTH pretreatment has the potential to produce Class A biosolids as defined by the United States CFR 40 Part 503.32 (USEPA, 1999). The most well known HPTH pretreatment process is CAMBI™, which operates in batch mode. The sludge is initially heated to 80 °C, then thermally hydrolyzed at 165 °C and 7 bars and finally delivered to a flash tank. Another commercial HPTH pretreatment process is Exelys™, which operates at similar temperatures and pressures however it is a continuous plug flow system and does not include a flash period (Gurieff et al., 2011).

Based on a literature review of HPTH pretreatment research, a temperature of 150 °C was selected for the current study with a corresponding pressure of 3 bars. Heating the sludge at this temperature was expected to improve the degradability while minimizing the generation of refractory compounds, i.e. soluble unbiodegradable COD ($S_U$). The selected heating duration was 30 min which is similar to that employed by the CAMBI™ and Exelys™ processes.

Previous studies have shown that HPTH pretreatment solubilizes organic materials. Soluble materials are more easily hydrolyzed than particulate materials hence it is expected that HPTH pretreatment would increase the level of $S_B$ in WAS, i.e. the rate at which WAS is digested. Bourgrier et al. (2008) used a laboratory autoclave to pretreat five different WAS samples obtained from WWTPs in France for 30 min at temperatures ranging from 90 to 210 °C. The authors showed that COD solubilization increased linearly with temperature. The reported average COD solubilization at 150 °C was 40%. In a second study, the performance of the CAMBI™ process was evaluated at three full-scale WWTPs (Morgan-Sagasume et al., 2010). The authors showed that the CAMBI™ process caused a