Kinetics on Anaerobic Digestion and Wastewater Treatment of Chicken Slaughterhouse

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Article info

Abstract

The kinetics of anaerobic mixed culture treatment of chicken slaughterhouse wastewater was investigated in this research. Experiments were conducted in the serum bottle containing 90 ml of chicken slaughterhouse wastewater including 10 ml sludge (2,000 mg/l mixed liquor volatile suspended solids, MLVSS) from upflow anaerobic sludge blanket (UASB) system. The bottles were operated in anaerobic condition with the chicken slaughterhouse wastewater at various chemical oxygen demand (COD) concentrations of 400, 800, 1200 and 1600 mg/l at pH 7.00±0.02. The serum bottles were incubated for 30 days at 37±1 °C without shaking. Based on the data, the order kinetics of the reaction were found in different COD concentrations of organic matter in chicken slaughterhouse wastewater treatment. The reaction order in the degradation of higher COD concentrations (800, 1200 and 1600 mg/l) of chicken slaughterhouse wastewater treatment is a fit for first order kinetic model. On the other hand, the COD degradation of the anaerobic treatment of chicken slaughterhouse wastewater at low COD concentration (400 mg/l) appeared to be close to the second order. The increasing of COD and color removal efficiencies of the slaughterhouse wastewater treatment was observed with a greater concentration of COD. The maximum COD and color removal efficiencies (90.40 and 48.96%, respectively) were found at the 1600 mg COD/l. Moreover, the biogas production increased with an increase in COD concentration of the wastewater and incubation time. The highest biogas production reached was 267.0 ml biogas volume (64.03% CH_4) with wastewater treatment of COD concentration at 1600 mg/l for 30 days.

Introduction

The slaughterhouse wastewater has incurred water pollution, causing environment and health impact in discharge water sources. Anaerobic treatment is con- sidered to be employed for slaughterhouse wastewater treatmentas a sustainable andeconomical technology. Slaughterhouse wastewater is a rich source of organic compounds which is well suitable for the anaerobic treatment process (Tritt, 1992; Ruiz et al., 1997; Caixeta

et al., 2002). The anaerobic treatment process converts the organic matter into CH_4 CO_2 and others gases. Anaerobic treatment process turns complicated when the composition is rich in fats and suspended solids. Once the fats and suspended solids are removed by the pretreatment process, the result enhances the efficiency of the anaerobic treatment. Minimizing of the BOD and COD concentrations in the slaughterhouse wastewater is the main objective of the secondary treatment process by reducing the soluble organic compound present after the primary treatment processes. In general, to treat the slaughterhouse wastewater through anaerobic digestion there are several methods available such as Anaerobic Lagoon, Anaerobic Filter, Anaerobic Baffle Reactor, Upflow Anaerobic Sludge Blanket Reactor, Hybrid Upflow Anaerobic Sludge Blanket Reactor (Tritt, 1992; Ruiz et al., 1997; Caixeta et al., 2002; Miranda et al., 2005; Oliveira & Von Sperling, 2009; Rajakumar et al., 2011; Loganath & Mazumder, 2018).

The performance of slaughterhouse wastewater has been predicted and described by process modeling (Spyridonidis et al., 2018; Martinez et al., 2002). The kinetic analysis has significant importance for improvement and optimization of anaerobic treatment. Mathematic order models have been derived from the chemical reaction kinetics (Zuniga, 1935). These kinetic models can be a useful tool for describing organic matter removal in terms of BOD and COD, optimization of the plant design and evaluation of the treatment efficiency of anaerobic system (Işik & Sponza, 2005; Mullai & Yogeswari, 2015). First order and second order models are common and would be suitable to predict substrate removal depending on influent organic concentration (Abyar et al., 2017; Ahmadi et al., 2015). However, there is no information available for description of the anaerobic chicken slaughterhouse wastewater treatment process by kinetics. Therefore, the present study investigated kinetics and anaerobic treatment of chicken slaughterhouse wastewater. The data results were used to determine the kinetic coefficients involved in the order models. The kinetics of chicken slaughterhouse wastewater treatment focused on COD concentrations. As the performance parameters include: COD, color, mixed liquor suspended solids (MLSS), pH, temperature, biogas production and methane content and have been selected to monitor the quality of influent and effluent chicken slaughterhouse wastewater.

Materials and methods

1. Wastewater

The chicken slaughterhouse wastewater used in this work was obtained from chicken slaughterhouse at Mahasarakham Province. The characteristics of the chicken slaughterhouse wastewater are summarized in Table 1. Various influent COD concentrations were prepared by diluting the chicken slaughterhouse wastewater with distilled water to give the levels of 400, 800, 1200 and 1600 mg COD/l. The pH was adjusted at 7.00 ± 0.02 by using NaOH and H_2SO_4.

Table 1 The characteristics of the chicken slaughterhouse wastewater

Parameters	Chicken slaughterhouse wastewater
COD (mg/l)	1818 ± 5.65
Color (SU)	154.55 ± 0.77
TKN (mg/l)	20.16 ± 0.43
pH	7.20 ± 0.00
Temperature (°C)	29.00 ± 0.00

2. Microorganisms

The seed partially granulated anaerobic sludge from the UASB treatment plant of starch wastewater was used in this study. Acclimatization of sludge was carriedout using slaughterhouse wastewater.

3. Serum bottle batch experiments

The 120 ml serum bottles with total working volume of 100 ml were used in the experiments. The bottles were operated with 90 ml of chicken slaughterhouse wastewater and filled with 10 ml sludge from UASB. MLVSS of the sludge was 2000 mg/l. The COD removals were experimented in various concentrations of 400, 800, 1200 and 1600 mg/l. The pH of the wastewater was adjusted to 7.0 ± 0.02. Anaerobic operation was done by flushing with nitrogen gas in the headspace of the serum bottles and then sealed with a butyl rubber stopper and an aluminum crimp seal. The serum bottles were kept at 37 ± 1°C without shaking for 30 days and samples were taken every 5 days during the incubation for analysis. The treatments were also carried out in duplicate.

4. Analytical methods

The samples were filtered through GF/C and the filtrates were used for analysis of COD and color. The soluble COD and MLSS concentrations were analyzed as described in the standard methods (Rice et al., 2012),

while the pH and the temperature were measured using pH meter type CD500 WPA type Sension 378 and thermometer, respectively. Color was determined by absorbance with a UV-VIS spectrophotometer (Genesys 10 series) at wavelengths of 400-700 nm (Space Unit, SU). Gas composition (CH_4, CO_2 and N_2) was analyzed by a gas chromatograph (SHIMADZU, GC- 2014, Japan) and biogas volume was measured by displacement of the water into syringe.

5. A kinetic study of chicken slaughter house waste-water treatment

The COD removal model was determined using kinetic models which can be presented in Eq. (1)-(3). Zero, first, second and Monod kinetic models were applied to the residual COD values in the batch incubation period in order to detect the kinetic model of substrate degradation. The residual COD concentrations remained in the anaerobic digestion system were plotted in form of COD concentration (C_t) versus time (t), ln C_t/C_0 versus t, and $1/C_t$ versus t, respectively, where C_0 and C_t express the COD concentration (mg/l) at time zero (days) and at time t (days), respectively in order to determine the COD kinetic (Bras et al., 2001; Isik & Sponza, 2004; Laowansiri et al., 2008). The COD reduction rate of zero, first, second-order reaction kinetic were equalized to the reduction rate of the zero, first, second -order kinetic, in the kinetics linear equation (1), (2) and (3), respectively.

Zero-order: $C_t = k_0t+b$ (1)
First-order: $\ln C_t/C_0 = k_1t+b$ (2)
Second-order: $1/C_t = k_2t+b$ (3)

where k_0 is zero-order rate constant COD removal (mg/l•day); k_1 is first-order rate constant COD removal (per day); k_2 is second-order rate constant COD removal (l/mg•day).
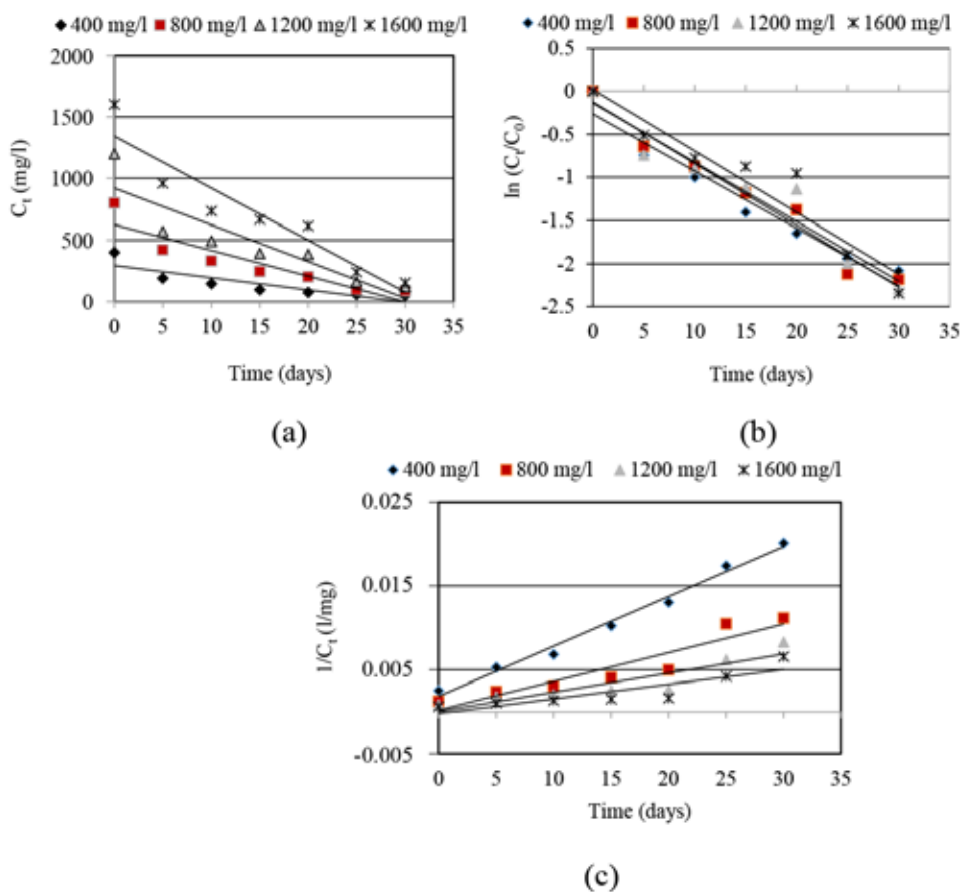

Fig. 1 Zero-(a), first-(b) and second-(c) order from COD kinetics in anaerobic batch treatments at differences of COD

6. Statistical analysis

The results reported in this work were expressed as mean values. All the statistical analyses were carried out with a one-way analysis of variance (ANOVA), and statistical differences were considered at a significance level of 0.05.

Results and discussion

1. Kinetics of chicken slaughterhouse wastewater treatment with respect to COD concentrations

Kinetic modeling is described as system performance and evaluation of the organic removal in the change of COD. The value of constants in Zero, first and second order models were obtained by plotting in form of COD concentration (C_t) versus time (t), ln C_t/C_0 versus t, and $1/C_t$ versus t, respectively in order to determine the through COD kinetic (Fig. 1) (where C_0 is COD concentration at the beginning of the incubation through COD and C_t is residual COD concentration at selected time (t) of batch test through COD concentration reduction). Zero-order reaction, in which the rate is not proportional to the concentration of reacting substance. The first order reaction, in which the rate is proportional to the concentration of only one reacting substance, and for the second order reaction, in which the rate is proportional to the product of two concentrations.

Table 2 The rate constants of COD kinetics from chicken slaughterhouse wastewater at various COD concentrations in anaerobic batch treatments

Para meters	Constants	COD concentrations of chicken slaughterhouse wastewater (mg/l)			
		400	800	1200	1600
COD	k_0 (mg/l•day)	9.8980	20.7830	29.6910	42.1410
	R^2	0.7568	0.8332	0.7987	0.8900
	k_1 (per day)	6.63×10^{-2}	7.15×10^{-2}	6.88×10^{-2}	7.13×10^{-2}
	R^2	0.9531	0.9663	0.9264	0.9132
	k_2 (l/mg•day)	6×10^{-4}	3×10^{-4}	2×10^{-4}	2×10^{-4}
	R^2	0.9879	0.8824	0.8184	0.7589

Table 2 shows k_0, k_1 and k_2 in anaerobic batch tests with COD concentrations of 400, 800, 1200 and 1600 mg/l. The COD reduction kinetics with respect to COD concentrations of 400, 800, 1200 and 1600 mg/l were yielding a high regression coefficients ($R^2 > 0.91$) that the COD was removed according to first order and second order kinetics (R^2 approach 1). The COD removal was suited to first order kinetics with COD concentrations of 800, 1200 and 1600 mg/l that the rate constants (k_1) were achieved 7.15×10^{-2}, 6.88×10^{-2} and 7.13×10^{-2} per day,

respectively. On the other hand, the COD was removed according to second order kinetics with COD concentration of 400 mg/l the rate constant (k_2) was 6×10^{-4} l/mg•day.

The COD reduction process approximates first order kinetics with respect to COD concentration. As the values for this study were of the same order of magnitude with respect to COD concentrations as reported by Laowansiri et al. (2005; 2006) and Lee et al. (2017), whereas Tunit et al. (2014) found second order kinetics. A probable explanation for these contradictory observations is that the rate limiting step in the reduction of COD may be due to the different experimental conditions studied.

2. Wastewater treatment of chicken slaughterhouse

Table 3 shows the average wastewater treatment of chicken slaughterhouse at 30 days. The COD and color removal efficiencies increased with increase in COD concentration of the slaughterhouse wastewater and incubation time. The maximum COD removal efficiency was 90.40% with the 1600 mg COD/l. The COD removal at 30 days, significant statistical differences (P<0.05) for COD concentrations of 400, 800, 1200 and 1600 mg/l were 87.57, 88.75, 89.93 and 90.40%, respectively. The reduction COD of slaughterhouse wastewater has also been reported and is well suitable for the anaerobic treatment process (Tritt, 1992; Ruiz et al., 1997; Caixeta et al., 2002; Loganath & Mazumder, 2018)

The results obtained in this work indicated that the increase in color removal was observed with an increase in the COD concentrations of chicken slaughterhouse wastewater. It is notable that the highest color removal efficiency with COD of 1600 mg/l was 48.96%. The color removal at 30 days, significant statistical differences (p<0.05) for COD concentrations of 400, 800, 1200 and 1600 mg/l were 12.59, 15.29, 18.66 and 48.96%, respectively. The reduction of color has been reported and this preference may be explained by anaerobic degradation (Carliell et al., 1995; Laowansiri et al., 2008; Laowansiri & Tharasena, 2018).

The MLSS increased with increases in COD concentrations of chicken slaughterhouse wastewater at 30 day (Table 3). The results obtained show a gradual increase of bacteria growth were 3509, 3808, 4149 and 3950 mg/l with COD concentrations of 400, 800, 1200 and 1600 mg/l, respectively. The MLSS was significantly different (p<0.05) in various COD concentrations (400, 800, 1200 and 1600 mg/l).

Table 3 The average wastewater treatment of chicken slaughterhouse at 30 days

Parameters	COD concentrations of chicken slaughterhouse wastewater (mg/l)			
	400	800	1200	1600
COD (mg/l)	49.8±1.1[d]	90.0±2.8[c]	120.9±3.4[b]	153.6±4.8[a]
COD removal (%)	87.57±0.26[c]	88.75±0.35[b]	89.93±0.28[a]	90.40±0.30[a]
Color (SU)	31.10±0.14[d]	33.70±0.28[c]	59.50±0.71[b]	67.35±0.49[a]
Color removal (%)	12.59±0.40[d]	15.29±0.71[c]	18.66±0.96[b]	48.96±0.37[a]
MLSS (mg/l)	3509±1.4[d]	3808±5.6[c]	4149±4.2[a]	3950±1.4[b]
pH	7.10±0.00[a]	7.15±0.07[a]	7.15±0.07[a]	7.15±0.07[a]
Temperature (°C)	24.25±0.07[a]	23.55±0.07[b]	23.00±0.00[c]	23.00±0.00[c]
Biogas production (ml)	149.0±1.4[c]	147.0±1.4[c]	207.5±0.7[b]	267.0±0.0[a]
Methane content (%)	30.35±0.0[d]	45.49±1.4[c]	55.69±0.1[b]	64.03±2.1[a]
Methane yield (ml)	45.23±0.43[d]	66.87±1.44[c]	115.56±0.69[b]	170.97±5.67[a]

Remark: a, b, c, d with difference letter in row show significant statistical difference (p<0.05)

The pH values of chicken slaughterhouse wastewater treatment at 30 days with various COD concentrations showed in the range of 400 - 1600 mg/l remained through the operation about 7.10 - 7.15, which is suitable for methanogenic bacteria growth and methane production. In addition, the temperature is an important factor to consider in anaerobic wastewater treatment. In the present study, it was found that the temperature of anaerobic treatment processes of chicken slaughterhouse wastewater at 30 days in all bottles with different COD concentrations (400 - 1600 mg/l) was observed in the range between 23.00 - 24.25 ºC, which is the optimum temperature for mesophilic bacteria growth (Langenhoff & Stuckey, 2000).

The variations of biogas production and methane content were evaluated under different COD concentrations (400, 800, 1200 and 1600 mg/l). According to Table 2, the increase in biogas production and methane content correlates with an increase in COD concentration of the slaughterhouse wastewater and incubation time. It was discovered that an increase in COD concentration resulted in an increase of organic matter for anaerobic degradation of organic matter for producing biogas and methane gas (Tunit et al., 2014; Rathamuang et al., 2015). The maximum biogas production (267.0 ml) and methane content (64.03) were obtained at concentration of chicken slaughterhouse wastewater 1600 mg COD/l. Initial COD concentrations had a significant (p<0.05) effect on biogas production and CH_4 content of anaerobic chicken slaughterhouse wastewater treatment. The volumes of biogas at 30 days in effluent were 149.0, 147.0, 207.5 and 267.0 ml with different COD concentrations

of 400, 800, 1200 and 1600 mg/l, respectively. Moreover, the CH4 content at 30 days were 30.35, 45.49, 55.69 and 64.03% by anaerobic treatment of chicken slaughterhouse wastewater containing COD concentrations of 400, 800, 1200 and 1600 mg/l, respectively. Methane yield at 30 days were 45.23, 66.87, 115.56 and 170.97% by anaerobic treatment of chicken slaughterhouse wastewater containing COD concentrations of 400, 800, 1200 and 1600 mg/l, respectively.

Conclusion

In this present study, the resulting model is capable of predicting the decrease of COD in the anaerobic degradation of chicken slaughterhouse wastewater. The organic matter removal kinetics is shown to be dependent on applied organic concentration. The anaerobic treatment reaction of chicken slaughterhouse wastewater appeared to be close to first order kinetic model in COD concentrations of 800, 1200 and 1600 mg/l, while second order kinetics model seemed to describe the substrate removal for COD concentration of 400 mg/l. The COD and color removals increased with increases in COD concentrations of chicken slaughterhouse wastewater. The increase of methane yield (45-170 ml) was observed to be influenced by increasing concentration of COD in anaerobic chicken slaughterhouse wastewater treatment.

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