Applied Mechanics and Materials
ISSN: 1662-7482, Vols. 773-774, pp 1173-1177
doi:10.4028/www.scientific.net/AMM.773-774.1173

Submitted: 2014-08-01
Revised: 2015-01-15
Accepted: 2015-01-18
Online: 2015-07-15

# KINETIC STUDY OF UASB AND HUASB SYSTEM IN TREATING MUNICIPAL WASTEWATER

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**Keywords:** UASB, HUASB, kinetics, Municipal, Monod, Grou second-order, first order

**Abstract.** A combined laboratory-scale system UASB-DFAF and HUASB-DFAF was operated for treating Municipal wastewater at six hydraulic retention times (HRT) of 45.08, 30.06, 22.54, 18.03, 15.03, 12.88 h. COD removal efficiency in range from 72% to 82% in UASB, while in HUASB range from 84 to 89% with decrease of HRT. There are several method have been developed to represent biodegration of municipal sewerage in a combined treatment system. The Monod, Grou second-order and first order model have been used to analyze this studies. The combined of HUASB reactor, 5.41 L working volume, followed by DFAF reactor, having a working volume 2.67L were analyzed. The kinetic parameters were determined through line regression using experimental data. The predicted COD concentration was calculated using the kinetic constant. The kinetic models applied for this study were Grou second-order, followed by first order method and Monod method.

## Introduction

Wastewater treatment using biological technology especially for up-flow anaerobic sludge blanket (UASB) reactor has been widely adopted because of easy operation and low pollution generation. A very good chemical oxygen demand (COD) removal has led to its increasing applicability in the treatment of domestic, industrial and agricultural wastewaters, [1]. Unfortunately, due to environmental issue, anaerobic reactors do not allow a nitrification process, which can be adopted with further phase of studies [2].

The improvements of UASB reactor design for treating any wastewater are now developed. Many researchers have also studied the hybrid-UASB (HUASB). HUASB reactor is a combination of up-flow anaerobic sludge blanket reactor and anaerobic filter. The lower part of the HUASB reactor consists of inoculums as sludge to developed a granular and an upper part will fill with some material to avoid biomass wash out together with effluent. It retains the advantages of both systems and is also stable and resilient to shock loadings and combines the best features of both suspended bed and fixed film technologies into one unit, with the added benefit of methane production for reuse, [4].

However, in order to eliminate N-pollution it is necessary to introduce a denitrification phase in which products of nitrification would be converted into environmentally harmless $N_2$ gas. Various sources can provide carbon for denitrification, [2]. The modification of HUASB followed by DFAF-Down flow aerobic filter consist with material such as zeolite are investigated to find the process of nitrification are works in the second phase of reactor.

The aim of this paper investigated on a feasibility of UASB and HUASB system by providing some data on the kinetic aspects of this treatment.

## Materials and Methods

A laboratory scale combination of two laboratory scale reactor Hybrid Up-Flow Anaerobic Sludge blanket (HUASB) with Down-Flow Aerobic filter (DFAF) are use in the experiment. There are two identical reactor UASB as R1 and HUASB as R2 were fabricated to give a working volume of 5.41L (9.0 cm diameter, 100 cm height), with six sampling ports placed at different heights. The wastewater used in this study was taken from wastewater treatment plant located in UTHM campus, Batu Pahat, Johor, Malaysia. All effluent samples were collected in 100 ml polyethylene bottles (PTFE) based on standard methods for examination of water and wastewater 22th edition (APHA, 2009). The wastewater was modified to increase COD value up to 1000 mg/l COD concentration by addition of 65% glucose, 25% peptone and 10% meat extract. The reactors were seeded with sludge one third of reactor collected from anaerobic pond sewerage treatment plant UTHM. Analysis of parameters such as pH, COD, TP, Ammonia Nitrogen, suspended solids (SS), and Mass liquid suspended solids (MLSS) was accomplish as per APHA standard method (APHA, 2009). Hydraulic retention time (HRT) ranging from 45 to 13 h was used under different loading rates. All experiments were performed at ambient room temperature 26±3° C. In each experimental run, performance of the reactor was evaluated under constant organic loading rate (OLR). Overall kinetic coefficients have been determined at steady-state conditions using the data sets summarized in Table 1(UASB-DFAF) and (HUASB-DFAF) in Table 2.

Table 1:Average operational parameters and steady state for R1 result during the study period

| | UASB | | | | DFAF | | | |
|---|---|---|---|---|---|---|---|---|
| (OLR) (kg CODm$^{-3}$d$^{-1}$) | COD Influent (mgL$^{-1}$) | HRT (d) | COD Effluent (UASB) (mgL$^{-1}$) | COD Removal efficiency (%) | HRT (d) | COD Effluent (DFAF) (mgL$^{-1}$) | COD Removal efficiency (%) | pH |
| 0.53 | 1045±44 | 1.88 | 202±140 | 80 | 0.93 | 137±91 | 86.89 | 6.83±0.56 |
| 0.80 | 991±43 | 1.25 | 272±167 | 73 | 0.46 | 161±100 | 83.75 | 7.24±0.37 |
| 1.06 | 1047±61 | 0.94 | 298±154 | 72 | 0.31 | 162±77 | 84.53 | 7.09±0.38 |
| 1.33 | 1045±51 | 0.75 | 277±136 | 73 | 0.23 | 168±96 | 83.93 | 7.29±0.38 |
| 1.60 | 995±0 | 0.63 | 182±119 | 82 | 0.19 | 122±105 | 87.74 | 6.95±0.29 |
| 1.86 | 1010±0 | 0.54 | 233±130 | 77 | 0.15 | 131±81 | 87.03 | 7.14±0.11 |

Table 2:Average operational parameters and steady state for R2 result during the study period

| | HUASB | | | | DFAF | | | |
|---|---|---|---|---|---|---|---|---|
| (OLR) (kg CODm$^{-3}$d$^{-1}$) | COD Influent (mgL$^{-1}$) | HRT (d) | COD Effluent (UASB) (mgL$^{-1}$) | COD Removal efficiency (%) | HRT (d) | COD Effluent (DFAF) (mgL$^{-1}$) | COD Removal efficiency (%) | pH |
| 0.53 | 1039±45 | 1.88 | 132±46 | 87 | 0.93 | 58±25 | 94.38 | 7.29±0.59 |
| 0.80 | 1033±39 | 1.25 | 115±19 | 89 | 0.46 | 43±23 | 95.57 | 7.21±0.64 |
| 1.06 | 962±40 | 0.94 | 159±65 | 84 | 0.31 | 53±28 | 95.11 | 7.49±0.19 |
| 1.33 | 1066±47 | 0.75 | 120±37 | 89 | 0.23 | 56±20 | 93.99 | 7.32±0.47 |
| 1.60 | 1037±48 | 0.63 | 155±63 | 85 | 0.19 | 47±32 | 95.37 | 7.10±0.47 |
| 1.86 | 1016±47 | 0.54 | 133±44 | 87 | 0.15 | 58±25 | 94.38 | 7.29±0.59 |

### *Applied Monod Kinetics*

For UASB and HUASB reactor without biomass recycles the rate of change of biomass and substrate in the system can be expressed as equation. (1) and (2)

$$\frac{d_x}{d_t} = \frac{Q.X_i}{V} - \frac{Q.X_u}{V} + \mu.X - K_d.X \quad (1)$$

$$-\frac{d_s}{d_t} = \frac{Q.S_i}{V} - \frac{Q.S_e}{V} + \frac{\mu.X}{Y} \tag{2}$$

The ratio of the total biomass in the reactor to biomass in the average time called as mean cell-residence time ($\Theta_c$) and calculated from equation (3)

$$\Theta_c = \frac{V.X}{Q.X_e} \tag{3}$$

The relationship between specific growth rate and rate limiting substrate concentration can be expressed by Monod equation (4) as follow:

$$\mu = \frac{\mu_{max} - S_e}{K_s + S_e} \tag{4}$$

Assumins the concentration of biomass in the influent can be neglected at steady state conditions ($d_x/d_t = 0$ and $-d_s/d_t = 0$ and HRT ($\Theta$) is defined as the volume of the reactor divided by the flow rate of influent, equation (5) and (6) are derived from substituting from equation (3) and (4) into equation (1) and (2).

$$\mu = \frac{1}{\Theta_c} + K_d \tag{5}$$

$$\frac{\mu_{max}.S_e}{K_s + S_e} = \frac{1}{\Theta_c} + K_d \tag{6}$$

Kinetic parameters Y and $K_d$ for Monod model can obtained by rearranging and linearization of the equation as shown in equation (7), [3].

$$\frac{S_i - S_e}{\Theta.X} = \frac{1}{Y}.\left(\frac{1}{\Theta_c}\right) + \frac{1}{Y}.K_d \tag{7}$$

The value of μmax and KS could be determined by plotting Eq. (8), which was derived by rearranging Eq. (6).

$$\frac{\Theta_c}{1+\Theta_c.K_d} = \frac{K_s}{\mu_{max}}.\frac{1}{S} + \frac{1}{\mu_{max}} \tag{8}$$

***Grou second-order Model***

General equation of second order kinetic model is shown in equation (9), [1].

$$-\frac{d_s}{d_t} = K_s.X.\left(\frac{S_e}{S_i}\right)^2 \tag{9}$$

If Eq. (9) is integrated (boundry condition: $S=S_o$ to $S_e$ and t = 0 ot Θ) and then linearilized Eq. (10) will be obtained:

$$\frac{S_i.\Theta}{S_i - S_e} = \Theta - \frac{S_i}{K_s.X} \tag{10}$$

If the second term of the right part of equation (10) is accepted as a constant, the equation (11) will be obtained,

$$\frac{S_i.\Theta}{S_i - S_e} = b.\Theta + a \tag{11}$$

$(S_i - S_e)/S_i$ expresses the substrate removal efficiency and is symbolized as *E*. Therefore, the last equation can be written as follows:

$$\frac{\Theta}{E} = a + b.\Theta \tag{12}$$

***First order method***

The rate of change in substrate concentration in the system with assuming the first order model for substrate removal could be expressed as follows:

$$\frac{d_s}{d_t} = \frac{Q.S_i}{V} - \frac{Q.S_e}{V} - K.S \quad (13)$$

Under steady-state conditions, the rate of change in substrate concentration (−dS/dt) is negligible and the equation given above can be reduced to the equation (14):

$$\frac{S_i - S_e}{\theta} = K.S \quad (14)$$

**Result and Discussion**

In order to estimate the functional of kinetic coefficients for the model indicated, analysis has been carried out with the results obtained from the present study as well as in order to obtain overall kinetic coefficients for the models, analyses have been carried out with the results obtained from the present study at steady-state conditions (Table 1). The kinetic coefficients thus obtained from experiments on UASB and HUASB reactor under different operating conditions offer a meaningful comparison and greater insight into applicability of the kinetic models in designing UASB reactors.

**Monod method**

The experimental data under steady-state condition were used and kinetic parameters are evaluated using linear expressions. Six steady state were used to determine the kinetic value. Figure 1 was plotted from Eq. 7 to find the values of Y and $K_d$ for monod, where Y and kd were calculated from intercept and slope of the straight line. Y value is 0.00869g VSS/g COD and $K_d$ value is 0.0037 per day. The value of $\mu_{max}$ and $K_s$ were determined from figure 2 using Eq. 8 as 0.007 per day and 60 mg/l, respectively.

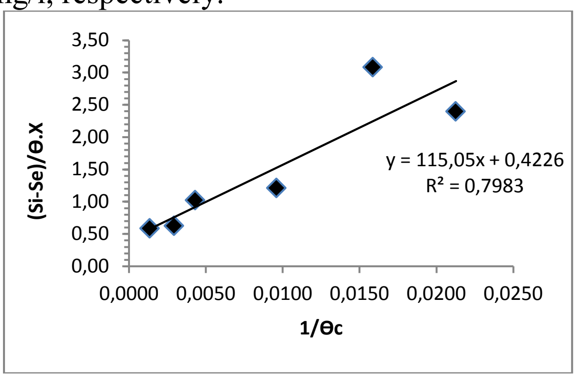


Figure 1: Determination coefficients of Y, $K_d$ in Monod model

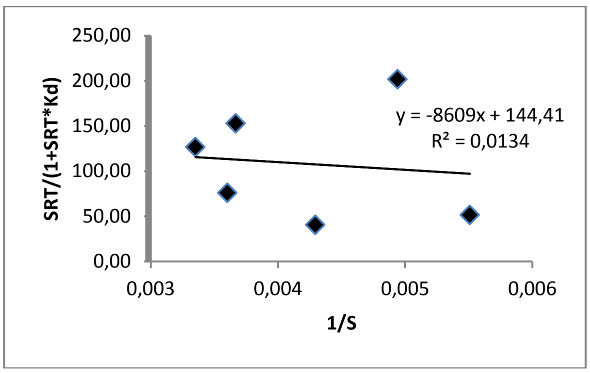


Figure 2: Determination of max specific growth rate ($\mu_{max}$) and half saturation constant ($K_s$) for monod

**Grou second-order Model & first order Model**

Figure 3 shown a plotted graf for Grou second oder to determined a kinetic coefficients (a, b and $K_s$). The value of a, b and $K_s$ calculated from the intercept and slope of straight line on graph. The value of a and b were found to be 0.071 and 1.242 with high correlation of ($R^2$) 0.985. value of $K_s$ was calculated from Eq. a=So/Ks.X as 0.257 per day. In figure 4 shown a resulted of first order model, value of $k_1$ was obtained from slope of the line by plotting (So-S)/HRT versus S in Eq. (14), it was calculated as 0.507 per day for $k_1$with correlation of 0.971.

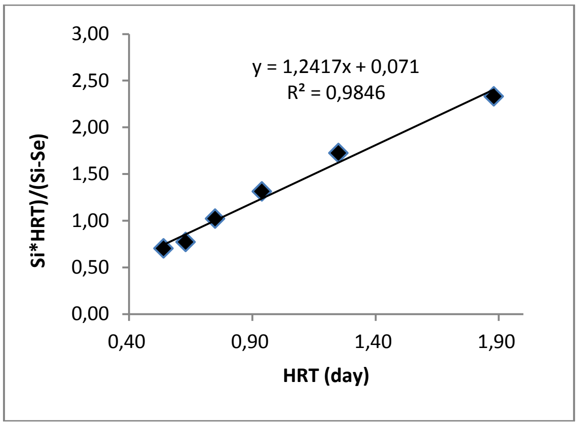


Figure 3: Determination of kinetic constatnt (a,b and $K_s$) for Grou second-order Model

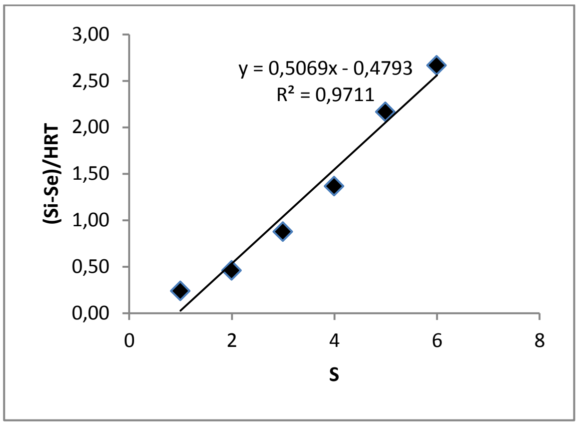


Figure 4: Model Plot of first order removal method to obtain $K_1$

**Summary**

In this study the kinetic 0f UASB and HUASB reactor trating wastewater with COD range of 900-1100 mgL$^{-1}$ has been anlyzed using Monod, Grau and first order model. The result of analysis indicated that Grau second order model was most suitable for estimation of kinetic coefficients in UASB and HUASB with values of correlation 0.985. The values of first order model also shown the best correlation coefficients 0.971. Monod model are in good agreement with kinetic coefficient values as reported in the literature but its need to undatake nonlinear regression technique using different error function in determination kinetic coefficent.

**Nomenclature**

Q = Influent Discharge to Reactor
V = Reactor Volume
$S_i$ = Influent substrates concentration (g COD/L)
$S_e$ = Effluent substrates concentration (g COD/L)
X = total biomass concentration in reactor (g VSS/L)
$X_i$ = Influent biomass concentration (g VSS/L)
$X_e$ = Influent biomass concentration (g VSS/L)
Y = yielding Coefficient (g VSS/g COD)
$K_d$ = endogenous decay coefficient (d$^{-1}$)
μ = specific growth rate (d-1)
$\mu_{max}$ = maximum specific growth rate (d$^{-1}$)
$K_s$ = half-velocity constant (g COD/L)
K = maximum substrate consumption rate per microorganism mass (g COD/g VSS.d)
Θ = hydraulic retention time (d)
$\Theta_c$ = solids retention time (d)

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