Advances in Computational Sciences and Technology
ISSN 0973-6107 Volume 10, Number 8 (2017) pp. 2721-2728

http://www.ripublication.com

Modelling of Granule Diameter in UASB Reactor: a Mathematical Approach

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Abstract

A dimensionless approach was used to model the granule size variations in UASB reactor under different operating conditions like organic loading rate, operation time, polymer loading, upflow velocity and granule density. This study examines mathematically the effect of introducing a novel cationic polymer Chitosan to enhance the granule diameter in a UASB reactor and effect of enhancement with another polymer (AA 184 H ,ACGC, Acrylamide-chitosan graft copolymer) used for low strength wastewater. In addition, a non linear regression analysis was also carried out to evaluate the enhancement of granule sizes in UASB reactor with above variables. From results, it is observed that dimensionless model show better performance of UASB reactor. Statistical analysis shows less deviation between predicted and experimental mean granule diameter.

Keywords: UASB, mean granule diameter, dimensionless modelling, polymer loading

INTRODUCTION

The upflow anaerobic sludge blanket (UASB) reactor introduced by Lettinga G. et al[1] has become a popular high-rate anaerobic treatment system throughout the world . The importance of granules in the operation of UASB reactors has led to an increasing number of studies on the relevant theories and mechanisms of anaerobic granulation Liu Y. et al[2,3], Schmidt J. E. et al[4]. Important parameters affecting the treatment efficiency of UASB reactors include sludge granulation in the reactor, characteristics of wastewater to be treated, selection of proper inoculums, influence of nutrients and several other physical and environmental factors Bhunia P. et al[5]. Factor governing granulation are pH, temperature, composition and concentration of organic compounds in wastewater, hydrodynamics, microbial ecology, production of exo-cellular polymeric substances by anaerobic bacteria. Some of these important factors such as organic loading, HRT, upflow velocity, presence of metal ions and trace metals and dosing of polymers Show K. Y. et al[6] , Wang Y. et al[7] and Wang J.S. et al[8] have been tried to enhance the granulation in UASB reactor especially when dealing in the low strength wastewater. In granulation process the presence of divalent and trivalent cations exert positive impact by neutralizing negative charges on bacterial surfaces, serving as cationic bridges between bacteria. In recent past, development of granular biomass in UASB reactor using synthetic or natural polymer addition has been evaluated by many researchers Show K. Y. et al[6] , Wang Y. et al[7] and Wang J.S. et al[8]. In addition the use of multivalent cations, the addition of natural polymers, such as water extract of the Moringa Oleifera seeds (WEMOS) Kalogo Y. et al[9], ACGC (Acrylamide-chitosan graft copolymer) Wang J.S. et al[8], Chitosan, Reetha extract and powdered bamboo-charcoal Cao Y et al[10] as well as commercial and synthetic polymers, such as the commercial cationic polymer "AA 180H" Show K. Y. et al[6] , Wang Y. et al[7] and organic-inorganic hybrid polymers Jeong H. S. et al[11] also showed promising results in enhancing the start-up and granulation in UASB reactors. Chitosan and Reetha extract (bulk, cationic fraction, and anionic fraction): Chitosan is a modified polysaccharide, mostly produced by alkaline deacetylation of chitin. Chitosan has shown positive results in enhancing sludge granulation and has exceeded Percol 763 as well as both the cationic and anionic fraction of Reetha extract in treating synthetic wastewater. The importance of granules in the operation of UASB reactors has led to an increasing number of studies on the relevant theories and mechanisms of anaerobic granulation.

Granule diameter are affected by many parameters like OLR, upflow velocity, polymer loading, specific gravity of granules, operating time etc. for modelling of granule size. The specific objectives of the present study included: 1) factor influencing the granule size, 2) make a dimensionless approach for modelling and simulation of granule size in UASB reactor.

MATERIALS AND METHODS

Using the data of Show K. Y. et al[6] have operating condition a plexiglass UASB reactor with volume 4.4 L, an internal diameter of 100 mm and a height of 680 mm.

The reactor was placed in a temperature-control room set at 35±1ºC and pH in the system between 6.5 and 7.3. The reactors started with an influent COD of 5000 mg/L (constant) and a corresponding organic loading rate of 2 g COD/L.d. To examine the effects of polymer concentration, reactor were dosed with polymer 80 mg/L. ‘‘AA 184 H’’ cationic polymer is used in this study. Using the experimental data of Wang J.S. et al[8] four identical reactors (5.03 L) for 136 d at 35 ± 1°C. R1 injected with bioflocculant, R2 was operated with ACGC (Acrylamide-chitosan graft copolymer), R3 was operated with polyacrylamide and R4 used as control reactor. The COD in the influent ranged from 550 mg/L to 650 mg/L throughout the study. These above are experimental and operating conditions of Testing and validation references. For prediction of mean granule diameter a dimensionless modelling was used.

DIMENSIONLESS MODELLING

Dimensionless approach By using Buckingham π method, mean granule diameter (D) is a function of these independent variables operating time(t_o), organic loading rate(O),upflow velocity (V_{up}), polymer loading (P_L), acceleration(g), %COD removal(r), specific density of water (ρ_w), specific density of granule (ρ_g) and viscosity of water (μ).

$$D=f\,(t_o, O, V_{up}, P_L, \rho_g, \rho_w, g, r, \mu) \quad (1)$$

Hence total number of variables (n) is 10, and repeating variables (m) is (O, t_o and V_{up})

so, m=3, n-m=7

Repeating variables is (O, t_o and V_{up})

Dimensionless groups are- $\left[\frac{D}{t_o * V_{up}}, \frac{P_L}{O*t_o^3*V_{up}^3}, \frac{\mu}{O*t_o^4*V_{up}^4}, \frac{t_o*g}{V_{up}}, \frac{\rho}{O*t_o}, r \text{ and } \frac{\rho_w}{\rho_g} \right]$ (2)

$$\frac{D}{t_o * V_{up}} = \emptyset\left[\frac{P_L}{O*t_o^3*V_{up}^3}, \frac{\mu}{O*t_o^4*V_{up}^4}, \frac{t_o*g}{V_{up}}, \frac{\rho}{O*t_o}, r \text{ and } \frac{\rho_w}{\rho_g} \right] \quad (3)$$

RESULTS AND DISCUSSION

In Show K. Y. et al[6] 6 reactors are used at different operating conditions and polymer concentrations. At each organic loading rate (O) the mean granule diameter of all reactor varies with operation time. Compared with control reactor the polymer-assisted reactors exhibited better granule characteristics and better reactor performance throughout the operation. At particular polymer dose, percentage granulation increases with increase in influent COD and upflow velocity. This is due to increased mixing in the sludge bed which can be done by increasing upward movement of biogas, due to increase in influent COD and liquid upflow velocity. The R4 reactor added with optimum dosage of 80 mg/l polymer could reduce the start up time by more than 52% at an OLR of 8gCOD/L.d when compared with control reactor. Data of mean granule diameter versus time of R4 reactor read by gatedata software. All reactors were operated with different polymer concentration. All reactor have same volume 4.4 L, with internal diameter 100mm. R4 reactor operated at 80mg/L polymer concentration, at this polymer concentration, calculated the polymer loading in g/l. Organic loading rate are varies with time HRT are also varies with operation time. Flow rate of reactor are calculated at each HRT, then upflow velocity are calculated.

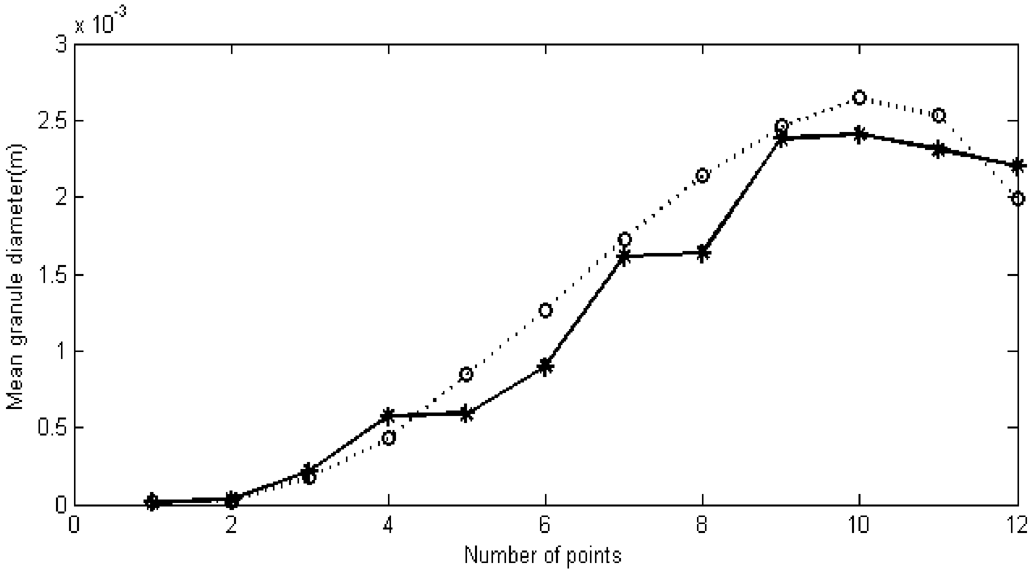
In Show K. Y. et al[6] operating time(t_o), organic loading rate(O), upflow velocity(V_{up}), polymer loading (P_L), acceleration(g in m/day^2), %COD removal(r), specific density of water (ρ_w), specific density of granule(ρ_g) and viscosity of water (μ in g/m.day) are independent variables. Mean granule diameter (D) is a dependent variable. By using Buckingham π method, found some relationship between dependent and independent variables, then make 7 dimensionless groups. In dimentionless groups these groups are $\frac{D}{t_o * V_{up}}$, $\frac{P_L}{O * t_o^3 * V_{up}^3}$ $\frac{t_o * g}{V_{up}}$, $\frac{\rho_w}{\rho_g}$ more pronounced effect shown, so these groups are consider for dimensionless modelling. Between these dimensionless groups, find a relationship between these groups, as shown below in form of equation 4. Using the Eq. (4) predicted granule diameter was observed.

$$D = \left(t_o V_{up}\right)\left(P_L / O t_o^{3} V_{up}^3\right)^{0.01204}\left(t_o g / V_{up}\right)^{-0.409}\left(\rho_g / \rho_w\right)^{0.1132} \tag{4}$$

For validation Wang J.S. et al[8] data was used. By using Buckingham π method using these dimensionless groups obtained a relationship shown below in equation 5.

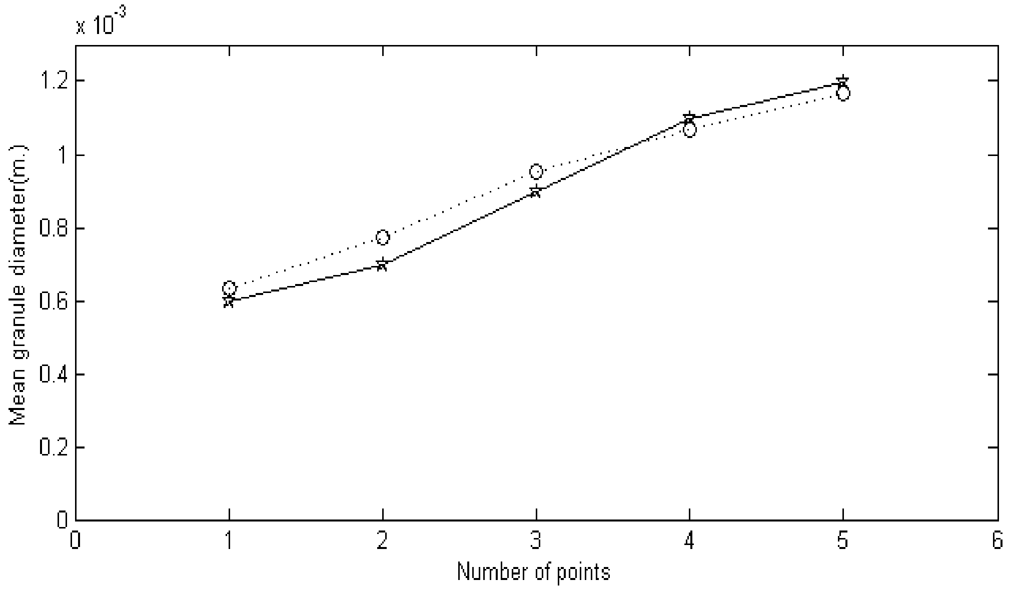
$$D = \left(t_o V_{up}\right)\left(P_L / O t_o^{3} V_{up}^3\right)^{0.015}\left(t_o g / V_{up}\right)^{-0.5012}\left(\rho_g / \rho_w\right)^{1.001} \tag{5}$$

Experimental mean granule diameter was read from Show K. Y. et al[6] and predicted mean granule diameter was calculated from dimensionless modelling using Eq. (4). Using these mean granule diameter draw a plot of experimental and predicted mean granule diameter with number of points shown in figure 1.



Note: (o) Experimental mean granule diameter, (*) Predicted mean granule diameter

Figure 1: Agreement between the predicted as well as experimental granule diameters with number of points in testing



Note: (o) Experimental mean granule diameter, (*) Predicted mean granule diameter

Figure 2: Agreement between the predicted as well as experimental granule diameters with number of points in validation

In case of validation using the data of Wang J.S. et al[8], indices of these dimensionless groups are very close to indices of Eq. (4). Operating conditions of testing and validation data are close to each other. In case of validation, obtained predicted mean granule diameter and experimental mean granule diameter is draw with numbers of points shown in figure (2). The efficiency of UASB reactor decreased with shorter hydraulic retention time (HRT). It can be stated that UASB reactor showed a remarkable performance under varying organic and hydraulic loading conditions applied in the systems. Predicted granule diameter obtained from Eq. (4) and (5) in case of testing and validation simultaneously. Then using these Predicted granule diameter, calculate the % error between experimental and predicted granule diameter in case of testing as well as validation, which shown in Table 1. From table 1in case of testing % error lies within the remarkable range between 2 to 25 and in validation 1 to 8 %. Calculate the statistical parameters between the experimental and predicted granule diameter shown in Table 2. Statistical parameters such as sum of residuals (SR), average residuals of error (AR), residuals sum of square (RSS), standard error of estimate (SEE), R^2 , R_a^2, Mean , standard deviation (S.D) and root mean square error (RMSE) values are calculated from matlab2010a software. From these statistical analysis, the values of statistical parameters are very less means predicted mean granule diameter is very close to experimental mean granule diameter.

CONCLUSION

In this study using five independent variables operating time, OLR, polymer loading, upflow velocity and specific density, find the dependent variable mean granule diameter. Predicted granule diameter observed by dimensionless modelling using Buckingham π theorem. From dimensionless modelling predicted granule diameter is very close to experimental granule diameter. In case of testing % error lies in the range of 2 to 25% and in validation its values are 1 to 8%. By dimensionless modelling, generate in general form for the prediction of mean granule diameter which shown below in Eq. (6).

$$D = \left(t_o V_{up}\right)\left(P_L / O t_o^{3} V_{up}^{3}\right)^a \left(t_o g / V_{up}\right)^b \left(\rho_g / \rho_w\right)^c \tag{6}$$

In above equation a lies upto 0.012-0.15, b lies between –(0.40-0.50) and c lies 0.11-1.00.

Table 1: % Error between experimental and predicted mean granule diameter

Testing (Using Eq. 4)			Validation (Using Eq. 5)		
Experimental granule diameter (m×10^{-3})	Predicted granule diameter (m×10^{-3})	Error (%)	Experimental granule diameter (m×10^{-3})	Predicted granule diameter (m×10^{-3})	Error (%)
0.018	0.016	12.5	0.633	0.601	5.32
0.02	0.0183	9.12	0.771	0.71	8.59
0.175	0.214	18.6	0.951	0.91	4.50
0.43	0.424	1.27	1.10	1.11	0.90
0.843	0.789	25.86	1.21	1.20	0.83
1.263	1.09	19.19			
1.727	1.42	6.13			
2.138	1.82	5.65			
2.459	2.39	2.55			
2.647	2.52	4.71			
2.532	2.45	3.22			
1.986	2.07	4.21			

Table 2: Statistical analysis of predicted granule diameter in testing and Validation

Model	RSS	SR	AR	SEE	R^2	R_a^2	Mean	S.D	RMSE
Testing	1.27E-07	8.19E-04	7.45E-05	1.34E-04	0.993	0.992	1.30E-03	9.98E-04	8.84E-05
Validation	6.63E-09	1.34E-04	2.68E-05	7.59E-05	0.993	0.991	1.2E-03	2.54E-04	2.14E-05

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