

ADM1 modeling of UASB treating domestic wastewater in Nepal



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ARTICLE INFO

Article history:

Received 30 October 2015

Received in revised form

12 March 2016

Accepted 7 April 2016

Available online 18 April 2016

Keywords:

ADM1

Domestic wastewater

UASB

SRT

COD

ABSTRACT

The Anaerobic Digestion Model 1 (ADM1) was applied to the anaerobic digestion process in an Upflow Anaerobic Sludge Blanket (UASB) reactor treating domestic wastewater. It was evaluated based on data from a 250 L pilot scale reactor. The wastewater influent degradable characteristics and Sludge Retention Time (SRT) were established by several trial and errors simulation to establish appropriate values for parameters not measured experimentally. The model was further verified against varying load experimental results to ensure its usefulness for a wide range of relevant loads. The best fit was obtained using 60 d SRT and parameters recommended for mesophilic conditions, with average experimental values within 10% of the simulated results. The model gave a good estimation of reality and could be applied for feasibility analysis, design and operation of full-scale small plants to be used in rural areas. Kathmandu University (KU) domestic wastewater treatment plant simulation was used as example of such. It showed that a reactor volume of about 4 m³ (6 h HRT) would give reasonable reactor performance with 1.7 m³/d biogas production.

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1. Introduction

Anaerobic treatment of domestic wastewater is an alternative to secondary wastewater treatment in warm climates that can be used to recover energy as methane from organic waste and subsequently reduce greenhouse gas emission [1–3]. The costs of aeration and sludge handling associated with aerobic sewage treatment can significantly be reduced.

Different anaerobic digestion (AD) models have been developed and used for simulating AD of different organic substrates at varying operational conditions [4–6].

The International Water Association (IWA) task force has developed the Anaerobic Digestion Model Number 1 (ADM1) to serve as a general platform for anaerobic digestion modeling [7,8]. ADM1 involves 19 biochemical processes for substrate disintegration, hydrolysis, acidogenesis, acetogenesis and methanogenesis, which are conducted by seven bacterial groups. It also involves 7 physico-chemical processes for ion association/dissociation and gas liquid transfer. Though ADM1 was developed primarily to model

sludge digestion at mesophilic or thermophilic temperature, it has already been implemented for mesophilic anaerobic digestion of blackwater [9], high strength CO₂ capture amine waste [10] and various other organic waste/wastewater at varying temperature conditions [11].

Sludge retention and mass transfer are two important aspects related to design, construction and mode of operation of an anaerobic reactor in achieving good biological wastewater treatment [12]. Sludge retention time (SRT) plays an important role in AD, such as for methanogens' to consume organics, especially at low operational temperatures [13]. Long sludge retention is a key characteristic in the UASB concept, which is achieved by the efficient retention of granular sludge in the process. Modeling and simulation of AD by ADM1 at long and varying sludge retention and temperature conditions should give clues for design and operation of anaerobic digestion in cool climates such as in Nepal.

The aim of this study was to implement ADM1 simulations of UASB digestion of a septic tank (ST) pretreated domestic wastewater. Experimental results of a pilot-scale 250 L pulse fed UASB reactor treating the above mentioned wastewater at ambient condition [14] was used for calibrating and evaluating the applicability of ADM1 for such cases. The model was intended to be used for assessing involved biochemical processes, estimating kinetic

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parameters, simulating relevant cases and designing treatment plants in the future.

2. Material and methods

2.1. Pilot plant operation

The UASB reactor 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 for about 1, 1.5 and 2 months, respectively at varying load conditions (Fig. 1) were used for simulation. Details of the plant operation, analysis and results were given in Ref. [14].

2.2. Biodegradability of wastewater from septic tank

Wastewater biodegradability was determined by calculating the difference between input and output total COD in the wastewater before and after anaerobic treatment (Eq. (1)). The biodegradability of wastewater influent to the UASB reactor were measured in batch reactor using 50 ml wastewater incubated at 30 °C for 110 days [15]. Wendland, 2008 found that maximum COD removals were achieved in 20 d and 85 d, in a biodegradability test of wastewater with and without inoculation, respectively. Hence, this test used 110 days as incubation time to ensure maximum COD removal can be achieved.

$$\text{Biodegradability (\%)} = 100 * (\text{CODT, } t = 0 \text{ days} - \text{CODT, } t = t \text{ days}) / \text{CODT, } t = 0 \text{ days} \quad (1)$$

Where CODT is total COD amount in the tested samples (g COD/L).

2.3. Model description

The biochemical processes in the ADM 1 includes disintegration, hydrolysis, acidogenesis, acetogenesis and methanogenesis. Disintegration and hydrolysis processes are extracellular solubilization steps and are described by first order kinetics as given in Eq. (2) [7].

$$\rho = K_{dis,hyd} \cdot X_{dis,hyd} \quad (2)$$

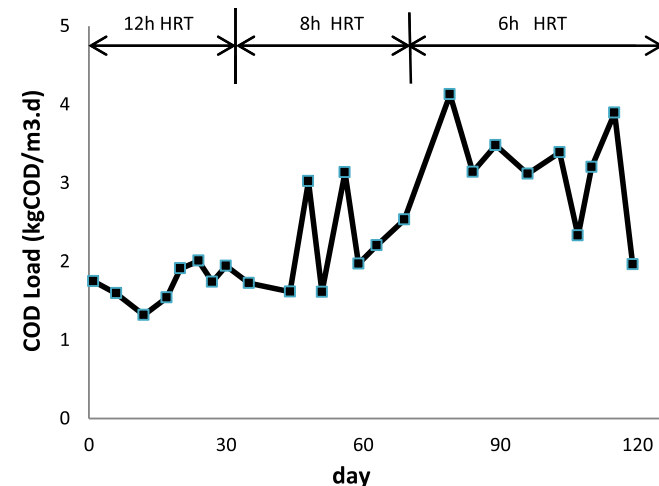


Fig. 1. COD load at HRT of 12 h, 8 h and 6 h.

Where ρ = disintegration or hydrolysis rate of solid substrate (kg COD/m³·d), $X_{dis,hyd}$ = solid substrate concentration (kg COD/m³), $K_{dis,hyd}$ = Kinetic parameter for disintegration or hydrolysis (1/d).

The acidogenesis, acetogenesis and methanogenesis processes are intracellular biochemical reactions and are described by substrate-based uptake Monod-type kinetics (eq. (3)).

$$\rho = k_m \cdot \frac{S}{K_s + S} \cdot X \cdot I \quad (3)$$

Where k_m is the maximum substrate uptake rate constant (kg COD substrate/kg COD biomass·d), X = biomass concentration (kg COD biomass/m³), S = substrate concentration (kg COD substrate/m³), K_s = half saturation constant (kg COD substrate/m³) and I = inhibition factor.

The physico-chemical processes are chemical equilibria to calculate hydrogen ions concentration, free ammonia and carbon dioxide and non-equilibrium liquid-gas transfer [7].

2.4. Mass balance

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 STR comparing with HRT. Mass balance of the reactor state variables are expressed as shown in Eqs. (4) and (5).

$$\frac{dS_i}{dt} = \frac{q_{in}S_{in,i}}{V_{liq}} - \frac{q_{out}S_{out,i}}{V_{liq}} + \sum_{j=1,19} \rho_j \nu_{i,j} \quad (4)$$

$$\frac{dX_i}{dt} = \frac{q_{in}X_{in,i}}{V_{liq}} - \frac{q_{out}X_{out,i}}{V_{liq}} + \sum_{j=1,19} \rho_j \nu_{i,j} \quad (5)$$

Where S_i is the concentration of a soluble substrate component, X_i is the concentration of a particulate substrate component and active biomass. q_{in} and q_{out} are the influent and effluent flow rates, respectively. V_{liq} is the reactor working volume, $\sum \rho_j \nu_{i,j}$ is the sum of specific kinetic rates for process j multiplied by the stoichiometric coefficients [7].

Mass transfer of three gases CH₄, H₂ and CO₂ between liquid and headspace phases are calculated based on Henry's law. The gas phase dynamics is given in Eq. (6):

$$\frac{dS_{gas,i}}{dt} = \frac{q_{gas}S_{gas,i}}{V_{gas}} + \rho_{T,i} \frac{V_{liq}}{V_{gas}} \quad (6)$$

$\rho_{T,i}$ = specific mass transfer rate of gas i , (kg COD/m³·d for CH₄ and H₂; kmole C/m³·d for CO₂).

2.5. Model implementation

ADM1 was implemented in the software AQUASIM 2.1, a computer program for data analysis and simulation of aquatic systems [16]. The model was implemented for the reference scenario of 12 h HRT operation for calibrating the model. The model calibration involved only variables that can actually vary and/or be manipulated, which is feed composition and SRT. All other parameters (e.g. intrinsic kinetic and stoichiometric coefficients) are assumed constant and used in accordance with recommendation by Refs. [7,8]. The calibrated model was used to simulate higher load condition (8 and 6 h HRT operation) for verifying the model's ability to predict process load variations.

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