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Estimation of biogas and methane yields in an UASB treating potato starch processing wastewater with backpropagation artificial neural network

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HIGHLIGHTS

- Estimation of CH_4 and biogas yield from a UASB with BP-ANN and MnLR.
- Evaluation and selection of optimum algorithm from eleven training algorithms.
- Optimization of anaerobic parameters to identify their effects on methanation.
- BP-ANN models predictions were more reliable compared to MnLR.

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ABSTRACT

Three-layered feedforward backpropagation (BP) artificial neural networks (ANN) and multiple nonlinear regression (MnLR) models were developed to estimate biogas and methane yield in an upflow anaerobic sludge blanket (UASB) reactor treating potato starch processing wastewater (PSPW). Anaerobic process parameters were optimized to identify their importance on methanation. pH, total chemical oxygen demand, ammonium, alkalinity, total Kjeldahl nitrogen, total phosphorus, volatile fatty acids and hydraulic retention time selected based on principal component analysis were used as input variables, whiles biogas and methane yield were employed as target variables. Quasi-Newton method and conjugate gradient backpropagation algorithms were best among eleven training algorithms. Coefficient of determination (R^2) of the BP-ANN reached 98.72% and 97.93% whiles MnLR model attained 93.9% and 91.08% for biogas and methane yield, respectively. Compared with the MnLR model, BP-ANN model demonstrated significant performance, suggesting possible control of the anaerobic digestion process with the BP-ANN model.

1. Introduction

Energy recovery through biological processes is an environmentally sensitive means to generate energy and reduce greenhouse gases that has the potential to impacts negatively on the environment (Angenent et al., 2004; Şentürk et al., 2010; Akkaya et al., 2015). Anaerobic wastewater treatment can yield methane, hydrogen or other scarce biochemicals that can effectively be used as energy. Potato starch processing generates tons of wastewater which contains organic by-products such as starch, proteins, amino acids sugars, and potassium (Dabestani et al., 2017). These organic by-products that are biodegradable contributes to the high records of chemical oxygen demand (COD), 5-day biochemical oxygen demand (BOD_5) and suspended solids (SS) in the potato starch processing wastewater (PSPW) (Dabestani et al., 2017). Regarding the biodegradability characteristics, valuable energy resources such as methane or biogas could be harnessed from the wastewater (PSPW) through anaerobic digestion (AD) (Arhoun et al., 2013).

AD has not only been employed to treat sewage and industrial wastewater but also generate biogas (Şentürk et al., 2010; Zheng et al., 2012; Arhoun et al., 2013). So far, various types of processes

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have been proposed and reported in the treatment of potato wastewater, among which AD has proven to be very effective and improved the final effluent quality (Wang, 2013). As known, process modeling can be employed as a tool for predicting and describing performance of biological processes (Hu et al., 2002). Artificial neural networks (ANN) could be developed into process models and used successfully due to its capacity to capture the non-linear relationships that might exist among variables (multi-input/output) in a complex system (Kanat and Saral, 2009; Delnavaz et al., 2010; Khataee and Kasiri, 2011; Sun et al., 2012; Ghosh et al., 2013; Yetilmezsoy et al., 2013; Gong and Ordieres-Meré, 2016; Nair et al., 2016). Nasr and coworkers (Nasr et al., 2013) were successful in predicting hydrogen production profile with an ANN model. Khataee and coworkers also investigated the biological treatment of a dye solution by macro algae *Chara* sp., where 97% of the variations in the output variable were well explained by the input variables within the ANN framework (Khataee et al., 2010). Mechanistic modeling has also been implemented successfully, although means to acquire kinetic parameters is often laborious and difficult (Nasr et al., 2013; Brooks et al., 2016). Comparatively, the ANN methodology and framework can investigate and model AD processes without dependence on kinetic parameters acquired from the anaerobic process or system. However, few researches could be found employing ANN modeling to estimate biogas and methane yield in an upflow anaerobic sludge blanket (UASB) reactor treating PSPW.

Herein, the aim was; to develop a rapid and efficient methodology able to estimate biogas and methane production processes given initial substrate compositions and operational parameters; to identify and optimize essential process variables capable of making reliable predictions; and to develop a process that could possibly reduce cost and time of analysis. pH, COD, ammonium (NH_4^+), alkalinity (ALK), total Kjeldahl nitrogen (TKN), total phosphorus (TP), volatile fatty acids (VFAs) and hydraulic retention time (HRT) obtained from the anaerobic process were selected based on principal component analysis and used as input variables to develop three-layered ANN models ($8{:}N_H{:}1$) and multiple nonlinear regression models. The anaerobic process parameters were optimized to identify their effects on methanation from the UASB. The efficiency of the developed ANN-based models was compared with the multiple nonlinear regression models to make reliable simulations and predictions about biogas and methane yields within the UASB.

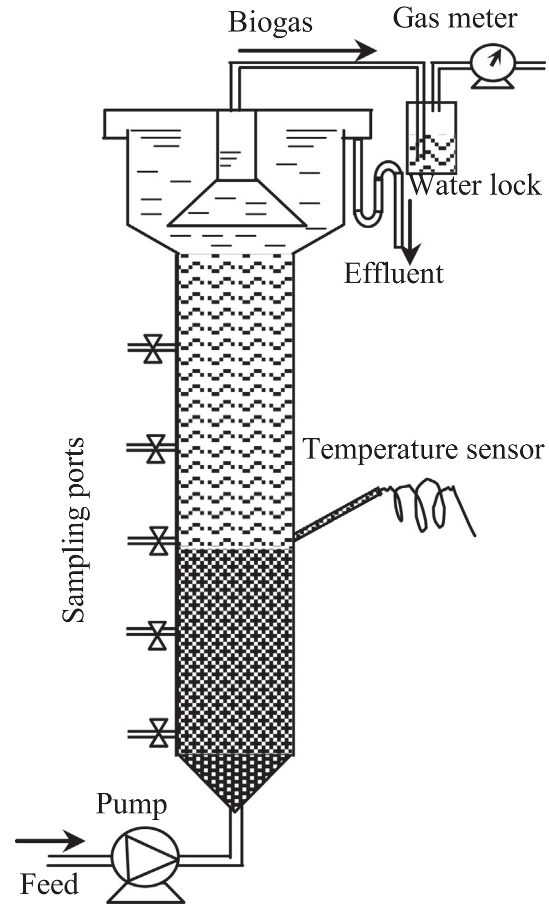

Fig. 1. Schematic diagram of the upflow anaerobic sludge bed reactor.

2. Materials and methods

2.1. Experimental setup and operation

Experiments were conducted in a 120 cm high UASB constructed with a Plexiglas column (Fig. 1). The reactor had a total and effective working volume of 8.8 L and 7 L, respectively. Five sampling ports at approximately 25 cm interval were allocated along the vertical height of the cylinder under the gas-liquid-solid separator. The reactor was operated at 35 ± 1 °C which was maintained with a controller. Excess activated sludge collected from a local anaerobic-anoxic-oxic process treating municipal sewage was used to inoculate the UASB. At the started up of the reactor, the mixed liquor suspended solid (MLSS) and mixed liquor volatile suspended solid (MLVSS) was 11.5 and 5.6 g/L, respectively. PSPW was collected from a local starch producing industry and kept under 4 °C.

The concentration of the wastewater in terms of COD, NH_4^+, TP, TKN, ALK and VFAs averaged 49179, 302, 190, 1023, 4945 and 534 mg/L, respectively. The raw wastewater was diluted to a favorable quality and fed to the UASB by a peristaltic pump (BT100-2J, Langer Instruments, UK). The average feed concentration in terms of COD, NH_4^+, pH, ALK, TKN, TP and VFAs was 4029, 110, 7, 2152, 511, 45, 103 mg/L, respectively. Within the startup period, operation of the UASB was divided into two stages in terms of HRT. The first 49 days was the first stage with a HRT of 48 h. HRT was subsequently curtailed to 24 h in the following 63 days as the second stage. The evolved biogas were collected by the gas-solid-liquid separator and was measured daily by a wet gas meter (Model LML-1, Changchun Filter Co., Ltd., China).

2.2. Analytical methods

All chemical analysis were conducted in accordance with Standard Methods for the Examination of Water and Wastewater, APHA (APHA, 2007). Influent and effluent COD, ALK (in terms of $CaCO_3$), TKN, NH_4^+ and TP were analyzed daily. pH was determined using a DELTA 320 (Mettler Toledo, USA). VFAs in liquid samples were measured by a gas chromatograph (SP6890, Shandong Lunan Instrument Factory, China) equipped with a 30 m capillary column (Stabilwax-DA, i.d.0.32 mm, 11054, Restek) and a flame ionization detector (FID) (Liu et al., 2015). The operational temperatures of the injection port, oven and detector were 210 °C, 180 °C, and 210 °C, respectively. Nitrogen gas was used as the carrier gas, with a 0.75 MPa column head pressure. The split ratio was 1:50. Liquid sample of 1 mL was centrifuged at 13000 rpm for 3 min. A 0.5 mL of the supernatant after centrifuge was pipetted and acidified with 25% H_3PO_4, and then 1 μL of the final solution injected. For biogas fraction, 0.5 mL biogas was sampled from the headspace of the UASB to determine methane (CH_4) and carbon dioxide (CO_2) fractions by another gas chromatograph (SP-6800A, Shandong Lunan