ARTICLE IN PRESS

Water-Energy Nexus xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Water-Energy Nexus

journal homepage: www.keaipublishing.com/en/journals/water-energy-nexus/

Modeling temperature effects in anaerobic digestion of domestic wastewater

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ARTICLE INFO

Article history:
Received 5 March 2018
Revised 10 June 2018
Accepted 4 July 2018
Available online xxxx

Keywords:
ADM1
Domestic wastewater
UASB
Biogas
Low temperature

ABSTRACT

A combination of septic tank (ST) and up-flow anaerobic sludge blanket (UASB) as treatment for domestic wastewater was modeled with the anaerobic digestion model 1 (ADM1). The model was used to visualize the influence of temperature and organic load. The UASB process alone and the combined ST-UASB were simulated with temperature compensation kinetics for low temperature conditions 10, 15 and 20 °C. The combination of ST and UASB reactor allowed high and predictable overall COD removal even at low temperatures and high organic loads. This model underestimates COD accumulation and COD removal, while overestimating biogas production by up to 15%. However, the UASB model applied is quite reasonable in predicting the behavior of such a process in estimating biogas production and COD removal of domestic wastewater pretreated by a ST. The modeling approach presented can become a useful tool to evaluate and design low cost ST-UASB systems for fluctuating climatic environment such as Nepal.

1 Introduction

Anaerobic treatment of domestic wastewater is gaining wider acceptance due to the development of high rate anaerobic systems such as the UASB reactor. The success of such systems relies on the application of a relatively high loading rate, while maintaining long sludge retention times (SRT) at relatively short hydraulic retention times (HRT) due to sludge immobilization (Ratanatamskul and Siritiewsri, 2015).

SRT, HRT, temperature and mass transfer are important properties in construction, design and mode of operation of an anaerobic reactor to achieve good biological wastewater treatment (Michael-Kordatou et al., 2015; Lettinga, 1995). The SRT plays an important role in anaerobic digestion especially for methanogens at low operational temperatures (Halalsheh et al., 2005). The initial hydrolysis step to convert particulate matter into soluble substrate is considered to be significantly affected by temperature and HRT and is usually a rate limiting step at low temperature conditions (Lew et al., 2011). An additional measure to improve anaerobic digestion (AD) of wastewater is to use septic tank (ST) for primary treatment before pumping it to the UASB reactor for further digestion (Lohani et. al., 2015a).

Standard septic tanks are useful for removal of inert solids and preliminary hydrolysis of particulate organic matter (Richard et al., 2005). Though different anaerobic digestion (AD) models have been developed and used for simulating AD of different organic substrates at varying operational conditions (Gavala et al. 2003, Mairet et al., 2011; Muha et al., 2012), the Anaerobic Digestion Model Number 1 (ADM1) is a general platform of anaerobic modelling, simulation and understanding of AD processes, that was developed by the International Water Association (IWA) task force (Batstone et al., 2002). Though ADM1 was initially developed to model sewage sludge digestion at mesophilic or thermophilic temperatures, it has already been implemented for a range of other cases, such as anaerobic digestion of: Blackwater (Feng et al., 2006); high strength CO_2 capture of amine waste (Wang et al., 2014); co-digestion of organic waste and wastewater (Derbal et al., 2009); and various other organic waste/wastewater at varying temperature conditions (Batstone et al., 2006). Modeling and simulation of AD by ADM1 at long sludge retention and varying temperature conditions can provide clues for design and operation of anaerobic digestion in cool climates such as in Nepal (Lohani et al., 2016).

The aim of this study is to use ADM1 to model, simulate and gain further insight into the use of a ST-UASB reactor combination treating domestic wastewater at various (low) temperatures. The ST-UASB combined system appears to be a sustainable and suitable approach for domestic wastewater treatment (Lohani et al., 2015a,

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https://doi.org/10.1016/j.wen.2018.07.001
2588-9125/

Please cite this article in press as: Lohani, S.P., et al. Modeling temperature effects in anaerobic digestion of domestic wastewater. Water-Energy Nexus (2018), https://doi.org/10.1016/j.wen.2018.07.001

b), a claim further evaluated here, using ADM1 at adequate sludge retention time and low temperatures.

2 Material and methods

2.1 Plant description

The pilot-scale 250 L pulse feed UASB reactor, fed with ST (about 18 h HRT in ST) treated effluents was operated at different hydraulic retention time (HRT) from 10 d to 18 h for about 8 months before the test runs from which data were collected for the simulations in this study. The data of the reactor monitored at HRT of 12, 8 and 6 h with average temperatures 10, 15 and 20 °C for about 1, 1.5 and 2 months, respectively, at varying load conditions (Fig. 1) were used for simulation. The raw wastewater COD influent at ST was not measured accurately since it was not possible to get representative samples so a constant COD of 1.1 g/L was used in the simulations. The ST effluent, used as COD influent to the UASB, was measured regularly and the details of the plant operation, analysis and results were given in (Lohani et al., 2015b). These measured values were used as influent data for the UASB simulations. The SRT in the UASB was not controlled and it was not possible to measure with the available methods. However, long sludge retention is a key characteristic in the UASB concept, which can be achieved by the efficient retention of granular sludge in the process. A sensitivity analysis on SRT showed SRT importance in such AD and longer SRT gave better simulation fit (Lohani et al., 2016). Hence, 100 d SRT was used in the simulations to ensure that the UASB process occurs as expected.

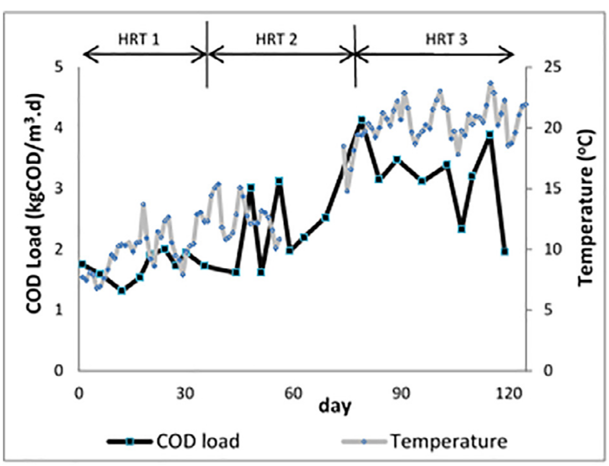

Fig. 1. Measured temperatures and UASB reactor COD load at HRT1 of 12 h (T_{ave} = 10 °C), HRT2 of 8 h (T_{ave} = 15 °C) and HRT 3 of 6 h (T_{ave} = 20 °C).

2.2 Model description

ADM1 was originally used for modeling a Continuous flow Stirred Tank Reactor (CSTR) and was provided with sludge recycle to enhance the anaerobic sludge retention in the digester. The sludge retention in a UASB reactor is thus modeled by increasing the external recycle giving a relatively high SRT in comparison to the HRT, however, ST was modelled with relatively low SRT. The combined ST-UASB model was like two step treatment process primary at ST and the secondary at UASB.

2.3 Model implementation

The ADM1 was implemented in the software AQUASIM 2.1, a computer program for data analysis and simulation of aquatic systems (Reichert 1994). The model was used to simulate various loads at 12, 8 and 6 h HRT and with SRT of 100 d for the UASB. The model was also used to simulate the ST-UASB combination, in which case, SRT of 10 d was assumed for the ST. The input wastewater organic substrate concentrations were assumed 65% degradable by AD and the rest were inert (Al-Shayah and Mohmoud, 2008). All other parameters (e.g. intrinsic kinetic and stoichiometric coefficients) were assumed constant and used in accordance with recommendation by Batstone et al. (2002), but, with temperature effects included for disintegration, hydrolysis and uptake kinetics as suggested by Donoso-Bravo et al. (2009) and Rebac et al. (1995) for low temperature conditions at 10, 15 and 20 °C (Table 1).

2.4 Temperature effect

Modified kinetics k_{dis}, k_{hyd} and k_m at different temperatures were used for modeling temperature effects on anaerobic digestion of domestic wastewater with the ST and UASB reactor. The temperature compensated kinetic parameters were estimated from Donoso-Bravo et al. (2009) and Rebac et al. (1995). Relative temperature effects on these kinetics at 10, 15 and 20 °C were expressed in factors (Table 1) taking 35 °C as the reference condition. The absolute temperature compensated kinetic values were the multiplication of original ADM1 kinetics (Batstone et al., 2002) by these factors.

3 Results and discussion

3.1 UASB simulation with temperature compensation kinetics

The UASB was simulated at different measured temperatures utilizing temperature compensation kinetics (Table 1) reported from Donoso-Bravo et al. (2009), and Rebac et al. (1995), which is different from the earlier studies of the author at mesophilic

Table 1
Relative change of kinetic parameters k_{dis}, k_{hyd}, k_m with temperature. Calculated from (A) Donoso-Bravo et al. (2009), and (B) Rebac et al. (1995).

Process	Temperature (°C)				Ref.
	10	15	20	35	
Disintegration, k_{dis}	Same as for hydrolysis of carbohydrates				
Hydrolysis of Carbohydrates, $k_{hyd,su}$	0.12	0.14	0.29	1	A
Hydrolysis of Protein, $k_{hyd,pr}$	Same as for hydrolysis of carbohydrates				
Hydrolysis of lipids, K_{hyd}, li	Same as for hydrolysis of carbohydrates				
Sugar Uptake, K_m	0.16	0.16	0.19	1	A
Amino acid, uptake, K_m	Same as for sugar uptake				
Fatty acid uptake, k_m	Same as for sugar uptake				
Butyrate uptake, K_m	0.2	0.36	0.5	1	B
Propionate Uptake, K_m	0.13	0.29	0.48	1	B
Acetoclastic methanogenes, K_m	0.14	0.2	0.29	1	B
Hydrogenotrophic methanogens, K_m	Same as for acetoclastic methanogens				