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Modelling Biogas Fermentation from Anaerobic Digestion: Potato Starch Processing Wastewater Treated Within an Up flow Anaerobic Sludge Blanket

[1]State Key Laboratory of Urb95b95b9ta OFKey 76 TmRe TJEMC /Span <</Lang (en-US)/MCID 114 BDC /TT1 1 Tf-0.003 Tw -1.772 -1.2 Td[(blanket)-0.8((UASB) reactor treating

wastewater characteristics normally results in a laborious calibration, comprehensive computer analysis as well as laboratory work [14] The International Water Association (IWA) Anaerobic Digestion Model No.1 (ADM1), a typical deterministic model, has been successfully used for modeling the whole anaerobic digestion process [19] However, its mathematical complexity associated with extreme analytical difficulty of measuring kinetic parameters turns out to be laborious and time consuming [20,21] On the other hand, stochastic based non-linear multiple regression model is preferably easy to handle as well as capable to estimate the relation between variables and numerical parameters [22,23] The advantage of a regression based model compared to other models such as neural networks is its ability to write down relationships and to relate with underlying processes, whereas neural networks only produce an approximation that is opaque.

Keywords: Upflow anaerobic sludge blanket (UASB); Potato starch processing wastewater; Biogas yield; Modeling; Multiple non-linear regression

Introduction

Potato is one of the most valuable food crop grown in many countries [1]. It has been reported that, a considerable proportion of the potato cultivated globally consumed through starch processing which subsequently generates tons of wastewater that goes to pollute water bodies [1-3]. Wastewater of raw potato processed into starch are classified as complex wastewater [4,5], and its concentration of chemical oxygen demand (COD), total suspended solid (TSS) and volatile suspended solid of (VSS) can yield concentrations of 50000, 9700 and 9500 mg/L, respectively [6]. Arhoun et al. argued that recovering valuable resource such as bioenergy (biogas) from such wastewater to supplement energy needs will be beneficial to humans and society at large [6,7]. Anaerobic digestion has severally been reported as a successful bioprocess treating various organic wastewaters and subsequently generating biogas [7-12]. However, the biological mechanism of anaerobic digestion is not well understood due to the complexity of the bacterial community structure and bioconversion [13]. Hu et al. asserted that process modeling is a good tool for predicting and describing the performance of biological processes [13]. Other reports also confirmed that process modeling based on previously acquired data is one technical route to enhancing the performance of anaerobic processes. These process models are often developed [14,15]. Nonetheless, modeling of anaerobic digestion is quite challenging and tough because performance of anaerobic systems is complex and varies considerably with influent characteristics and and Environment, School of Municipal and Environmental Engineering, Harbin Institute of Technology, 73 Huanghe Road, Harbin 150090, PR China, Tel: +8645186283761;

Fax: +8645186283761; E-mail: kobbyjeany@hoo.co.uk

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Volatile fatty acids (VFAs) 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). 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 collected from the top most sampling port was centrifuged at 13000 rpm for 3 min, and 0.5 mL of the supernatant was pipetted and acidified with 25% H_3PO_4 and then 1 μL of the final solution was injected. The VFAs were measured in terms of CH_3COOH.

A 0.5 ml of biogas was sampled from the headspace of the reactor to determine CH_4 and CO_2 fractions. Fraction of CH_4 was analyzed by another gas chromatograph (SP-6800A, Shandong Lunan Instrument Factory, China) equipped with a thermal conductivity detector (TCD) and a 2 m stainless column packed with Porapak Q (60/80 mesh). Temperatures of the injector, column and the TCD were 80°C, 50°C and 80°C, respectively.

Data preparation and correlation analysis

The experimental data was used as an open database connectivity data source for the regression analysis. MINITAB (version 17) and [illegible] was aecatin]/Lan/4n <</Laoime25ahigs24p Cw5ti/Sp

$$\bar{Y} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + \beta_7 x_7 + \beta_8 x_8 \qquad (17)$$

Results and Discussion

UASB performance

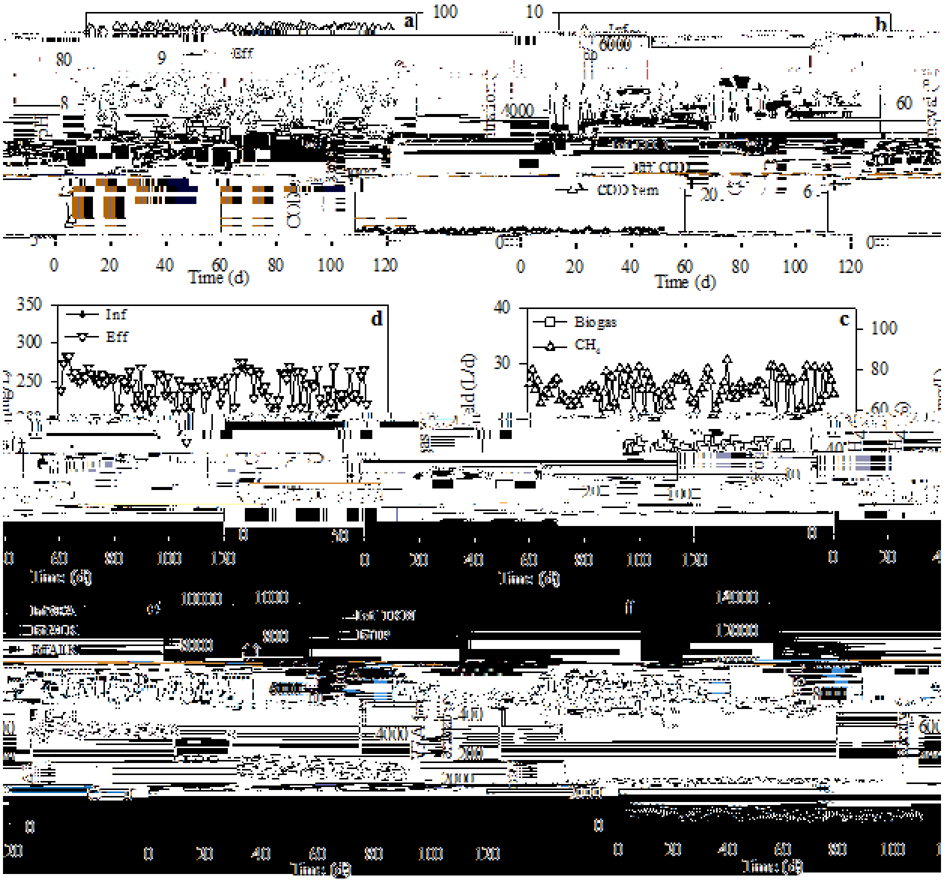
Performance of the UASB treating PSPW at 35 ± 1°C with HRTs of 48 h and 24 h by stages was presented in Figure 2 and Table 2. With an average influent COD of 3799 mg/L and an average organic loading rate (OLR) of 1.50 kgCOD/m^3·d for HRT 48 h, the effluent COD averaged 267 mg/L with a removal ranged from 83.5% to 92.0% was obtained in the reactor (Figure 2a). As the influent COD was increased to about 4185 mg/L along with the shortened HRT of 24 h, the COD removal ranged from 90% and 94.5% with an effluent COD of about 280 mg/L, though the OLR had been increased to about 4.23 kg COD/m^3·d. The higher COD removal at HRT 24 h resulted in an increase in biogas yield in the UASB. As shown in Figure 2b, the influent and effluent pH ranged from 5.35-8.05 (mean pH 7.00) and 7.35-8.86 (mean pH 8.00) for HRT 48 h and 24 h, respectively. The illustration in Figure 2c depicted biogas yield that ranged from 3.4 to 9.6 L/d obtained at HRT 48 h, while 11.3 to 17.4 L/d in HRT 24 h. The methane fraction throughout the performance of the reactor ranged from 56.2% and 84.5%.

Throughout the operation of the UASB, observed pH in both HRTs were almost similar in value even though a remarkable difference in ALK was observed in the reactor. Figure 2d indicated that no observable difference in NH$_4^+$ concentration was found when the reactor was operated at HRT 48 h or 24 h, with an influent and effluent concentration averaged 109 and 241 mg/L, respectively. The average influent and effluent ALK at HRT 48 h were 6010 and 10948 mg/L, while that of 3592 and 8638 mg/L for HRT 24 h, respectively (Figure 2e). The feasible pH and ALK enhanced the acetogenesis and methanogenesis in the reactor, resulting in the few VFAs observed in the effluent [38].

The average influent and effluent TKN at HRT 48 h were found to be 466 and 307, respectively (Figure 2f). With the shortened HRT 24 h, the influent and effluent TKN were increased to about 518 and 507, respectively. Within the 112 days' operation, the UASB showed no TP removal with the same concentration of about 45 mg/L in both influent and effluent (Figure 2f).

Correlations between output and input variables

Correlation analysis was performed during the data preparation to identify the potential input variables to build the model. The results as shown as Table 3 showed that influent COD, pH, NH$_4^+$, ALK, TKN, VFA, TP and HRT had remarkable influence on the biogas yield in the UASB. The eight variables correlated with biogas yield were therefore used as input and output variables in the models. Observably, NH$_4^+$ was the only variable included in all model types (Eq.13 to Eq.17), but it has seldom been used in predictive models before [23,39].



Fluctuation phenomenon of influent/effluent quality and reactor performance.

substituted into M3 (Eq.15) and M4 (Eq.16) to yield Eq.18 and Eq.19, respectively.

$$Y = 17.841 + 1.14\times10^{-3}x_1 + 1.11\times10^{-2}x_2 + 1.98\times10^{-3}x_7 - 0.4x_8 \quad (18)$$

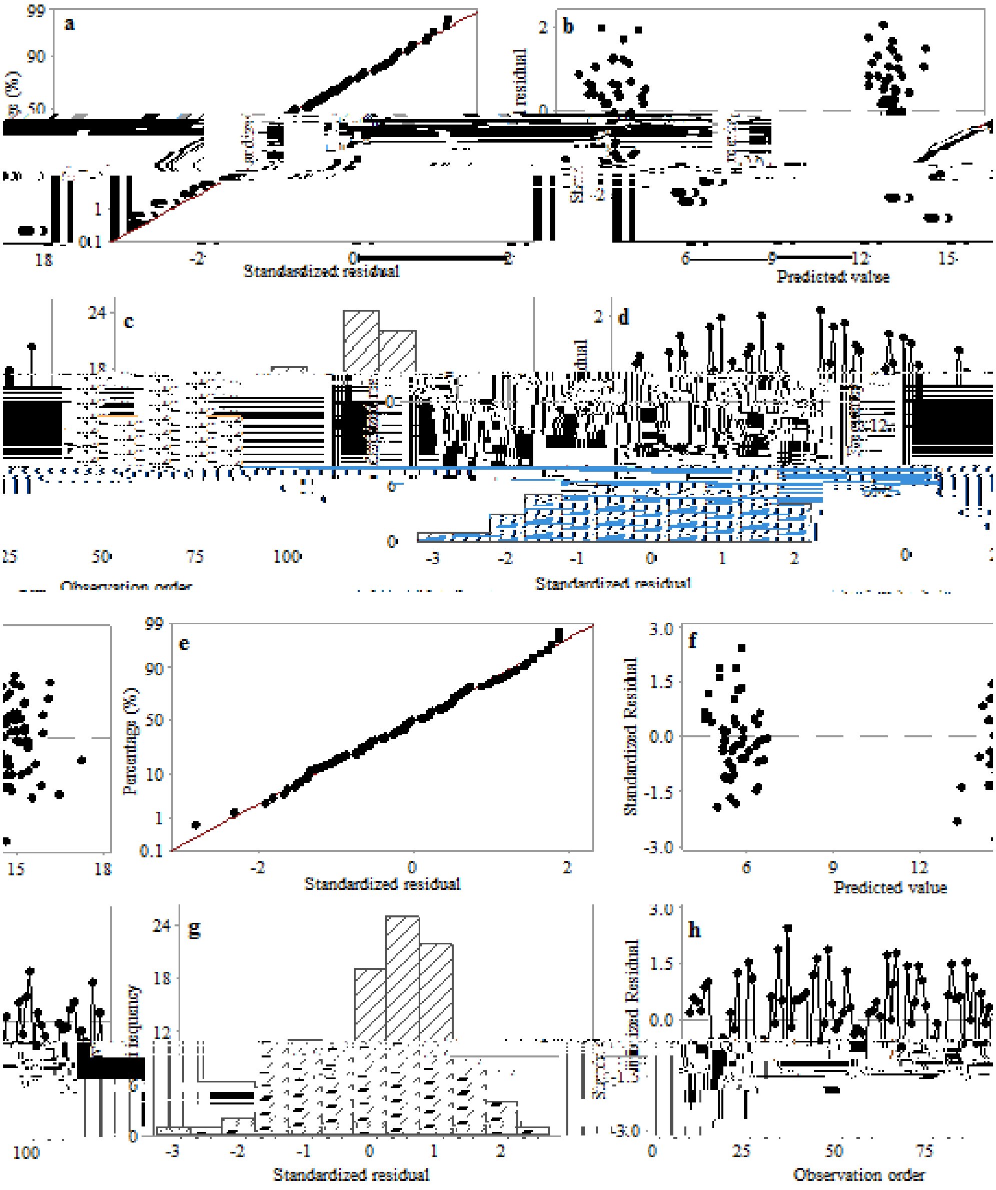
$$Y = 20.289 + 1\times10^{-7}x_1^2 + 8.8\times10^{-5}x_2^2 - 0.37x_8 \quad (19)$$

The final structure of the model equations expressed in Eq.18 and Eq.19 were rewritten and given in Eq.20 and Eq.21, respectively.

$$\begin{aligned}BgY &= 17.841 + 1.14\times10^{-3}COD + 1.11\times10^{-2}(NH_4^+)^2 + \\ &1.98\times10^{-3}VFAs - 0.4HRT\end{aligned} \quad (21)$$

$$BgY = 20.289 + 1\times10^{-7}COD^2 + 8.8\times10^{-5}(NH_4^+)^2 - 0.37HRT \quad (22)$$

Accordingly, independent variables $_1$, $_2$, $_7$ and $_8$ were used in M3 and M4 as shown in Eq.18 and Eq.19. Table 4 showed the results of the diagnostics statistics and performance criterion. Obviously, COD, NH



Residual plots of Normal Probability Plot (a, e), Versus Fits (b, f), Histogram (c, g) and Versus Order (d, h).

of 1.50 kg COD/m^3·d, COD removal efficiency ranging from 83.5% to 92.0% was obtained when HRT was 48 h. As the influent COD was increased to about 4185 mg/L along with the shortened HRT of 24 h, the COD removal reached 94.5%, although organic loading rate (OLR) had been increased to about 4.23 kg COD/m^3·d. The higher COD removal at HRT 24 h resulted in an increase in biogas yield in the UASB. Biogas yield at HRT 48 h ranged from 3.4 to 9.6 L/d, whiles 11.3 to 17.4 L/d were observed at HRT 24 h. The methane fraction throughout the performance of the reactor reached 84.5%. No signs of acidity were encountered in the UASB as effluent pH observed ranged from 7.35-8.86 (mean pH 8.00) for both HRT of 48 h and 24 h.

To predict the biogas yield in the UASB treating potato starch processing wastewater (PSPW), the dynamic relationship among PSPW parameters, reactor operational parameters and the biogas yield were modeled based on MnLR model and validated with residuals analysis. Among the 5 developed models, M3 and M4 were identified as the optimum ones due to their superior predictive performance on biogas yield. The R^2 emerged from M3 and M4 were 97.29% and 96.99%, respectively. COD, NH_4^+, VFAs and HRT were the most useful and favourable predictive parameters compared to ALK, TKN, TP and pH. Both model M3 and M4 turned out to be a good tool for predicting biogas yield in UASBs. These models can also contribute to the understanding of the factors that influence anaerobic processes, and subsequently be used as a guide to control the processes to enhance biogas yield.

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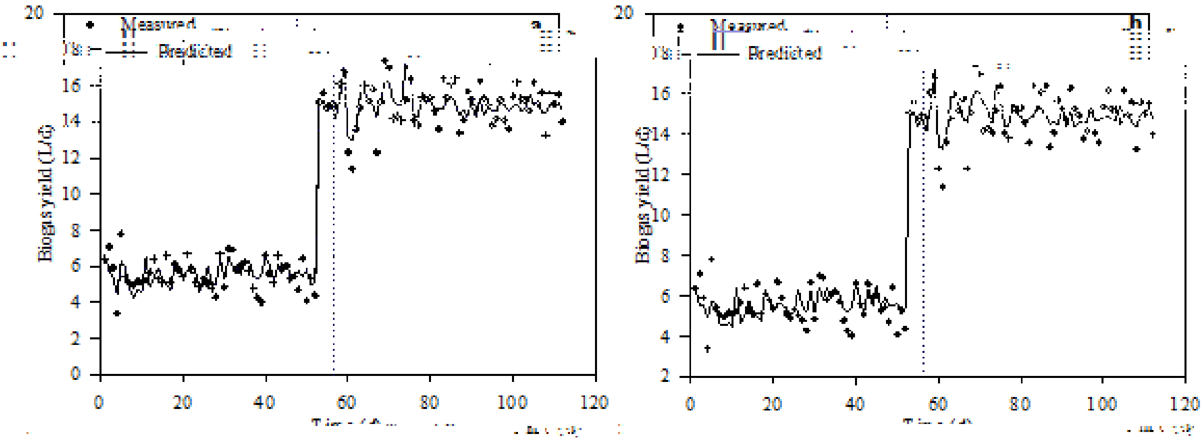
Correlation (a, c) and visual agreements (b, d) of the predicted and the experimental data in model M3 and M4, respectively.



Head-to-head comparisons of predicted and experimental results.

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