SIMULATION OF GRANULE SIZE IN UPFLOW ANAEROBIC SLUDGE BLANKET REACTOR USING DIMENSIONLESS APPROACH

Vidya Singh

Research Scholar, Department of Chemistry,

Motilal Nehru National Institute of Technology, Allahabad, U.P, (India)

ABSTRACT

A dimensionless approach was used to simulate the granule size variation in upflow anaerobic sludge blanket (UASB) reactor under different operating condition like organic loading rate (O), polymer loading (P_L), upflow velocity (V_{up}), operation time (t_0), density of water (ρ_g) and density of granule (ρ_g). The experimental results of different investigators on polymer loading, OLR, upflow velocity, operation time and granule density were collected and developed a mathematical model to the enhancement of granule size in UASB reactor. Using MATLAB software indices of power multiplier function obtained can be used to predict the granule size (D_g) variations in UASB reactor.

***Keywords*: Dimensionless Approach, Granule Size, Non Linear Regression, Organic Loading Rate, UASB**

I. INTRODUCTION

As compared to other anaerobic treatment technologies, such as anaerobic filter, anaerobic sequencing batch reactor, anaerobic expanded bed and fluidized bed reactors, the UASB system performance is highly dependent on granulation and the type of organic wastewaters treated. Anaerobic granular sludge is the core component of a UASB process. Microbial granulation is a complex process, involving different trophic bacterial groups and their physico-chemical and microbiological interactions. Granulation initiated by bacterial adsorption and adhesion to inert matters or inorganic participates provides a better settling characteristics and granule stability [1, 2].

UASB process performance can be judged by evaluating its performance within as well as beyond the granulation period and or start-up phase, as the system behaviour is under highly transient conditions within the granulation period [2-5].

Successful performance of UASB reactor can be achieved within a short period, if granules are developed quickly within the sludge bed under the proper environmental and operating conditions within the reactor [6]. Granulation process is affected by various factors like organic loading rate, upflow velocity, settling velocity, sludge volume index (SVI), gas production rate, liquid flow rate, polymer loading, Percent COD removal and effluent COD concentration. Granulation is also affected by several other factors such as pH and alkalinity, temperature, microbial ecology, production of exo-cellular polymeric substances by anaerobic bacteria, nutrients and trace metals, heavy metals etc.

Granules may range from 0.1 to 5 mm in size or even higher than 5 mm and are differentiated from flocculated sludge by their high shear strength [3, 7]. Approximately 2-3 % of the granules in the reactors were reported in the size range of 0.5-4.5 mm by [8]. [9] have documented that about 14 % granules were observed larger than 4.0 mm in size in UASB reactor. After increment in the organic loading rate, the granule sizes were reduced due to shearing of granules caused by high flow velocity and possible washout of lighter microorganisms [2, 3, 10]. An empirical model for gas production rate, effluent substrate concentration was developed for performance evaluation of UASB reactors treating poultry manure wastewater under different operational conditions [11].

In the present work, the independent variables like polymer loading, organic loading rate, upflow velocity, operation time and granule density influencing the granule size in UASB reactor have been collected from the literatures. Further a mathematical model was developed by non linear regression using MATLAB2010a software for prediction of granule size in UASB reactor. Various statistical measures such as standard deviation (S.D), root mean square error (R.M.S.E), R^2, sum of residuals of errors (SR), average residuals of errors (AR), residuals sum of squares (RSS) and standard error of estimate (SEE) were done between predicted output and experimental data of granule size to check the accuracy of developed model. It is believed that the developed model and tested in the present study may prove useful in assessing the granule size in UASB reactor.

II. DATA COLLECTION AND METHODOLOGY

In the analysis of granule size development in UASB reactor, the experimental results of [4, 6] have been used. These experimental data were read either from the figures or taken directly from the tables provided in [4, 6]. In [4] influent substrate concentration (S_0) was maintained at 4 g COD/L in all the four reactors R1 to R4 and OLR was varied in the range of 730-16030 g COD/m^3.d. Reactor R4 provided the shortest period of granulation compared to other reactors. In [6], influent substrate concentration was varied in range of 0.55 g/L to 0.65 g/L throughout the study in all four reactors R1 to R4. Organic loading rate was varied in the range of 1400-5700 g COD/m^3.d. Reactor R2 provided the shortest granulation period and large size of granule compared to other reactors. Subsequent granules characterization indicated that the granule developed in R4 reactors in [4] and R2 reactor in [6] exhibited the best settleability, short start-up period and good methanogenic activity at all COD loading rates, so analysis of these reactors considered in this study .

The organic loading rate (O) in the reactor can be varied either by varying influent COD concentration or by varying in flow rate. Using the experimental results of [4, 6] the variation of granule size as a function of organic loading rate is shown in figure 1. From fig. 1, it is evident that as organic loading rate increases, size of granules also increases.

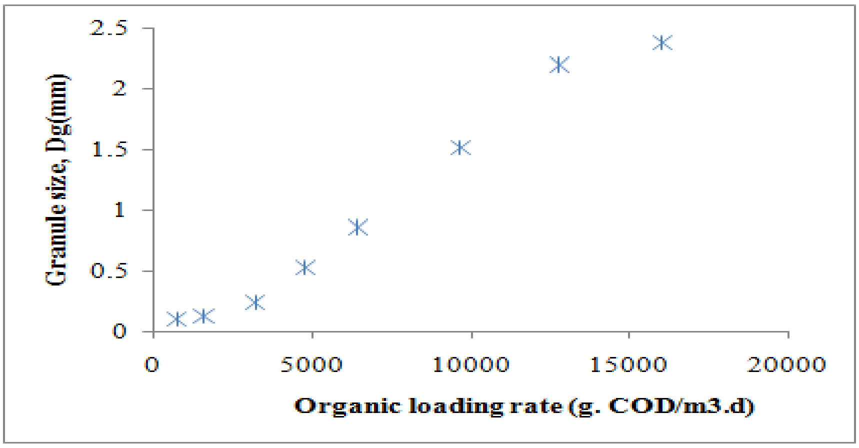

Fig.1. Variation of Granule Size with Organic Loading Rate

Granule formation and characteristics are strongly influenced by the liquid upflow velocity and at high upflow velocities (>1m/h), the granules may disintegrate due to shearing and resulting fragments may wash out of the reactor. Vigorous gas evolution at high organic loading and upflow velocity may result in vigorous shearing of bacterial cells from granule surface leading to granule erosion. The variation of granule size as a function of upflow velocity is shown in figure 2. From this figure, it is evident that granule size increases with increase in upflow velocity.

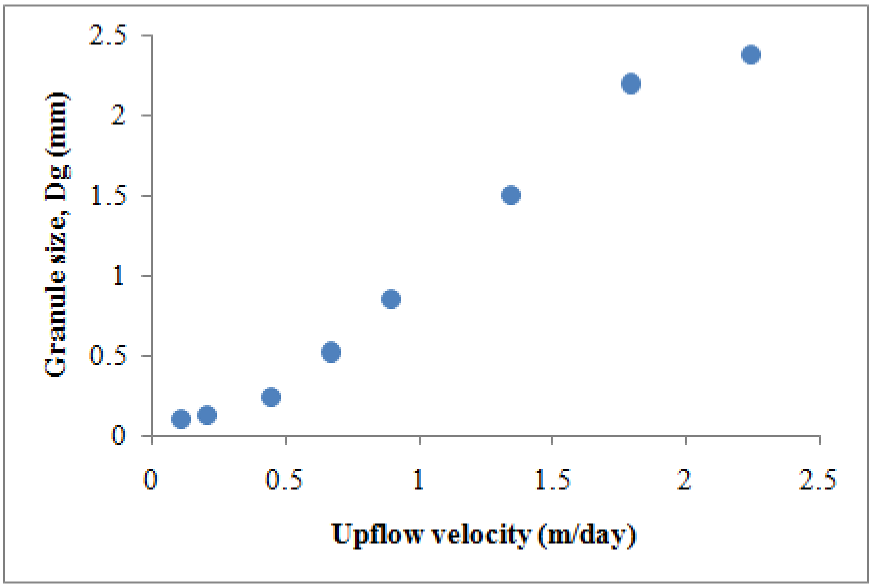

Fig.2. Variation of granule size with up flow velocity

III. RESULTS AND DISCUSSION

3.1 Dimensionless Approach

In the present work, a dimensionless approach using Buckingham π - theorem has been applied to developed model for granule size (D_g) in UASB reactor. As evident from the literature, granulation process is dependent on several factors enumerated in the proceeding section and hence the granule size is considered to be dependent on several independent variables such as operation time (t_o), COD loading rate (O), upflow velocity (V_{up}), polymer loading (P_L), acceleration (g), specific density of granule (ρ_g) and specific density of water (ρ_w).

Therefore, it can be written as:

$$\mathbf{D_g = f\ (t_o, O, V_{up}, P_L,\ \rho_g, \rho_w\ , g\ )} \tag{1}$$

By using Buckingham π - method, found some relationship between dependent and independent variables, then make 4 dimensionless groups which are given below in equation (2). Dimensionless groups are:

$$\left[\frac{D_g}{t_o.V_{up}}\right]\left[\frac{P_L}{O.t_o^3.V_{up}^3}\right]\left[\frac{t_o.g}{V_{up}}\right]\left[\frac{\rho_g}{\rho_w}\right] \tag{2}$$

Therefore, ($D_g/t_o.V_{up}$) can be written as:

$$\left[\frac{D_g}{t_o.V_{up}}\right] = \phi\left[\frac{P_L}{O.t_o^3.V_{up}^3}\right]\left[\frac{t_o.g}{V_{up}}\right]\left[\frac{\rho_g}{\rho_w}\right] \tag{3}$$

Equation (3) can be written as-

$$D_g = \left[t_o.V_{up}\right]\left[\frac{P_L}{O.t_o^3.V_{up}^3}\right]\left[\frac{t_o.g}{V_{up}}\right]\left[\frac{\rho_g}{\rho_w}\right] \tag{4}$$

Another attempt was made to develop a power multiplier function for prediction of granule size by raising the powers of each dimensionless groups of Eq. (4) and is expressed as:

$$\left[\frac{D_g}{t_o.V_{up}}\right] = \left[\frac{P_L}{O.t_o^3.V_{up}^3}\right]^a \left[\frac{t_o.g}{V_{up}}\right]^b \left[\frac{\rho_g}{\rho_w}\right]^c \tag{5}$$

Simplifying the equation (5) and can be written as:

$$D_g = \left[t_o.V_{up}\right]\left[\frac{P_L}{O.t_o^3.V_{up}^3}\right]^a \left[\frac{t_o.g}{V_{up}}\right]^b \left[\frac{\rho_g}{\rho_w}\right]^c \tag{6}$$

Where, D_g is a function containing each dimensionless term as power function used, and a, b and c are indices raised to the dimensionless groups formed in Eq. (6) used for prediction of granule size.

3.2 Prediction of granule size (D_g)

In this modelling work; the indices a, b and c were determined by non-linear regression analysis by fitting the Eq. (6) using NLINFIT tool in MATLAB 2010a. Equation (6) has been tested on experimental data of [4] and also validated by the data of [6] results are discussed in the succeeding sections.

a multiplier power function (D_g) containing powers of each dimensionless terms of Eq. (6) is developed by simulating the granule size term (R.H.S term of Eq. (6)) with the experimental results of [4] using NLINFIT tool of MATLAB 2010a and the resulting non-linear best fit equations for R4 reactors are given below as equation (7) .

$$D_g = \left[t_o.V_{up}\right]\left[\frac{P_L}{O.t_o^3.V_{up}^3}\right]^{0.073} \left[\frac{t_o.g}{V_{up}}\right]^{-0.292} \left[\frac{\rho_g}{\rho_w}\right]^{0.110} \tag{7}$$

From equation (7) predicted data of granule sizes are observed, compare these output predicted values of granule size with experimental data of granule sizes and obtained percentage error are 15 %. Fig. 3 illustrates the agreement between the proposed non linear regression model outputs and the experimental data.

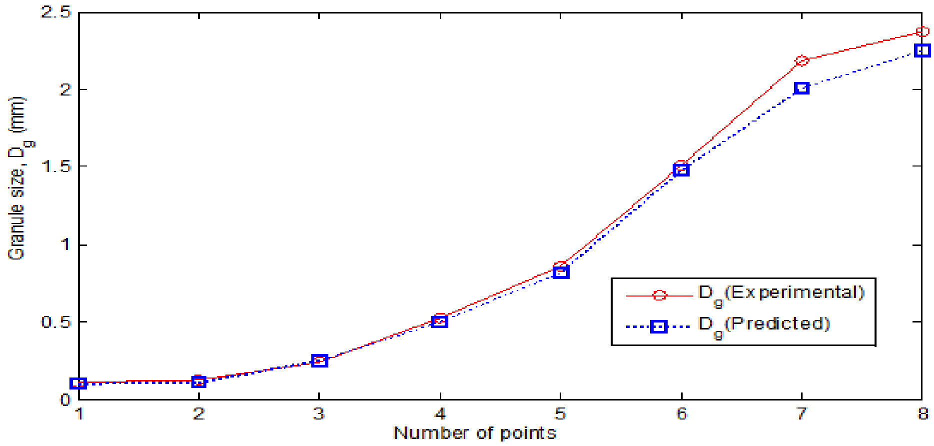

Fig.3. Agreement between the proposed model outputs and experimental data in testing

From Fig.3. It can be seen that predicted output data of granule sizes were very close to experimental data of granule size, means a better fitting was predicted between observed output data and experimental values of granule sizes. Proposed model gives better results for prediction of granule sizes in UASB reactor.

3.3 Validation of the proposed model

Multiplier power function (D_g) obtained in equation (7) are validated by experimental data of [6] for reactor R2 and compared these output predicted values of granule size with experimental data of granule sizes and obtained percentage error are 10 %. Fig. 4 illustrates the agreement between the proposed non linear regression model outputs and the experimental data.

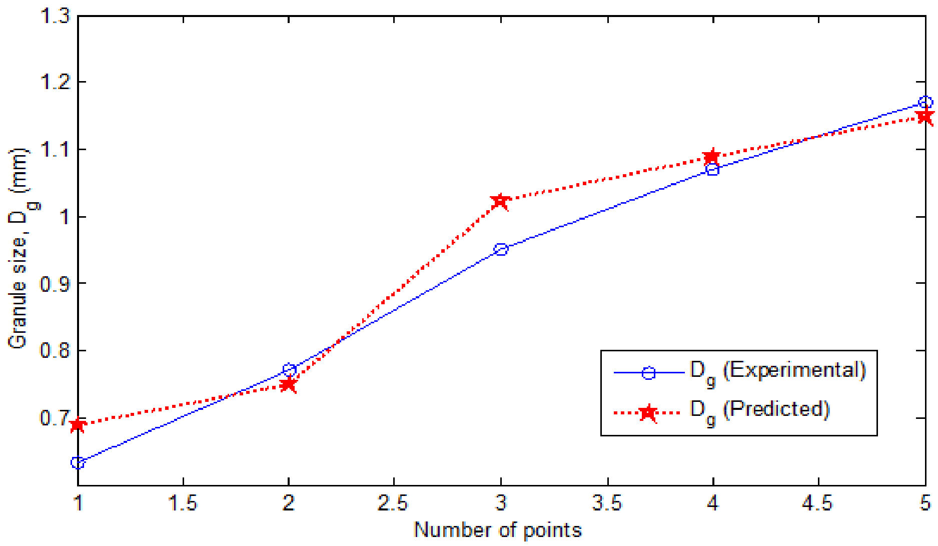

Fig.4. Agreement between the proposed model outputs and experimental data for validation

Statistical error estimates are determined to evaluate the goodness of fit using sum of residuals (SR), average residual errors (AR), Residuals sum of squares (RSS), standard errors of estimate (SEE), standard deviation (S.D) and root mean square error (RMSE). These statistical error estimates in experimental and predicted (D_g) values for all the six reactors are presented below in Table 1. SR measures the variance between experimental and predicted data. Small values of SR indicate a tight fitting of experimental and predicted values. RSS measures the amount of error between the regression function and the experimental data set. SEE measures the discrepancy between experimental data and model estimates. Similar to SR, the small SEE value indicates a tight fitting of data set. Standard deviation (S.D) measures the amount of variation or dispersion from the average. A low S.D values indicates that the data points tend to vary close to the mean values and a high S.D value indicates that the data points are spread out over a large range of values. RMSE is a measure of the difference between predicted values and observed experimental values.

Table1. Descriptive statistics of the residuals errors in prediction of D_g values

Residual statistics Calculation	Calculation	Regression results In Testing	In Validation
The sum of residuals of the errors	$SR = \sum_{i=1}^{n}(D_e - D_p)$	**3.18E-04**	**1.34E-04**
The average residuals of the errors	$AR = \frac{1}{n}\sum_{i=1}^{n}(D_e - D_p)$	**3.97E-05**	**2.68E-05**
The residuals sum of squares	$RSS = \sum_{i=1}^{n}(D_e - D_p)^2$	**1.43E-07**	**6.63E-09**
The standard error of estimate	$SEE = \sqrt{\frac{\sum_{i=1}^{n}(D_e - D_p)^2}{n-p}}$	**3.78E-04**	**7.59E-05**
Correlation coefficient	$R^2 = \frac{\sum_{i=1}^{n}(D_p - D_m)^2}{\sum_{i=1}^{n}(D_e - D_m)^2}$	**0.976**	**0.961**
Root mean square error	$RMSE = \sqrt{\frac{1}{n-2}\sum_{i=1}^{n}(D_e - D_p)^2}$	**1.47E-04**	**2.14E-05**
Standard deviation		**9.56E-04**	**2.54E-04**

D_e, experimental granule size; D_p, predicted granule size; D_m, mean granule size, n, no. of experimental data point.

From Table 1 all statistical error estimates are low for both analysis testing as well as validation, means observed predicted outputs are very close to experimental values. Predicted output granule sizes shows better fitting with experimental data of granule sizes, means proposed model for power multiplier function (D_g) gives better results for prediction of granules sizes in UASB reactor.

V. CONCLUSION

In dimensionless approach six independent variables operation time, organic loading rate, polymer loading, up flow velocity, specific density of granule and specific density of water are considered, which dependent on granule size in UASB reactor. From these dependent and independent variables make four dimensionless groups by using dimensionless approach Buckingham π - theorem. Indices of power multiplier function obtained by using NLINFIT tool of MATLAB2010a and simulate the granule size which are close to the experimental data of granule size. % error between experimental data and predicted output of granule size is approximately 15% in analysis of testing and 10% found in analysis of validation, means less % error shows closeness between predicted output and experimental data of granule size. Low values of statistical error and higher correlation coefficient R^2 (equal to 0.976 in testing and 0.961 in validations) indicates accuracy in predicted output of granule size in UASB reactor. From nonlinear regression obtained power multiplier function of D_g is used for the prediction of granule size in UASB reactor.

VI. ACKNOWLEDGMENTS

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