

Dynamic Performance of UASB Reactor Treating Municipal Wastewater

Vidya Singh^{*1}, R. P. Singh² and N. D. Pandey¹

¹Department of Chemistry, M.N.N.I.T Allahabad -211004, U.P, India

²Department of Civil Engineering, M.N.N.I.T Allahabad -211004, U.P, India

ARTICLE INFO

Received 16 Jan. 2016

Received in revised form 08 Feb. 2016

Accepted 12 Feb. 2016

Keywords: CSTR model,
Dynamic, MATLAB,
Performance,
Biomass

Corresponding author: Department of
Chemistry, M.N.N.I.T Allahabad -
211004, U.P, India

E-mail address:
vidyasingh005@gmail.com

ABSTRACT

The simultaneous dynamic equations for substrate and biomass mass were used to assess the UASB reactor performance of municipal wastewater. The dynamic model equations were solved by using a m.file in MATLAB2011a command window and dynamic equations for substrate and biomass. The objectives of this paper are (1) To develop a simple CSTR model for simulation of UASB reactors performance assuming the flow regime in UASB reactor as CSTR (2) To evaluate the dynamic performances of UASB reactor treating municipal wastewater using the experimental results of Álveraz et al. 2008.

© 2016 International Journal of Applied Science-Research and Review.
All rights reserved

INTRODUCTION

To date, a large number of experimental studies have been conducted at laboratory, pilot plants and full scale levels to study the treatability of a variety of wastes using UASB reactor. However, very few of these have been subjected to mathematical modelling and simulation. Most of the simulation efforts made so far have been concentrated towards the simplest type of effluents such as acetic acid or mixed volatile fatty acids (mixture of acetic, propionic and butyric acids) or lumping of all the volatile fatty acids into equivalent acetic acids. Also, little attention has been paid towards the simulation of industrial effluents of complex nature. Little or no efforts are made till date to model the performance of UASB reactors treating low strength or municipal wastewaters, where granulation is difficult or achieved after a

prolonged start-up (Lettinga 1991)¹⁰. It is imperative that data pertaining to UASB reactor should be modeled so that a better insight can be obtained into the performance of UASB reactors treating low strength wastewaters. A low-strength wastewater such as municipal wastewater or domestic wastewater sewage has COD concentration in the range of 500-1000 mg/L. UASB reactor has been worldwide applied recently for treatment of low strength wastewaters during past 2 to 3 decades (Ligero and Soto 2002; Álveraz et al. 2006; Álveraz et al. 2008; Das and Chaudhari 2009; Turkdogan-Aydinol et al. 2011; EL-Seddek et al. 2013; Bhatti et al. 2014; Lohani et al. 2015)^{2,3,4,5,6,9,11,14}. Several attempts have been made in the recent past to the accelerate the granulation phenomenon in treatment of low strength

wastewaters (Jeong et al. 2005; Sondhi et al. 2010)^{7,13}. Some excellent experimental works on acceleration of the start-up period in treatment of low strength wastewater by UASB reactor are well reported in the literature (Jeong et al. 2005)⁷. But, there are little efforts made towards the modelling and assessment of dynamic performances of UASB reactor treating low strength wastewaters (Agrawal et al. 1997; Singh and Viraraghavan 1998; Kalyuzhnyi et al. 2006; Álveraz et al. 2008; Turkdogan-Aydinol et al. 2011)^{1,3,8,12,14}.

Based on the above mention facts, the main objectives of the present paper are: (1) to evaluate the kinetic constants for UASB reactor treating low strength wastewaters idealizing flow regime of UASB reactor as CSTR. (2) to evaluate the dynamic performance of the UASB reactor treating low strength wastewaters using Monod kinetics for microbial growth and MATLAB2011a, ode15s tool. The present paper is devoted to explore the suitability of using a simple CSTR model for evaluating the dynamic performance of UASB reactor treating municipal wastewater. Depending upon the idealization of UASB reactor as a single CSTR, the dynamic state model equations available in the literature. In case of treatment of low strength wastewaters (Álveraz et al. 2008)³ where the stoichiometric relationships are not very clearly known/available from literature, the simple model equations are derived for effluent waste COD and biomass concentrations. Determination of kinetic constants for low strength wastewater treatment in UASB reactor is necessary to predict the dynamic performances of the UASB system. Therefore, the kinetic constants (k , K_s , μ_{max} , Y and K_d) were determined using experimental results of (Álveraz et al. 2008)³ treating municipal wastewater in UASB reactor.

MATERIAL AND METHODS

The simultaneous dynamic equations for substrate and biomass were solved to assess the UASB reactor performance. The dynamic model equations were solved by developing a m.file in MATLAB2011a command window and writing the dynamic equations for substrate and biomass. Then, the experimental results of

(Álveraz et al. 2008)³ were entered into Microsoft Excel Sheet and the file was imported by 'xlsread' tool in MATLAB2011a. By using the initial conditions and the kinetic constants were programmed in m.file in MATLAB2011a. Programmed file, Excel sheet and equations of substrate and biomass m.file must be present in the same path of the system. Programmed m.file was then run by using ode15s tool of MATLAB2011a and the solutions were obtained in command window of MATLAB2011a.

RESULTS AND DISCUSSION

Determination of kinetic parameters

In order to proceed with the simulation of UASB reactor performance data, it is necessary to evaluate the kinetic constants, i.e., maximum substrate utilization rate (k) and half saturation constant (K_s), biomass yield coefficient (Y) and decay coefficient (K_d). On the basis of the principles of ideal CSTR assumption without sludge recycle ($HRT = SRT$) and the following linear expressions can be obtained to evaluate the kinetic constants and re-written as (Metcalf and Eddy 1997).

$$\frac{\theta \cdot X_e}{(S_o - S_e)} = \frac{K_s}{k} \cdot \frac{1}{S_e} + \frac{1}{k} \quad (1)$$

$$\frac{(S_o - S_e)}{X_e} = \frac{K_d}{Y} \cdot \theta + \frac{1}{Y} \quad (2)$$

Where, θ is the hydraulic retention time (d) and SRT is the solid retention time (d). Using linear regression of the experimental data and using Eqs. (1) and (2), the kinetic parameters are determined. Further the kinetic constants were evaluated using the experimental results of (Álveraz et al. 2008)³ for the treatment of domestic wastewater at five different HRTs (0.962, 0.579, 0.27, 0.380 and 0.48 days) for 140 days of the operation period in a pilot scale UASB reactor. The linear fitting of Eq. (1) and (2) are shown in figures 1 and 2 respectively.

Evaluation of dynamic performance using experimental results of Álveraz et al. 2008

Using the experimental results of (Álveraz et al. 2008)³ on treatment of municipal

wastewater for a transient period of 33 days, the dynamic equations were solved simultaneously by using MATLAB2011a, ode15s for prediction of effluent soluble COD concentration (S_e) and effluent biomass concentration (X_e) with time interval of 5 days.

Experimental effluent COD concentration is in the dynamic period shows some deviation due to continuously increasing COD loading rate from 0.2 g COD/L.d to 0.7 g COD/L.d in the UASB reactor. The percentage error in predicted and experimental effluent COD concentrations (S_e) are also computed and presented in table 1, which varies from 0.75% to 22.17%. Comparison of predicted effluent soluble COD concentration and Experimental effluent soluble COD concentration with operation time was shown in figure 3.

Variation of calculated % COD removal and Experimental % COD removal with operation time was shown in figure 4.

After 5 days of operation predicted effluent biomass concentrations was observed fluctuating in nature. The percentage error in predicted and experimental effluent biomass concentrations (X_e) are also computed and presented in table 2, which varies from 0.775 % to 21.63 %. Comparison of predicted effluent biomass and Experimental effluent biomass concentrations with operation time was shown in figure 5.

Statistical error estimates are determined to evaluate the goodness of fit using SR, SSE, SEE, S.D and RMSE. These statistical error estimates in experimental, predicted data of effluent COD concentration and between experimental, predicted data of effluent biomass concentration during dynamic phase are presented below in Table 3.

From Table 3, Sum of residuals (SR) was determined for the predicted effluent COD and predicted effluent biomass concentrations and SR values were found as 2.58×10^{-2} and 2.09×10^{-2} respectively. From SR values, it is evident that predicted effluent COD and effluent biomass concentrations shows less variance hence, better fitting in the data points. Sum of square error (SSE) was determined for for the predicted effluent COD and predicted effluent biomass concentrations and SSE values were found as 1.85×10^{-3} and 3.19×10^{-5} respectively. From SSE values, it is evident that the data points show

less amount of error in predicted biomass concentration, linear fitting of data points is observed better than predicted soluble COD concentration. Sum of error estimate (SEE) was determined for predicted effluent COD and predicted effluent biomass concentrations and SEE values were computed as 2.48×10^{-2} , 1.03×10^{-2} respectively. From SEE values, it is evident that SEE values for predicted effluent COD and predicted effluent biomass concentrations are less indicating that small discrepancy in predicted data points and better linear fitting is observed. Standard deviation was determined for predicted effluent COD and predicted effluent biomass concentration and S.D values were found as 1.58×10^{-2} and 3.65×10^{-3} respectively. From S.D values, it is evident that deviation from mean for effluent COD and effluent biomass concentration deviation from mean values are relatively less, hence the data points are close to the mean values. Root mean square error (RMSE) was determined for predicted effluent COD and predicted biomass concentrations and RMSE values were found as 1.86×10^{-2} and 7.15×10^{-3} respectively. RMSE values are less for predicted effluent COD and effluent biomass concentration which shows that the predicted effluent COD and effluent biomass concentration are well coincident to the observed values and resulting into less average magnitude of errors.

A comparison between experimental and predicted data of effluent COD concentrations during dynamic period are shown in figure 6.

Values of predicted and experimental effluent soluble COD concentrations were close to each other and percentage error between the concentration values is 23%. A comparison between experimental and predicted data of effluent biomass concentrations during dynamic period are shown in figure 7.

Values of predicted and experimental effluent soluble COD concentrations were close to each other and percentage error between the concentration values is 22%.

CONCLUSION

(1) A simple CSTR model for evaluation of UASB reactor performance is developed by

considering the flow regime in UASB reactor as completely stirred tank reactor (CSTR) with or without consideration of influent biomass concentrations in the influent stream. Linear equations are derived for the evaluation of kinetic constants for their use in model equations.

(2) The kinetic constants required for prediction of performances in terms of effluent COD concentration and effluent biomass concentration are evaluated and presented using experimental result of (Álvarez et al. 2008)³ treating low strength wastewater in UASB reactor.

(3) The evaluation of dynamic performance of UASB reactors treating municipal wastewater were carried out by using experimental results of (Álvarez et al. 2008)³. From the results, in general, it is concluded that a simple CSTR model is inappropriate for the evaluation of dynamic performances of UASB reactors treating municipal wastewater as the errors in predictions were obtained too large with respect to their corresponding experimental values.

(4) From case study, it is inferred that there are large amount of errors in predictions in comparison to their corresponding experimental values for both effluent COD and biomass concentrations. Therefore, a simple CSTR model is not so suitable to evaluate the performance of UASB reactor in the treatment of municipal wastewater.

REFERENCES

1. Agrawal, L. K., Harada, H. and Okui, H. (1997), "Treatment of dilute wastewater in a UASB reactor at a moderate temperature: performance aspects." *Journal of Fermentation and Bioengineering*, 83(2), 179-184.
2. Álvarez, J.A., Ruiz, I., Gómez, M., Presas, J., and Soto, M. (2006), "Start-up alternatives and performance of an UASB pilot plant treating diluted municipal wastewater at low temperature." *Bioresour. Technol.*, 10.1016/j.biortech.2005.07.033, 97(14), 1640-1649.
3. Álvarez, J. A., Armstrong, E., Gómez, M., and Soto, M., (2008), "Anaerobic treatment of low-strength municipal wastewater by a two stage pilot plant under psychrophilic conditions." *Bioresour. Technol.*, 10.1016/j.biortech.2008.01.013, 99(15), 7051-7062.
4. Bhatti, Z. A., Maqbool, F., Malik, A. H., and Mehmood, Q., (2014), "UASB reactor start-up for the treatment of municipal wastewater followed by advance oxidation process." *Brazilian Journal of Chemical Engineering*, 10.1590/0104-6632.20140313s00002786, 31(3), 715-726.
5. Das, S., and Choudhari, S., (2009), "Improved in biomass characterization and degradation efficiency in modified UASB reactor treating municipal sewage: a comparative study with UASB reactor." *Asia-Pac. J. Chem. Eng.*, 10.1002/apj.298, 4(5), 596-601.
6. El-Seddek, M. M., Galal, M. M., Radwan, A. G., and Abdel-Halim, H. S., (2013), "Influence of kinetic parameters variation on the performance of modified UASB reactor model." *IWA World Water Congress & Exhibition, Lisbon, Portugal*.
7. Jeong, H. S., Kim, Y. H., Yeom, S. H., Song, B. K., and Lee, S. I., (2005), "Facilitated UASB granule formation using organic-inorganic hybrid polymers." *Process Biochemistry*, 10.1016/j.procbio.2003.11.041, 40(1), 89-94.
8. Kalyuzhnyi, S. V., Fedorovich, V. V., and Lens, P., (2006), "Dispersion plug flow model for upflow anaerobic sludge bed reactors with focus on granular sludge dynamics," *J Ind Microbiol Biotechnol*, 10.1007/s10295-005-0217-2, 33(3), 221-237.
9. Ligeró, P., and Soto, M., (2002), "Sludge granulation during anaerobic treatment of pre hydrolysed domestic wastewater." *Water S A.*, 28(3), 307-312.
10. Lettinga, G., and Hulshoff Pol, L. W. (1991), "UASB process design for various types of wastewaters." *Water Sci. Technol.*, 24(8), 87-107.
11. Lohani, S. P., Chhetri, A., and Khanal, S. N., (2015), "A simple anaerobic system for onsite treatment of domestic wastewater." *African Journal of Environmental Science and Technology*, 9(4), 292-300.
12. Singh, K. S., and Viraraghavan, T., (1998), "Start-up and operation of UASB Reactors at 20oC for Municipal wastewater Treatment." *Journal of fermentation and Bioengineering*, 10.1016/S0922-338X(98)80014-7, 85 (6), 609-614.
13. Sondhi, A., Guha, S., Harendranath, C. S., and Singh, A., (2010), "Effect of aluminum (Al³⁺) on granulation in upflow anaerobic sludge blanket reactor treating low-strength synthetic wastewater." *Water Environ. Res.*, 82(8), 715-724.

14. Turkdogan-Aydinol F.I., Yetilmezsoy, K., Comez, S., and Bayhan, H., (2011), "Performance evaluation and kinetic modeling of the start-up of a UASB reactor treating municipal wastewater at low temperature." *Bioprocess Biosyst. Eng.*, 10.1007/s00449-010-0456-0, 34(2), 153-62.

Table 1. Percentage error between experimental and predicted data of effluent COD concentrations during dynamic phase

Time	Se (Experimental)	Se (Predicted)	%Error
0	0.132	0.131	0.757
5	0.102	0.1200	17.668
10	0.11	0.1264	14.916
15	0.126	0.1194	5.162
20	0.085	0.0911	7.271
25	0.07	0.0813	16.221
30	0.092	0.1123	22.172

Table 2. Percentage error between experimental and predicted data of effluent biomass concentrations during dynamic phase

T	X _e (Experimental)	X _e (Predicted)	%Error
0	0.129	0.13	0.775
5	0.0452	0.0463	2.338
10	0.0671	0.0538	19.820
15	0.0467	0.0434	6.961
20	0.0502	0.0394	21.638
25	0.0219	0.0234	6.887
30	0.0204	0.0234	14.499

Table 3. Statistical error estimates between experimental, predicted effluent COD concentrations and between experimental, predicted effluent biomass concentrations during dynamic phase

Effluent concentration	SR	SSE	SEE	S.D	RMSE
S _e	2.58E-02	1.85E-03	2.48E-02	1.58E-02	1.86E-02
X _e	2.09E-02	3.19E-04	1.03E-02	3.65E-02	7.15E-03

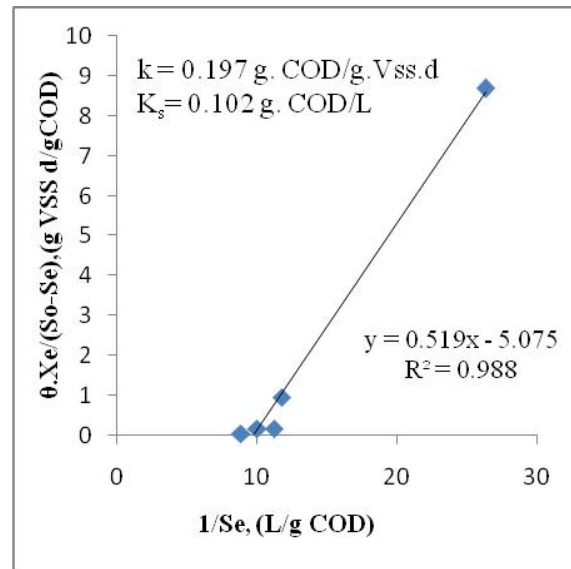


Figure 1. Determination of Maximum substrate utilisation rate (k) and half saturation constant (K_s) for Monod model

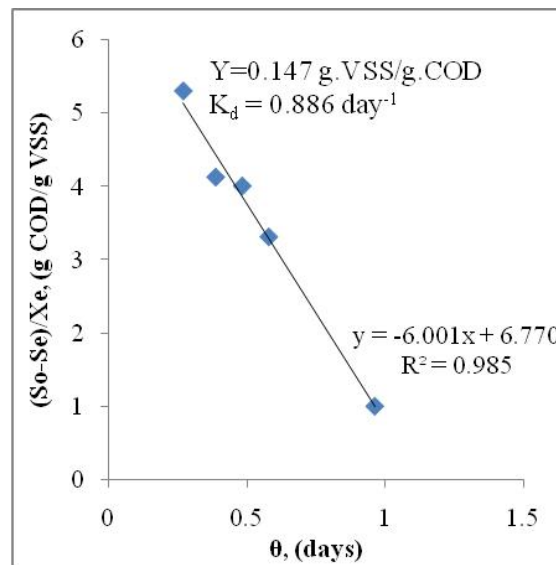


Figure 2. Determination of biomass yield coefficient (Y) and microorganism's decay coefficient (K_d) for Monod model

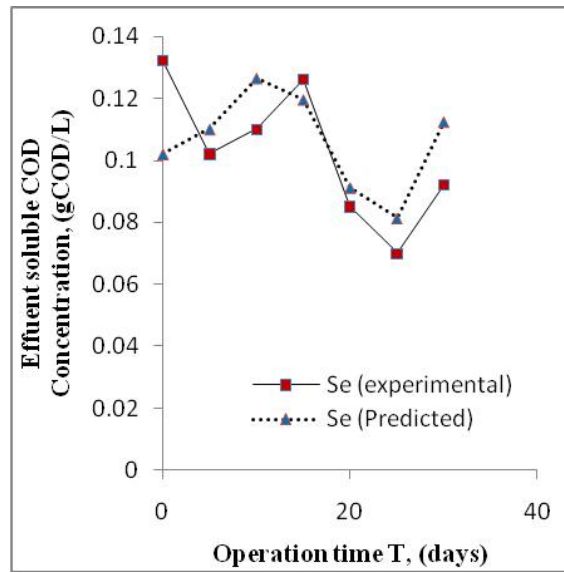


Figure 3. Agreement between the predicted effluent COD and experimental effluent COD concentrations at different operation time during dynamic phase

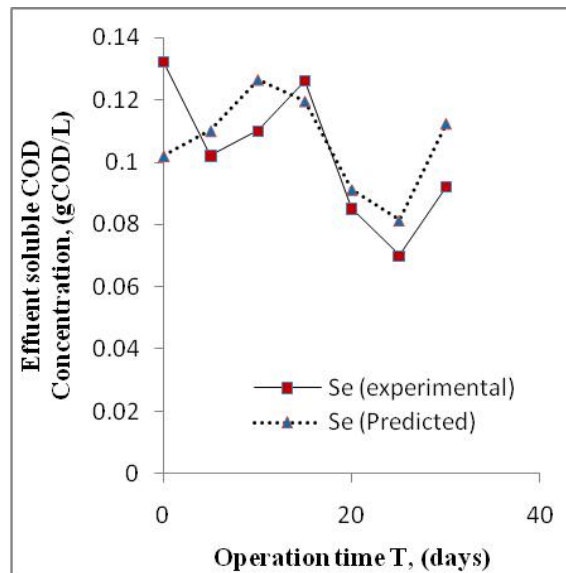


Figure 4. Agreement between the calculated % COD removal and the experimental % COD removal at different operation time during dynamic phase

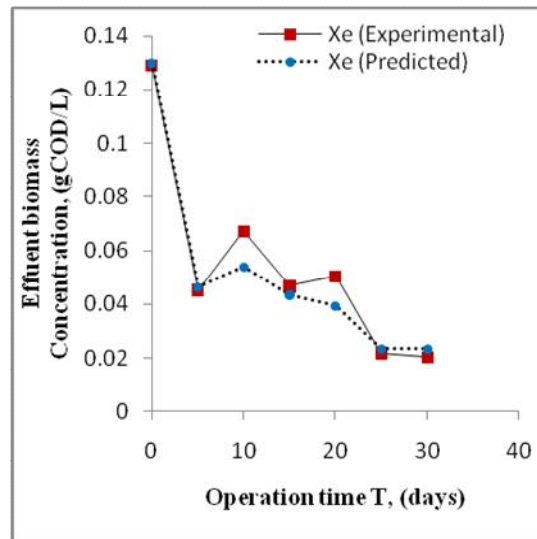


Figure 5. Agreement between the predicted effluent biomass and experimental effluent biomass concentrations at different operation time during dynamic phase

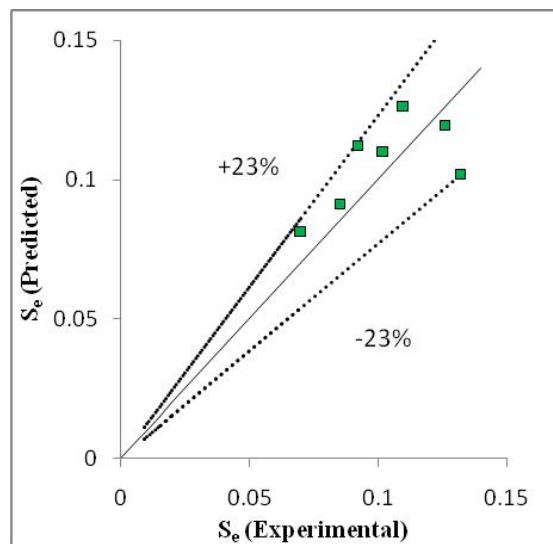


Figure 6. Comparison of experimental effluent COD concentrations with predicted COD concentrations for the dynamic period

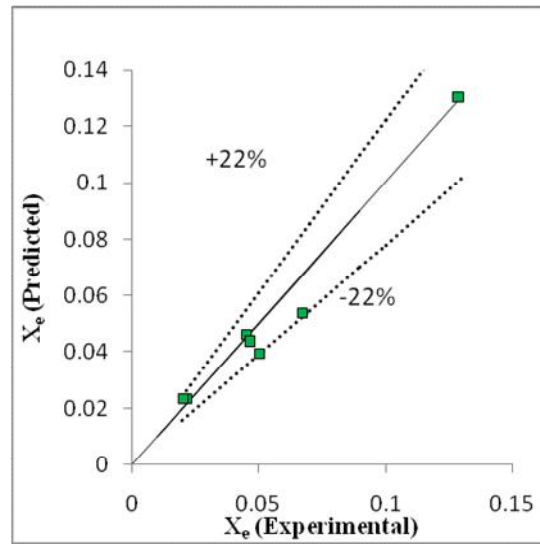


Figure 7. Comparison of experimental effluent biomass concentrations with predicted biomass concentrations for the dynamic period