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# Influencing Factors of Granule Size in UASB Reactor and Mathematical Approach for Its Prediction

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**ABSTRACT :** Various factors affecting granulation process as gleaned from the literature are operation time ( $t_o$ ), organic loading rate ( $O$ ), upflow velocity ( $V_{up}$ ), polymer loading ( $P_L$ ), acceleration ( $g$ ), specific density of granule ( $\rho_g$ ) and specific density of water ( $\rho_w$ ), temperature, pH, nutrients and trace metals, quantity of seed sludge, exocellular polymer, reactor configurations, its geometry and characteristics of wastewaters etc. A mathematical approach was used to model the granule size variation in upflow anaerobic sludge blanket (UASB) reactor under different operating conditions using Buckingham- $\pi$  theorem. Obtained power multiplier function of granule size ( $D_g$ ) can be used to predict the granule size variations in UASB reactor.

**KEYWORDS:** dimensionless approach, granule size, organic loading rate, non linear regression, UASB

### I. INTRODUCTION

The upflow anaerobic sludge blanket (UASB) reactor is now accepted as being a popular method for treatment of wastewater, including high strength industrial wastewater as well as low strength wastewater. The UASB process is attractive because of its compactness, low operational cost, low sludge production and production of useful methane gas. More than 1000 UASB units are currently being operated all over the world. The application of UASB reactors for the treatment of high strength industrial wastewater containing easily hydrolyzed substrates such as sugar industry wastes, distillery wastes and brewery wastes had been successful [1,2]. Sludge present in the reactor is composed of microorganisms that naturally form granules of 0.5-5 mm diameter that exhibit high settling velocity and thus resist wash out from the reactor even at higher loadings [3]. Hence, no support media is required for bacterial attachment to enhance sludge retention. Formation of good granular sludge is the prominent characteristics of UASB reactor to obtain higher COD removal efficiency [4]. Anaerobic microbial granulation is considered to be a key parameter for the successful operation of a UASB reactor. It is a biological process under favorable conditions due to the tendency of bacteria to self-immobilize. The granulation is often initiated by adsorption of bacteria to inert material, or with each other due to syntrophic relationship between methanogenic and acetogenic species in mixed consortia [5]. UASB process for the treatment of domestic wastewater (low strength) also suffers from a number of shortcomings, such as long start-up time, poor gas production, susceptibility to shock loadings, inability to form self-immobilized bacterial granules and necessity for post-treatment of the effluent.

Granules may range from 0.1 to 5 mm in size and are differentiated from flocculated sludge by higher shear strength [5]. It is believed to be the most critical parameter affecting successful operation of a UASB reactor because granulated sludge has better settling property allowing higher hydraulic and organic loading, granules can withstand high gas and liquid shear stress without disintegrating and granules provide increased resistance to process shocks and toxins compared to dispersed microorganisms [2, 5].

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The granulation process is commonly believed to be sensitive to the sudden change of environmental and operational conditions. Factors governing granulation have been extensively studied on a variety of wastewaters. Some of these factors are operating conditions [6,7], pH and alkalinity [8], temperature [9], strength and composition of wastewater [10], reactor hydrodynamics [9,11], presence of metal ions and trace metals [12-14], presence of polymers [15-16], microbial ecology [17] and production of exocellular polymeric substances by anaerobic bacteria [18-19]. A number of reviews are available on functioning of UASB reactor, its applicability to sewage treatment, treatment of some of the toxic wastes, nutrient requirements for UASB reactor [8] and mechanisms of granulation [5,20,21].

In the present work, the independent variables like polymer loading, COD 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 using Buckingham- $\pi$  theorem for prediction of granule size in UASB reactor. This paper presents an analysis of various factors such as OLR,  $V_{up}$ , polymer loading and operation time affecting granulation and granule size development in UASB reactor using the data available in literature [22].

## II. DATA COLLECTION AND METHODOLOGY

In the analysis of granule size development in UASB reactor, the experimental results of [22] have been used. These experimental data were read either from the figures or taken directly from the tables provided in [22]. In [22] influent substrate concentration ( $S_0$ ) was maintained at 4000 mg COD/L in all the four reactors R1 to R4 and OLR was varied in the range of 730-16030 g COD/m<sup>3</sup>.d. Reactor R4 exhibited the best settleability, shortest period of granulation compared to other reactors, so analysis of reactor R4 considered in this study.

## III. RESULTS AND DISCUSSION

### 3.1 Organic loading rate

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 [22] 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.

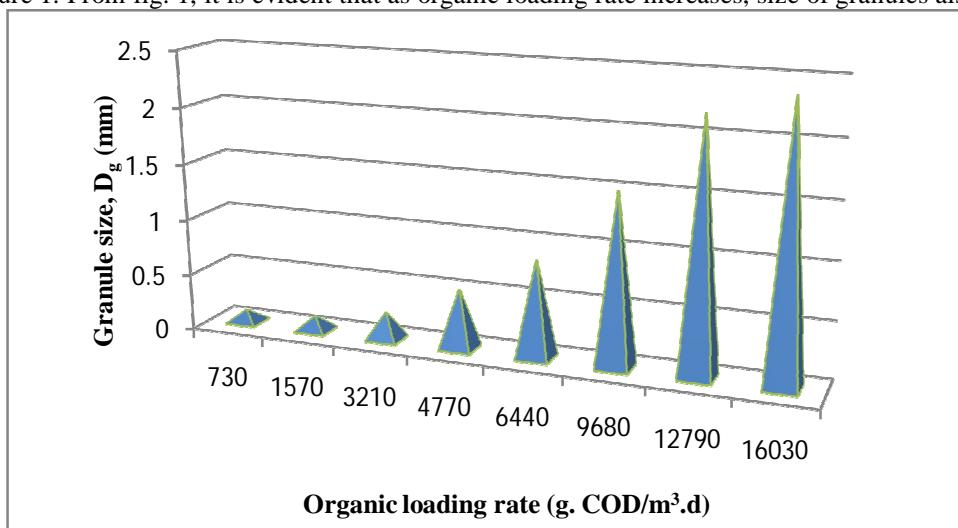


Fig. 1 Variation of granule size with COD loading rate

### 3.2 Upflow velocity

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

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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.

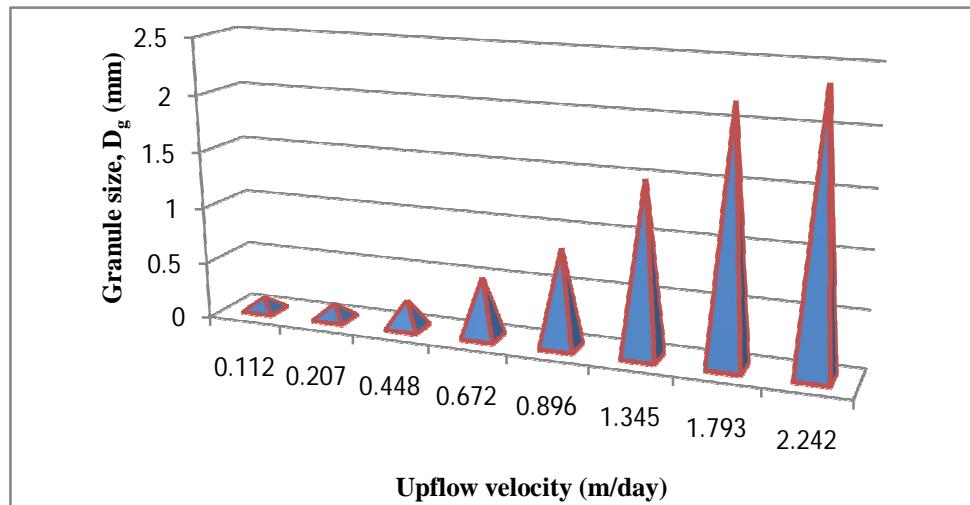


Fig. 2 Variation of granule size with upflow velocity

### 3.3 Polymer loading

Granule formation and characteristics are strongly influenced by organic loading rate, liquid upflow velocity and polymer loading. Different cationic and anionic polymer enhanced the granule size in UASB reactor. Concentration of polymer rate increases with time and granule size also increases in UASB reactor. Variation of polymer loading is 0.0176 to 0.352 g/day in reactor with increasing granule size continuously.

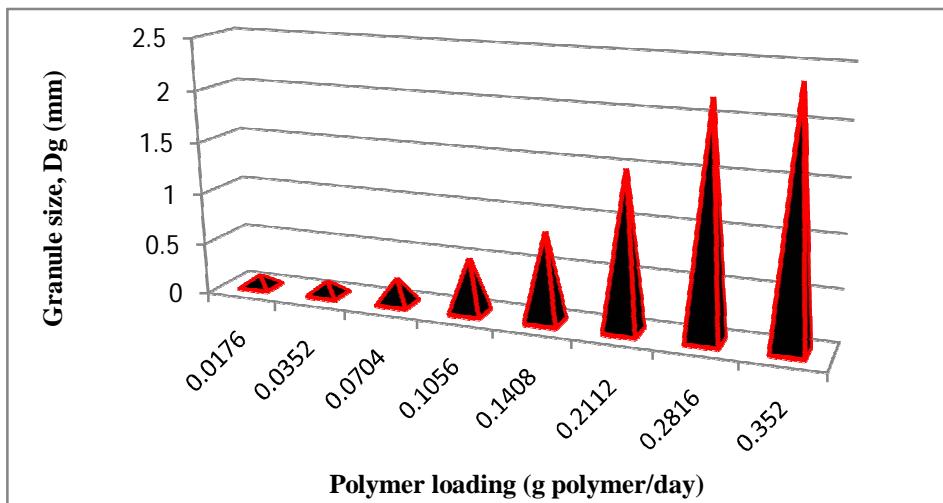


Fig.3 Variation of polymer loading with polymer loading

## International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 4, Issue 6, June 2015

### 3.4 Operation time

Granule size is affected by many factors organic loading rate, upflow velocity, different polymer concentrations and size of granulation is also influence by operation time. Granule size is continuously increases with operation time. Operation time is calculated in days in using paper.

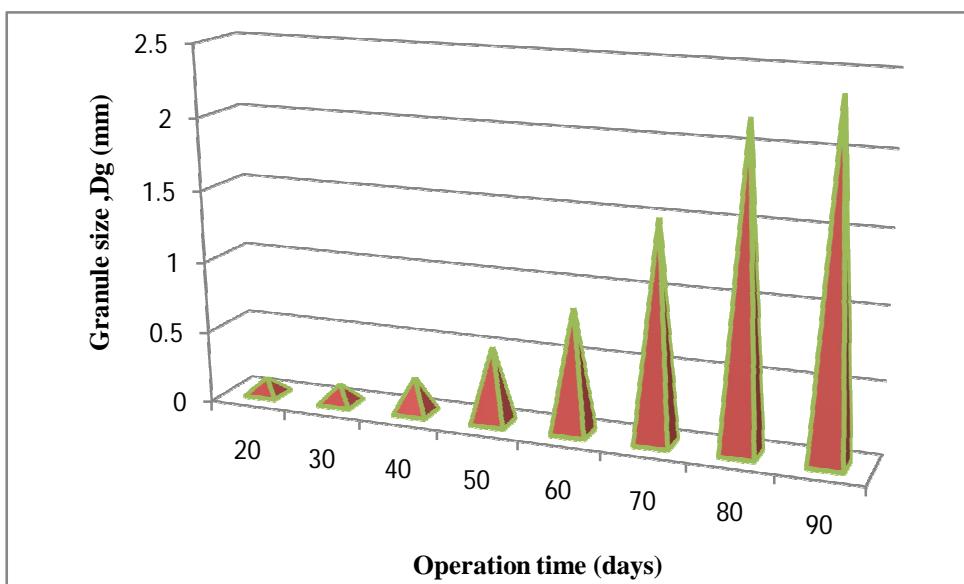


Fig.4 Variation of granule size with operation time

### 3.2 Dimensionless approach

In the present work, a dimensionless approach using Buckingham  $\pi$  - 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 ( $t_o$ ), organic loading rate (O), upflow velocity ( $V_{up}$ ), polymer loading ( $P_L$ ), acceleration (g), specific density of granule ( $\rho_g$ ) and specific density of water ( $\rho_w$ ). Therefore, it can be written as:

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

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

$$\left[ \frac{D_g}{t_o \cdot V_{up}} \right] \left[ \frac{P_L}{O \cdot t_o^3 \cdot V_{up}^3} \right] \left[ \frac{t_o \cdot g}{V_{up}} \right] \left[ \frac{\rho_g}{\rho_w} \right] \quad (2)$$

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

$$\left[ \frac{D_g}{t_o \cdot V_{up}} \right] = \phi \left[ \frac{P_L}{O \cdot t_o^3 \cdot V_{up}^3} \right] \left[ \frac{t_o \cdot g}{V_{up}} \right] \left[ \frac{\rho_g}{\rho_w} \right] \quad (3)$$

Equation (3) can be written as-

$$D_g = \left[ t_o \cdot V_{up} \right] \left[ \frac{P_L}{O \cdot t_o^3 \cdot V_{up}^3} \right] \left[ \frac{t_o \cdot g}{V_{up}} \right] \left[ \frac{\rho_g}{\rho_w} \right] \quad (4)$$

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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:

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

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

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

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.

### IV. CONCLUSION

In upflow anaerobic sludge blanket reactor granule size is affected by various factors like organic loading rate, upflow velocity, polymer loading rate and operation time. Using dimensionless approach six independent variables operation time, organic loading rate, polymer loading, upflow 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 Buckingham  $\pi$  - theorem. Prediction of granule size variations in UASB reactor obtained power multiplier function of granule size ( $D_g$ ) can be used.

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