Integrated chemical/physical and biological processes modelling Part 2 - Anaerobic digestion of sewage sludges

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Abstract

The development and validation of a two phase (aqueous-gas) integrated mixed weak acid/base chemical, physical and biological processes kinetic model for anaerobic digestion (AD) of sewage sludge are described. The biological kinetic processes for AD are integrated into a two phase subset of the three phase mixed weak acid/base chemistry kinetic model of Musvoto et al. (1997, 2000a,b,c). The approach of characterising sewage sludge into carbohydrates, lipids and proteins, as is done in the International Water Association (IWA) AD model No 1 (ADM1, Batstone et al., 2002), requires measurements that are not routinely available on sewage sludges. Instead, the sewage sludge is characterised with the COD, carbon, hydrogen, oxygen and nitrogen (CHON) composition. The model is formulated in mole units, based on conservation of C, N, O, H and COD. The model is calibrated and validated with data from laboratory mesophilic anaerobic digesters operating from 7 to 20 d sludge age and fed a sewage primary and humus sludge mixture. These digesters yielded COD mass balances between 107 and 109% and N mass balances between 91 and 99%, and hence the experimental data is accepted as reasonable. The sewage sludge is found to be 64 to 68% biodegradable (depending on the kinetic formulation selected for the hydrolysis process) and to have a $C_{3.5}H_7O_2N_{0.196}$ composition. For the selected hydrolysis kinetics of surface mediated reaction (Contois), with a single set of kinetic and stoichiometric constants, for all retention times good correlation is obtained between predicted and measured results for:

- COD,
- free and saline ammonia (FSA),
- short chain fatty acids (SCFA),
- $H_2CO_3^*$ alkalinity and pH of the effluent stream, and
- CO_2 and CH_4 gases in the gas stream.

The measured composition of primary sludge from two local wastewater treatment plants ranged between $C_{3.38}H_7O_{1.91}N_{0.21}$ and $C_{3.91}H_7O_{2.04}N_{0.16}$. The predicted composition is therefore within 5% of the average measured composition providing persuasive validation of the model.

Keywords: Anaerobic digestion, weak acid/base chemistry, kinetic modelling, sewage sludge

Abbreviations

Ac	Acetic acid/acetate
AD	Anaerobic digestion
ADM1	Anaerobic Digestion Model No 1
ASM1, 2	Activated Sludge Models Nos. 1 or 2
BD	Prefix for Biological anaerobic digestion processes
BEPR	Biological excess phosphorus removal
CED	Chemical equilibrium dissociation
CF	Cape Flats
CIP	Chemical ion pairing
COD	Chemical oxygen demand
CP	Chemical/physical
CPB	Chemical/physical/biological
FSA	Free and saline ammonia
IWA	International Water Association
K	Kelvin - absolute temperature scale
MW	Molecular weight
OrgN	Organic nitrogen
PGE	Physical gas exchange
pH	-ve log of the hydrogen ion activity
PMP	Physical mineral precipitation
Pr/HPr	Propionate/Propionic acid
SCFA	Short chain fatty acid
TKN	Total Kjeldahl nitrogen
TSS	Total suspended solids
UCT	University of Cape Town
UCTADM1	UCT Anaerobic Digester Model No. 1
VSS	Volatile suspended solids
WAS	Waste activated sludge
WWTP	Wastewater treatment plant

Symbols

$^{(1)}b$	Endogenous respiration/death rate of organisms
C_{disgas}	Dissolved (aqueous) gas concentration in reactor liquid (mol/ℓ)
C_{hsgas}	Head space gas concentration (mol/ℓ)
C_T	Total inorganic carbon concentration
C_{var}	Coefficient of variation
f_m	Monovalent ion activity coefficient
f_{PSR}	Fraction of COD removed by primary sedimentation
f_{PSup}	Fraction of unbiodegradable COD in the sewage sludge

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