[Singh* *et al.*, 5(8): August, 2016] ISSN: 2277-9655
IC™ Value: 3.00 Impact Factor: 4.116

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

DYNAMIC AND STEADY STATE PERFORMANCE OF UPFLOW ANAEROBIC SLUDGE BLANKET REACTOR

Vidya Singh*, R. P. Singh, N. D. Pandey

* Department of Chemistry, Motilal Nehru National institute of Technology, Allahabad -211004, U. P, India

Department of Civil Engineering, Motilal Nehru National institute of Technology, Allahabad -211004, U. P, India

DOI: 10.5281/zenodo.59538

ABSTRACT

The simultaneous dynamic and steady state equations for substrate and biomass mass were used to assess the upflow anaerobic sludge blanket (UASB) reactor performance of municipal wastewater. The dynamic model equations were solved by using a m.file in MATLAB2011a software and dynamic equations for substrate and biomass concentrations. The objectives of this paper are (1) To develop a simple CSTR model for performance of UASB reactors (2) To evaluate the dynamic and steady state performances of UASB reactor treating municipal wastewater using the experimental results of Álveraz et al. (2008).

KEYWORDS: Biomass, Dynamic, MATLAB, Performance, substrate concentration.

INTRODUCTION

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; Turkdogan-Aydinol et al. 2011; EL-Seddek et al. 2013; Bhatti et al. 2014; Lohani et al. 2015). Several attempts have been made in the recent past to the accelerate the granulation phenomenon in treatment of low strength wastewaters (Sondhi et al. 2010). 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. 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). 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). It is imperative that data pertaining to UASB reactor should be modelled so that a better insight can be obtained into the performance of UASB reactors treating low strength wastewaters.

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 software, 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. In case of treatment of low strength wastewaters Álveraz et al. (2008) 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 as well as performances of the UASB system. Therefore, the kinetic constants (k, Ks, $\mu_{max,}$ Y and K_d) were determined using experimental results of Álveraz et al. (2008) 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 concentrations. Then, the experimental results of Álveraz et al. (2008) 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 (Matcalf and Eddy 1997).

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

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

Further, for the steady state condition when X_o taken into account the linear expressions represented by Eqs. (1) and (3) as given below were used to evaluate the kinetic constants.

$$\frac{(X_o - X_e)}{\theta.X_e} = -Y\frac{(S_o - S_e)}{\theta.X_e} + K_d \quad (3)$$

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) 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.

ISSN: 2277-9655
Impact Factor: 4.116

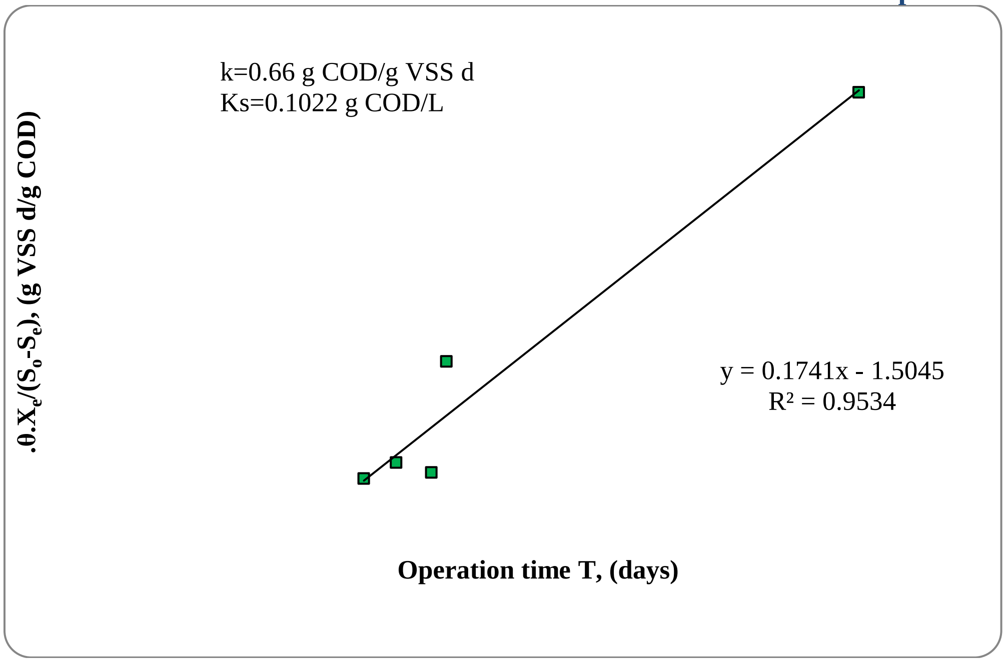

Figure 1: Determination of maximum substrate utilisation rate (k) and half saturation constant (K_s) using experimental results of Álveraz et al. (2008)

The linear fitting of Eq. (1) and (2) are shown in figures 1 and 2 respectively when X_o is negligible and the kinetic constants k, K_s, Y and K_d were determined. In the study by Álveraz et al. (2008), the influent biomass concentration X_o was monitored and reported. The kinetic constants were determined as per Eqs. (1) and (3) and the linear plots are shown in figure (1) and (3) respectively.

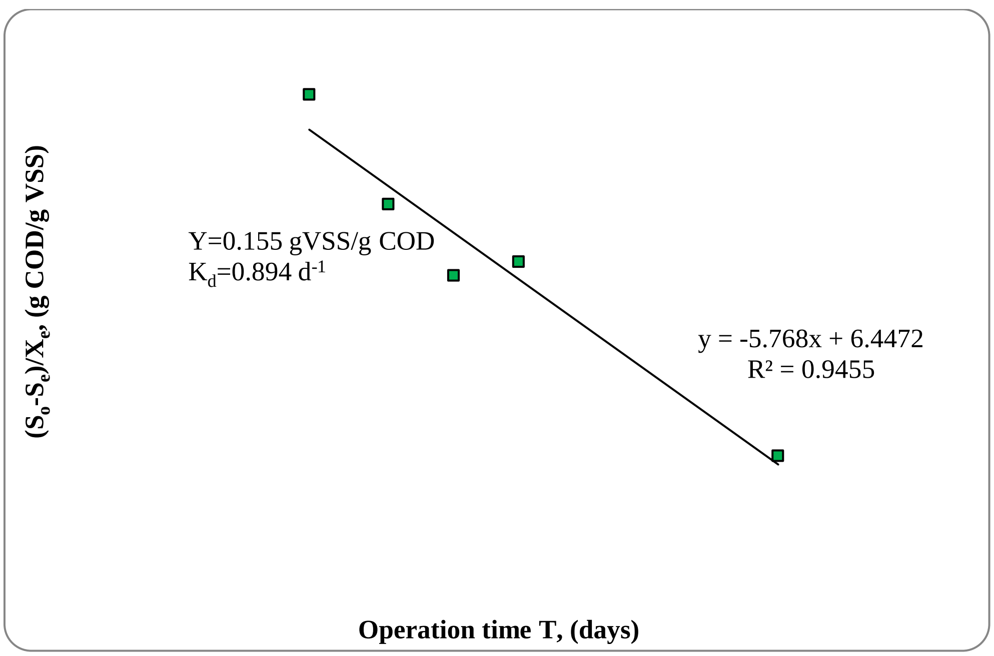

Figure 2: Determination of biomass yield coefficient (Y) and microorganism's decay coefficient (K_d), (when X_o negligible) using experimental results of Álveraz et al. (2008)

ISSN: 2277-9655
Impact Factor: 4.116

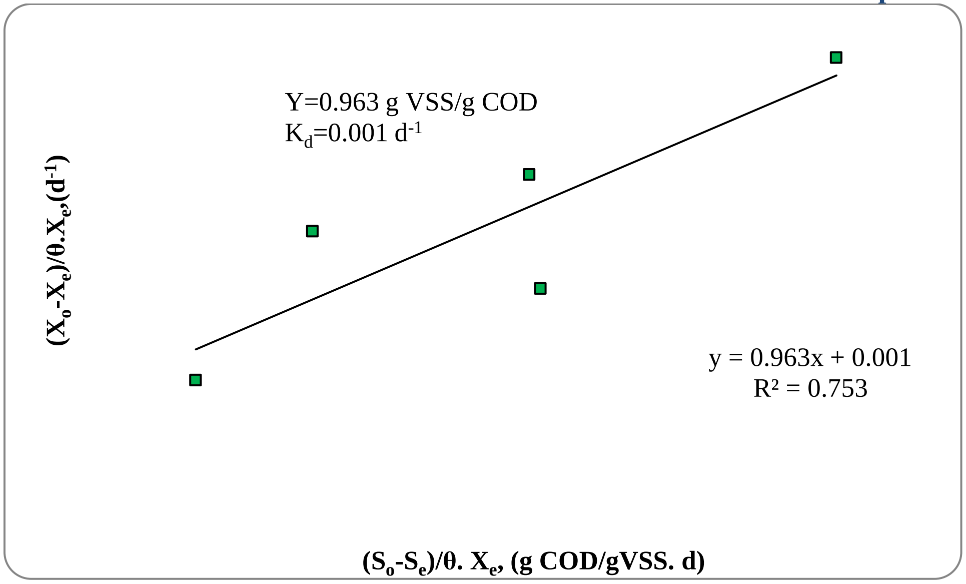

Figure 3: Determination of biomass yield coefficient (Y) and microorganism's decay coefficient (K_d), influent biomass concentration is considered using experimental results of Álveraz et al. (2008)

Evaluation of dynamic and steady state performance using experimental results of Álveraz et al. (2008) Evaluation of dynamic performance in terms of effluent COD and effluent biomass concentrations using experimental results of Álveraz et al. (2008) (X_o negligible) Using the experimental results of Álveraz et al. (2008) on treatment of the municipal wastewater for a transient period of 70 days, the dynamic equations from literature were solved simultaneously for effluent soluble COD concentration (S_e) and effluent biomass concentration (X_e) using MATLAB2011a software, ode15s tool with time step of 10 days. The results of simulation of effluent COD (Se) and effluent biomass (Xe) concentrations at 10 days intervals are presented in Table 1. The percentage error in predicted and experimental effluent COD (S_e) and effluent biomass concentrations (X_e) are also presented in table 1.

Table 1: Percentage error between experimental and predicted effluent COD and biomass concentrations during dynamic phase using experimental results of Álveraz et al. (2008) (X_o negligible)

Time	HRT	S_e (Exp.)	S_e (Pred.)	% Error	X_e (Exp.)	X_e (Pred.)	% Error
0	0.962	0.106	0.106	0	0.129	0.129	0
10	0.962	0.11	0.0715	34.95	0.067	0.081	21.5
20	0.962	0.085	0.0742	12.70	0.050	0.074	47.42
30	0.962	0.092	0.0899	2.26	0.020	0.073	257.16
40	0.579	0.085	0.0997	17.40	0.018	0.072	299.22
50	0.579	0.1	0.1388	38.81	0.018	0.086	358.19
60	0.579	0.137	0.1282	6.3	0.027	0.088	217.53
70	0.27	0.083	0.1279	54.16	0.005	0.088	1409.79

Percentage error in prediction of effluent COD and biomass concentrations varies from 2.26 % to 54.16% and 21.5% to 1409.79% respectively, which are too large and hence the dynamic predictions by simple CSTR model again fails in simulation of experimental results of Álveraz et al. (2008), when X_o is negligible. Due to this reason the statistical error estimates (MPSD, RMSE) were not computed.

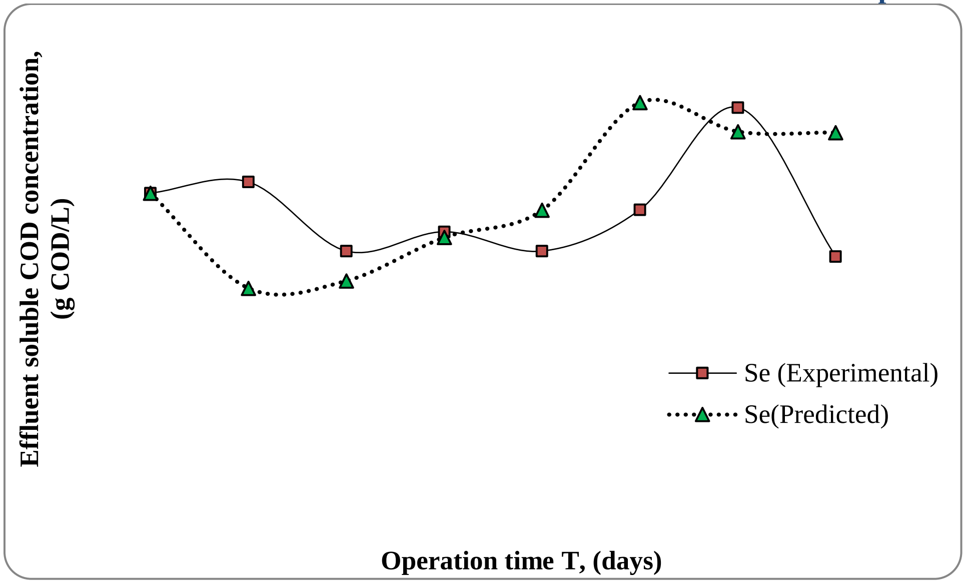

Figure 4: Agreement between the predicted effluent soluble COD and the experimental effluent COD concentrations at different operation time during dynamic phase using the experimental results of Álveraz et al. (2008) (X_o negligible)

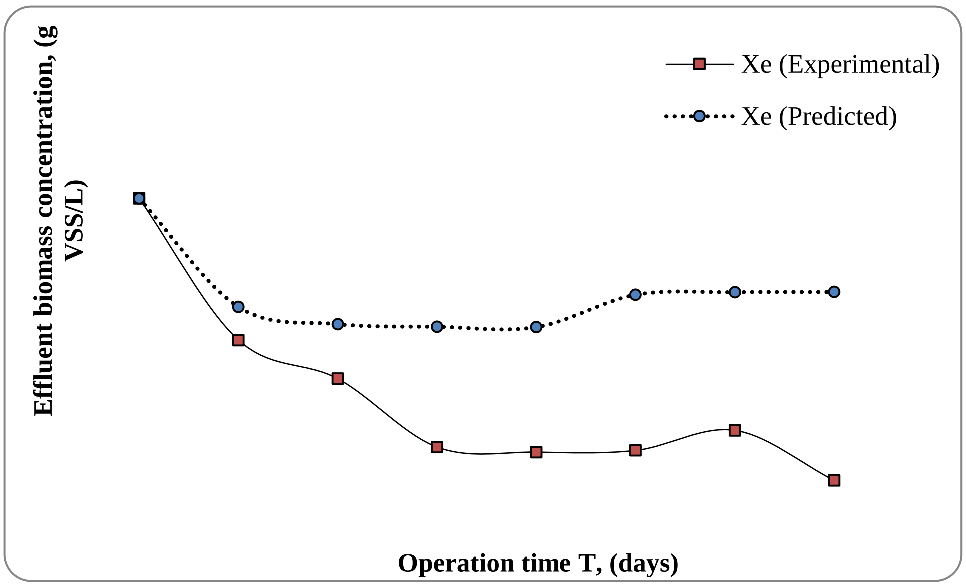

Figure 5: Agreement between the predicted effluent biomass and the experimental effluent biomass concentrations at different operation time during dynamic phase using the experimental results of Álveraz et al. (2008) (X_o negligible)

Variation of predicted effluent soluble COD concentration and experimental effluent soluble COD concentrations as a function of operation time are shown in figure 4 and that for effluent biomass concentrations is shown in figure 5. From both the figures 4 and 5, it is evident that both the predicted and experimental effluent COD and biomass concentrations do not agree well and large deviations are seen from their corresponding experimental values. Therefore, the results of simulation don't agree well with the experimental results and the application of Eqs. in simulation of dynamic performance of UASB reactor seems to be inappropriate with very limited accuracy. Therefore, dynamic simulation using simple CSTR model is not suitable to simulate effluent COD and biomass concentrations in UASB reactor in the present case also.

Evaluation of dynamic performance of effluent COD and effluent biomass concentrations using experimental results of Álveraz et al. (2008) (X_o accounted)

Using the experimental results of Álveraz et al. (2008) on treatment of the municipal wastewater for a transient period of 70 days, the dynamic equations were solved simultaneously for effluent soluble COD concentration (S_e) and effluent biomass concentration (X_e) using MATLAB2011a software, ode15s tool with time step of 10 days for the case when X_o is taken into account. The results of simulations of effluent COD (S_e) and effluent biomass (X_e) concentrations at 10 days intervals are presented in Table 2. The percentage error in predicted and experimental effluent COD (S_e) and effluent biomass concentrations (X_e) are also computed and presented in table 2. Percentage error in prediction of effluent COD and biomass varies from 9.13 % to 70.24% and 177.45% to 3285.41% respectively, which are significantly large. Therefore, the experimental results do not agree well with the correspondly predicted S_e and X_e values.

Table 2: Percentage error between experimental and predicted effluent COD and biomass concentrations during dynamic phase using experimental results of Álveraz et al. (2008) (X_o accounted)

Time	θ, (days)	S_e (Exp.)	S_e (pred.)	% Error	X_e (Exp.)	X_e (pred.)	% Error
0	0.962	0.106	0.106	0	0.129	0.129	0
10	0.962	0.11	0.061	43.81	0.067	0.186	177.45
20	0.962	0.085	0.055	34.87	0.050	0.218	334.58
30	0.962	0.092	0.033	63.97	0.020	0.232	1035.03
40	0.579	0.085	0.063	25.48	0.018	0.244	1240.24
50	0.579	0.1	0.090	9.13	0.018	0.208	996.13
60	0.579	0.137	0.174	27.03	0.027	0.200	621.57
70	0.27	0.083	0.141	70.24	0.005	0.197	3285.41

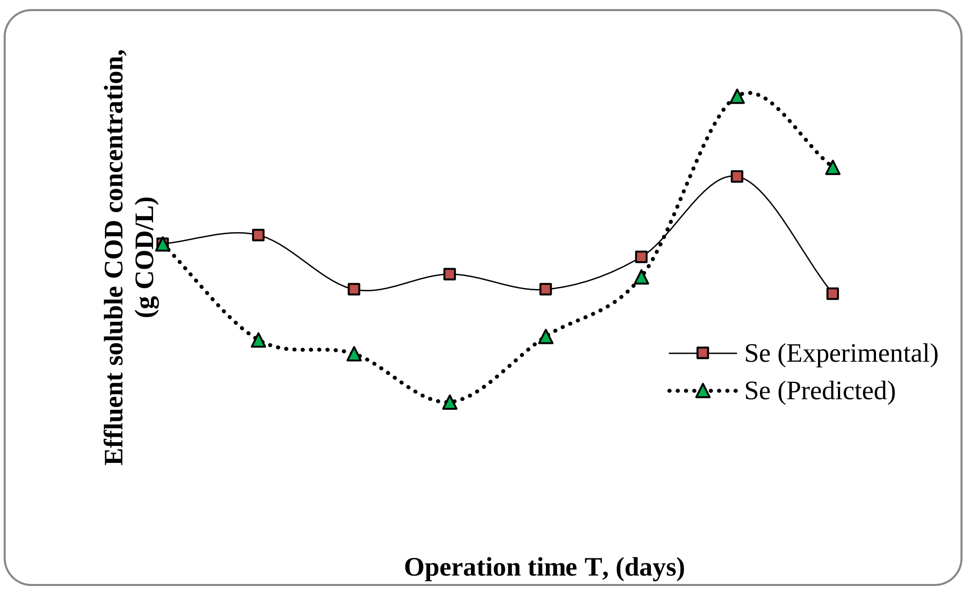

Figure 6: Agreement between the predicted effluent soluble COD and the experimental effluent COD concentrations at different operation time during dynamic phase using the experimental results of Álveraz et al. (2008) (X_o accounted)

Variation of predicted effluent soluble COD concentration (S_e) and experimental effluent soluble COD concentrations as a function of operation time are shown in figure 6 and that for effluent biomass concentrations are shown in figure 7.

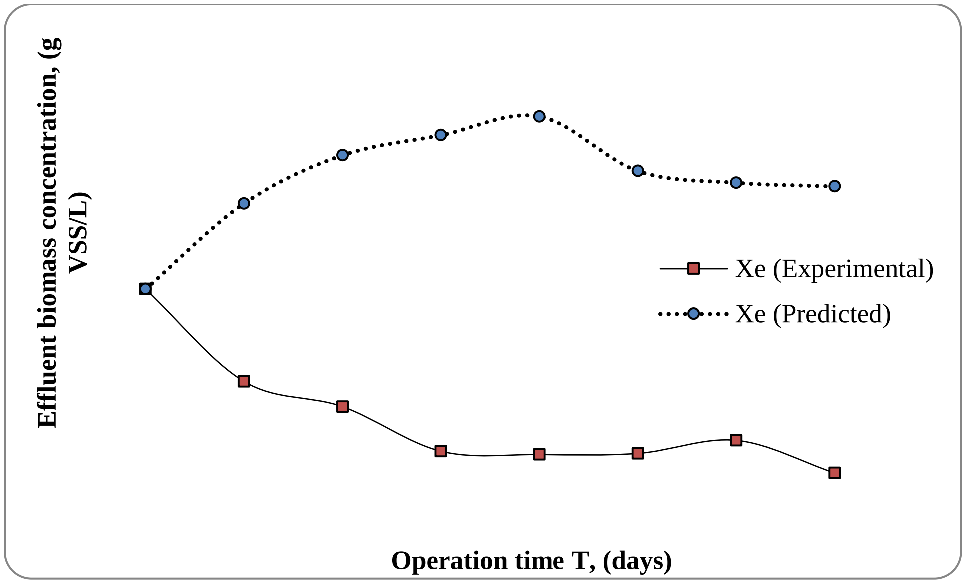

Figure 7: Agreement between the predicted effluent biomass and the experimental effluent biomass concentrations at different operation time during dynamic phase using the experimental results of Álveraz et al. (2008) (X_o accounted)

From both the figures, it is evident that predicted values are largely deviated from their corresponding experimental values and clearly demonstrate the non-suitability of simple CSTR model in the present simulation where X_o is accounted. The statistical error estimates are not computed due to large errors in predictions.

Computation of steady state performance of effluent soluble COD and biomass concentrations using experimental results of Álveraz et al. (2008) (X_o negligible)

Using the experimental results of Álveraz et al. (2008) for the steady state period of 71 to 130 days at three different HRTs (0.27, 0.387 and 0.483 days) and using steady state model Eqs. from literature, when X_o is negligible, the effluent soluble COD concentration (S_e) and effluent biomass concentration (X_e) were determined. From table 3, it can be seen that percentage error in computation of effluent COD and biomass concentrations varies from 57.74 % to 88.19% and 56.82% to 76.2% respectively, which are too large and hence the steady state computation by simple CSTR model equations again fails in computation of experimental results of Álveraz et al. (2008), when X_o is negligible. Due to this reason the statistical error estimates (MPSD, RMSE) were not computed in this case.

Table 3: Percentage error between experimental and predicted effluent COD and biomass concentrations during steady state phase using experimental results of Álveraz et al. (2008) (X_o negligible)

θ, (days)	**Operation period**	**Time at which S_e computed**	**S_e (Exp.)**	**S_e (Pred.)**	**% Error**	**X_e (Exp.)**	**X_e (Pred.)**	**% Error**
0.27	71-80	80	0.076	0.010432	86.27	0.016	0.003	76.20
0.387	81-100	90	0.089	0.010509	88.19	0.013	0.005	56.82
0.483	101-130	120	0.025	0.010565	57.74	0.006	0.002	65.39

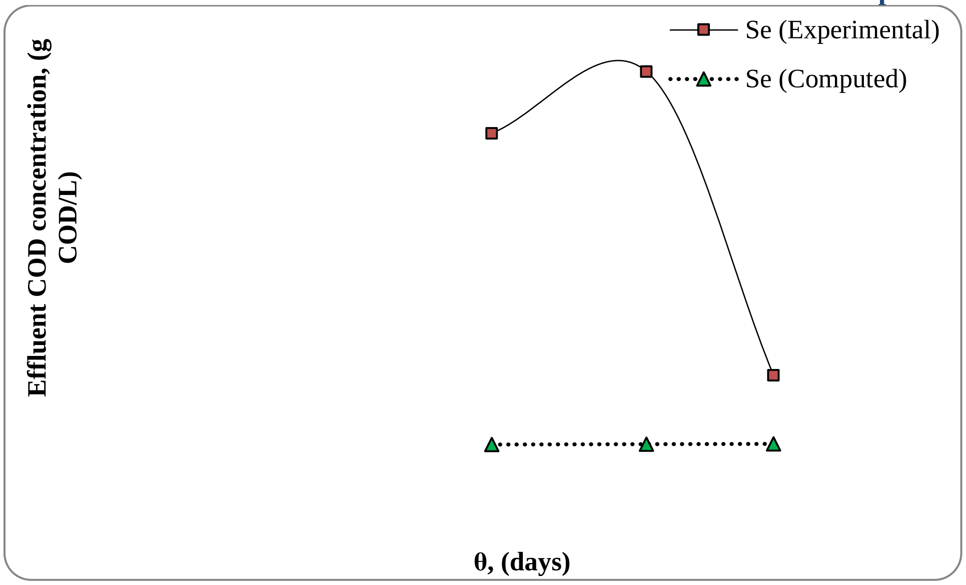

Figure 8: Agreement between the predicted effluent COD and the experimental effluent COD concentrations at different HRTs using experimental results of Álveraz et al. (2008) (X_o negligible)

Variation of computed effluent soluble COD concentration and Experimental effluent soluble COD concentrations as a function of HRT are shown in figure 8 and that for effluent biomass concentration is shown in figure 9.

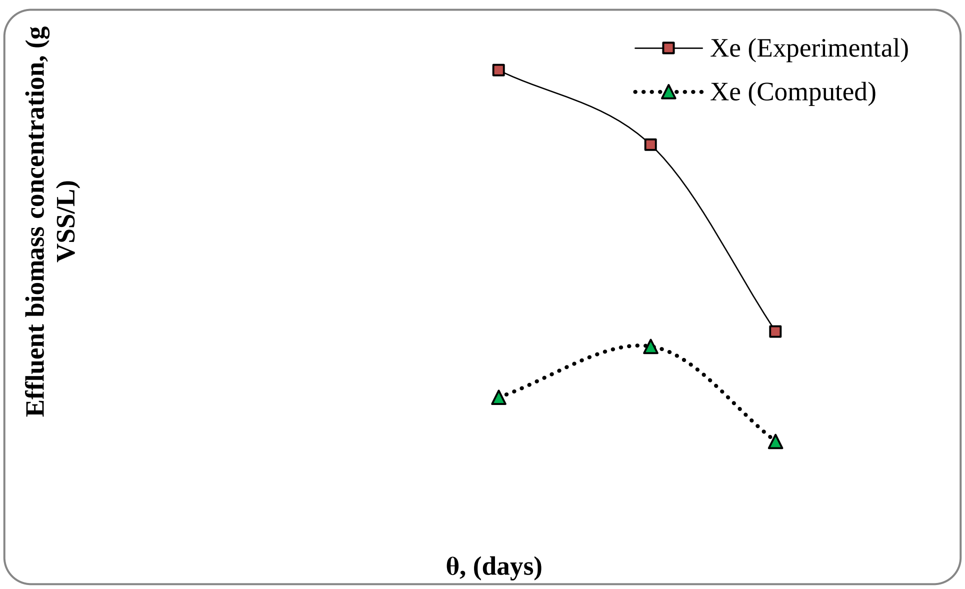

Figure 9: Agreement between the predicted effluent biomass and the experimental effluent biomass concentrations at different HRTs using experimental results of Álveraz et al. (2008) (X_o negligible)

From the figures 8 and 9, it is evident that both the computed and experimental effluent COD and biomass concentrations do not agree well and large deviations are seen in data points from their corresponding experimental values. Therefore, the computation results don't agree well with the experimental results and the application of Eqs. in computation of steady state performance of UASB reactor seems to be inappropriate. Therefore, steady state computation using simple CSTR model is not suitable to compute effluent COD and biomass concentrations in UASB reactor in the present case.

Computation of steady state performance in terms of effluent soluble COD and biomass concentrations using experimental results of Álveraz et al. (2008) (X_o accounted)

Using the experimental results of Álveraz et al. (2008) for steady state operation period of 71 to 130 days at three different HRTs (0.27, 0.387 and 0.483 days) and using steady state CSTR model Eqs., when X_o is accounted, the effluent soluble COD concentration (S_e) and effluent biomass concentration (X_e) were determined and presented in Table 4 along with percentage errors. From table 4, it can be seen that percentage error in computation of effluent COD and effluent biomass concentrations varies from as low as 1.30 % to 68.43 % and 612.46 % to 1347.0 % respectively, which are too large espacially in predictions of X_e values and hence the steady state computation by simple CSTR model again fails in validation of experimental results of Álveraz et al. (2008), when X_o is accounted. Due to this reason the statistical error estimates (MPSD, RMSE) were not computed for this case.

Table 4: Percentage error between experimental and predicted effluent COD concentrations during steady state period using experimental results of Álveraz et al. (2008) (X_o accounted)

θ, (days)	**Operation period**	**Time at which S_e computed**	**S_e (Exp.)**	**S_e (Pred.)**	**% Error**	**X_e (Exp.)**	**X_e (Pred.)**	**% Error**
0.27	71-80	80	0.076	0.076	1.309	0.016	0.119	612.46
0.387	81-100	90	0.089	0.092	4.419	0.013	0.122	786.14
0.483	101-130	120	0.025	0.007	68.43	0.006	0.095	1347.0

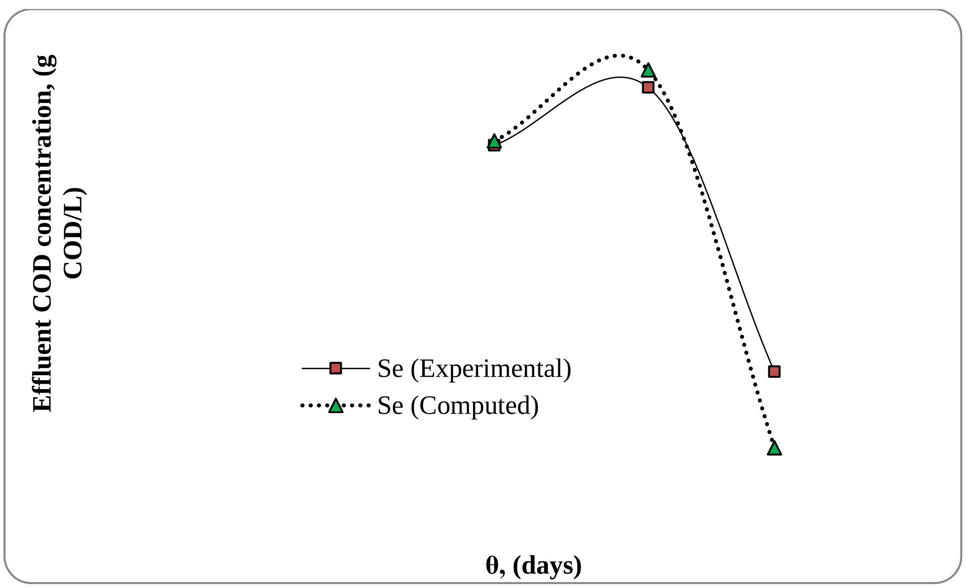

Figure 10: Agreement between the predicted effluent COD and the experimental effluent COD concentrations at different HRTs using experimental results of Álveraz et al. (2008) (X_o accounted)

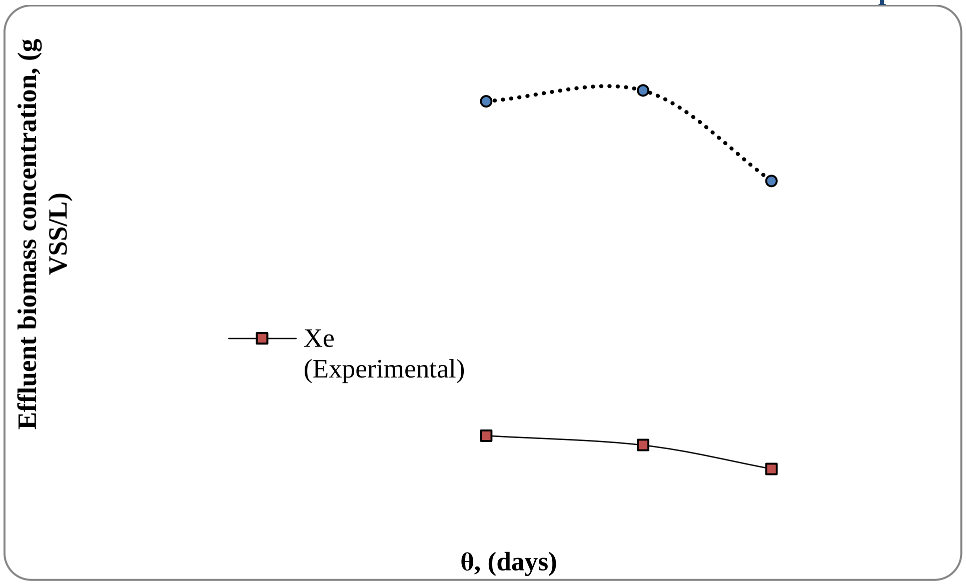

Figure 11: Agreement between the predicted effluent biomass and the experimental effluent biomass concentrations at different HRTs using experimental results of Álveraz et al. (2008) (X_o accounted)

Variation of computed effluent soluble COD concentration and experimental effluent soluble COD concentrations as a function of HRT are shown in figure 10 and that for effluent biomass concentrations are shown in figure 11. From both the figures 10 and 11, it is evident that both the computed effluent COD and biomass concentrations do not agree with their corresponding experimental values and large deviations are seen from their corresponding experimental values. Computed and experimental effluent COD concentrations at HRTs 0.27 and 0.387 d are quite close and margin of error less than 4.419%. However, a large deviation is observed at HRT of 0.483 days. Therefore, the computations of both Se and Xe values do not agree well with the experimental results and the application of steady state Eqs. in computation of performance of UASB reactor seems to be unreasonable. Therefore, steady state computations using simple CSTR model is not suitable to compute effluent COD and biomass concentration in UASB reactor in the present case.

CONCLUSION

A simple CSTR model for evaluation of UASB reactor performance is developed by considering the flow regime in UASB reactor with or without consideration of influent biomass concentrations. Linear equations are derived for the evaluation of kinetic constants for their use in model equations. The kinetic constants required for prediction of performances in terms of effluent COD and biomass concentration are evaluated and presented using experimental result of Álvarez et al. (2008) treating low strength wastewater in UASB reactor. The evaluation of dynamic as well as steady state performance of UASB reactors treating municipal wastewater were carried out by using experimental results of Álvarez et al. (2008). From the results, in general, it is concluded that a simple CSTR model is inappropriate for the evaluation of performance of UASB reactors treating municipal wastewater as the errors in predictions were obtained too large with respect to their corresponding experimental values.

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] 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.

[6] 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.

[7] Ligero, P., and Soto, M., (2002), "Sludge granulation during anaerobic treatment of pre hydrolysed domestic wastewater." Water S A., 28(3), 307-312.

[8] Lettinga, G., and Hulshoff Pol, L. W. (1991), "UASB process design for various types of wastewaters." Water Sci. Technol., 24(8), 87-107.

[9] 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.

[10] 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.

[11] 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.

[12] 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-o, 34(2), 153-62.