INFLUENCE OF EXTRINSIC FACTORS ON GRANULE SIZE IN UASB REACTOR

[1]Vidya Singh, [2]Balram Singh

[1]Research Scholar, Department of Chemistry,

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

[2]Assistant Professor, Govt. Raza P.G. College Rampur U.P (India)

ABSTRACT

The aim of this paper is to synthesize and analyze information on how the process of granulation is affected by environmental and operational conditions in the reactor. Various factors affecting granulation process as gleaned from the literature are organic loading rate (OLR), upflow velocity (V_{up}), sludge volume index (SVI), specific methenogenic activity (SMA), VSS/SS ratio, liquid in flow rate (Q), gas production rate (Qg), settling velocity (SV), temperature, pH, nutrients and trace metals, quantity of seed sludge, exocellular polymer, reactor configurations, its geometry and characteristics of wastewaters etc. The divalent cations such as calcium and iron may enhance granulation by ionic bridging and linking exo-cellular polymers. However, their presence in excess may lead to cementation due to precipitation leading to increased ash content and mass transfer limitation. The addition of external additives such as ionic polymers may enhance granulation in the upflow anaerobic sludge blanket reactors. Among the various factors and reported experimental results, the factors OLR, V_{up}, SVI, SMA, and VSS/SS ratio are identified as important factors for which experimental results are available in the literature. Comparision of results on granule size variations are presented and analyzed in this work. From the results, it is concluded that these factors are playing major roles in enhancing the granule size development, if regulated, monitored and maintained properly during initial phases of operation of UASB reactor.

Keywords: Granule Size, Organic Loading Rate, SMA, UASB, Upflow Velocity

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].

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].

This paper presents an analysis of various factors such as OLR, V_{up}, SVI, SMA, and VSS/SS ratio affecting granulation and granule size development in UASB reactor using the data available in literature.

II. DATA COLLECTION AND METHODOLOGY

In the analysis of granule size development in UASB reactor, the experimental results of [22, 23] have been used. These experimental data were read either from the figures or taken directly from the tables provided in [22,23]. In [22], influent substrate concentration (S_0) was maintained at 4000mg COD/L in all the four reactors R1 to R4 and OLR was varied in the range of 0.8-19.2 g COD/L.d. Reactor R4 provided the shortest period of granulation compared to other reactors. In [23], influent substrate concentration was varied in range of 550 mg/L to 650 mg/L throughout the study in all four reactor R1 to R4. OLR was varied in the range of 0.5-5.89 g COD/L.d. Reactor R2 provided the shortest period compared to other reactors. Subsequent granules characterization indicated that the granule developed in R4 reactors in [22] and R2 reactor in [23] exhibited the best settleability, short start-up period and good methanogenic activity at all OLRs.

III. INFLUENCE OF FACTORS AFFECTING GRANULE SIZE DEVELOPMENT

3.1 Organic Loading Rate (OLR)

The organic loading rate (OLR) in the reactor can be varied either by varying influent COD concentration or by varying in flow rate. Using the experimental results of [22, 23] the variation of granule size as a function of OLR is shown in figure 1. From fig. 1, it is evident that as OLR increases, size of granules also increases upto an OLR of 12.8 g COD/L.d, but at an OLR of 13 g COD/L.d, granule size is decreased due to possible wash-out and shearing of granules in [22]. In [23], no wash-out and shearing of granules are observed with increasing OLR upto 5.49 g COD/L.d.

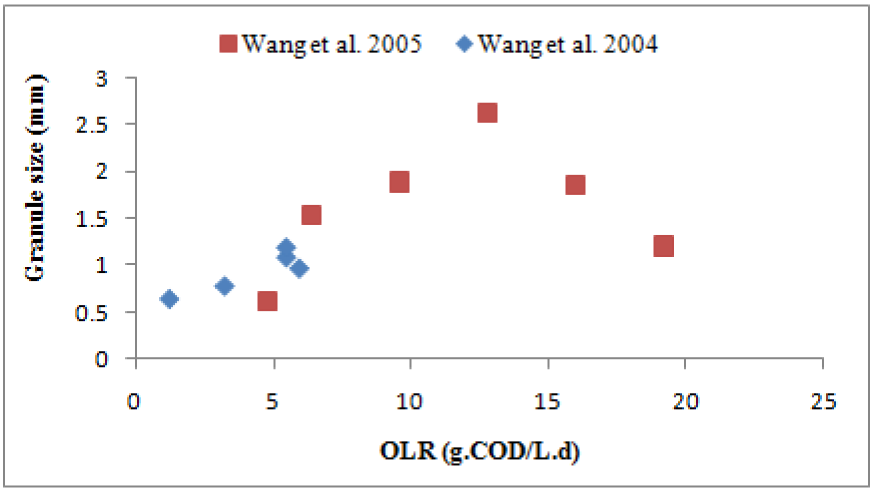

Fig.1 Variation of Organic Loading Rate with Granule Size

The successful operation of UASB reactor depends on the formation of granules with good settleability and high degradation activities. It was observed that the large granules may also exhibit loose structure and lots of white and black fluffy flocs may get attached on the surface. At higher OLR granule diameter may be reduced due to possible shearing of loose flocs and washout of loosely attached microorganisms [22, 23].

3.2 Upflow velocity (V_{up})

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 [11]. Vigorous gas evolution at high organic loading and upflow veloity may result in vigorous shearing of bacterial cells from granule surface leading to granule erosion [24]. In [22-23] upflow velocity are calculated from given data. The variation of granule size as a function of upflow velocity is shown in figure 2. From this figure, it is evident that As the organic loading rate increases, granule size as well as upflow velocity of the reactor continuously increases [22, 23].

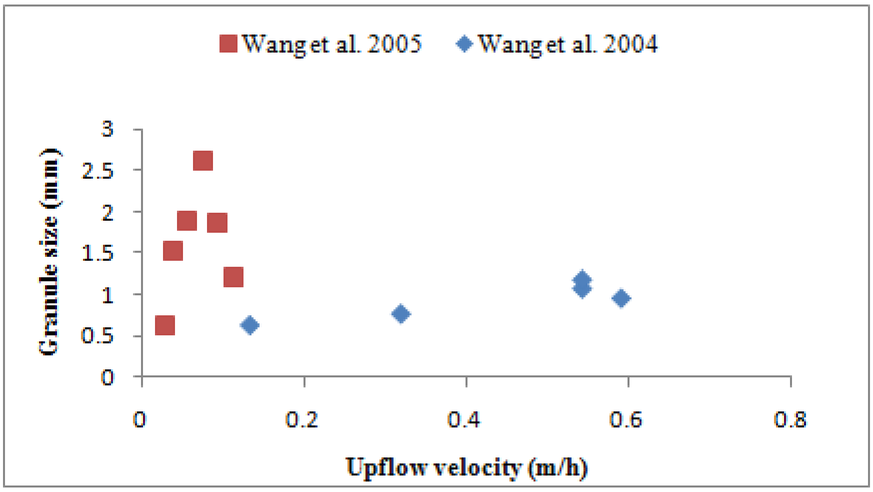

Fig.2 Variation of upflow velocity (V_{up}) with granule size

From fig. 2 in [22] upflow velocity are not more higher than 0.2 m/h, large size of granules [2.5-2.6 mm] are observed and at higher V_{up} reach upto 0.14 m/h shearing of granules occurs then diameter of granules decreases. Due to higher upflow velocity, shearing of granules and wash-out of microorganism occurs in the reactor size of granules decreases from their peak values. In [23] upflow velocity lies upto 0.6 m/h, higher upflow velocity but due to low organic loading rate small size of granules are observed as shown in fig. 2.

3.3 Sludge Volume Index (SVI)

Reduction of SVI, which is an important physical parameter, was generally considered as an indicator of improvement in granule settleability. SVI of granules in reactors, which has inverse ratio with settling velocity. Variation of SVI values with granule size is oscillating in nature, at maximum granule size 2.62mm SVI value is 0.016 L/g [22]. As SVI values decreases, size of granule increases continuously [23].

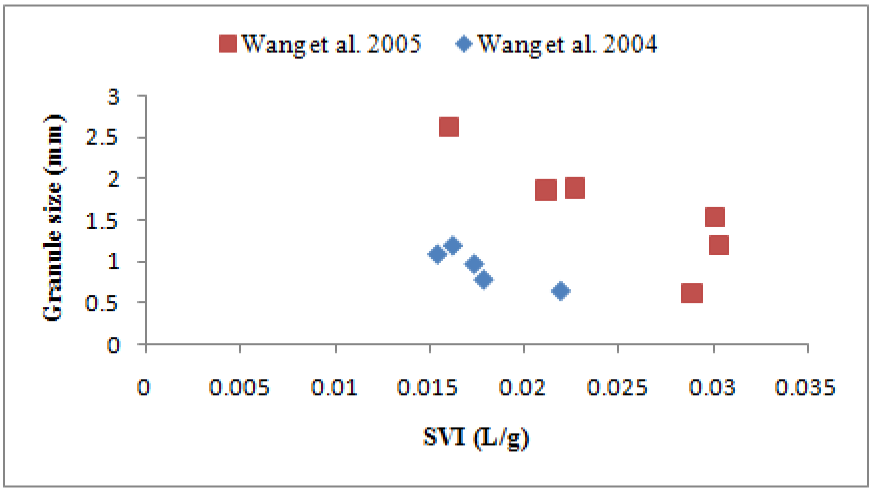

Fig.3 Variation of sludge volume index (SVI) with granule size

Enhanced granule settleability as indicated by settling velocity and SVI results could be due to improved bacterial adhesion. In reactor SVI fell more sharply as COD loading increased initially but rose again at the higher levels of COD loading. Enhanced granule settleability in reactor as indicated by the SVI values could be due to improved bacterial adhesion [22]. The sludge first became loose, the SVI of the sludge in reactor increased, then, because of improved bacterial adhesion, the SVI of sludge in reactor decreased [23]. In [22, 23] SVI values are decreased then better settleability of granules occurs, granule size increases.

3.4 Specific Methenogenic Activity (SMA)

Metabolic activities of granules can be expressed in term of specific methonogenic activity (SMA). In [22] maximum SMA value are 2.37 g CH_4-COD /g VSS.d and observed diameter of granule is 1.89 mm. After OLR 16 g COD/L.d SMA values are decrease with increasing granule size. SMA values are continuously increasing with increasing granule size and reach upto 1.21g CH_4-COD /g VSS.d at 1.18mm granule size because there is no shearing occurs [23].

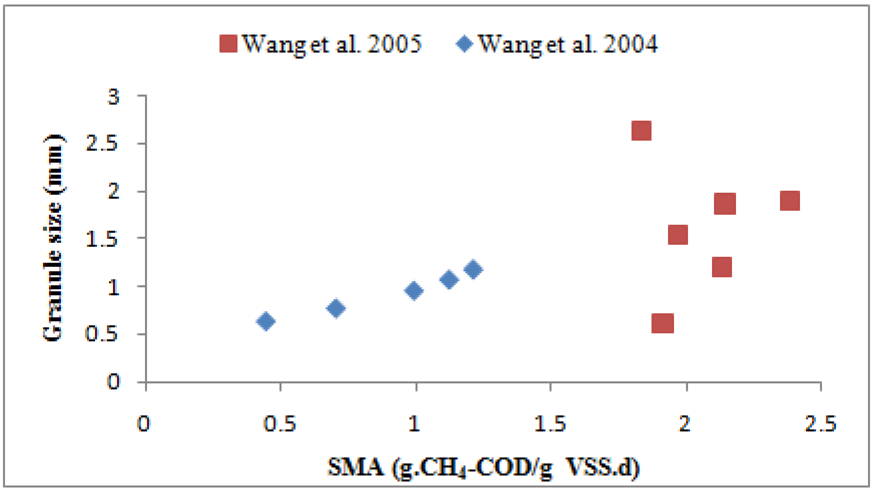

Fig.4 Variation of specific methanogenic activity (SMA) with granule size

SMA is important characteristics of granular sludge, as organic loading rate was increases activity of granules in reactor decreases. At very higher organic loading rate diameter of granule decreases as well as SMA values due to shearing of granules [22]. When OLR exceeded 16 g CH_4-COD /g VSS.d in reactor, the SMA decreased, indicating that methanogenic activity may have been inhibited by accumulation of fatty acids, although this is tentative suggestion since there was no direct determination of VFAs [23].

3.5 VSS/SS Ratio

The SS and VSS of the reactor contents increased with increasing granule size, indicating a corresponding increase in the biological solids inventory. VSS/SS ratio oscillating in nature with granule size in [22], VSS/SS ratio range varies in the order of 0.59 to 0.78. VSS/SS ratio continuously increasing with increasing granule size in [23], at maximum granule size 1.18mm VSS/SS ratio observed 0.69.

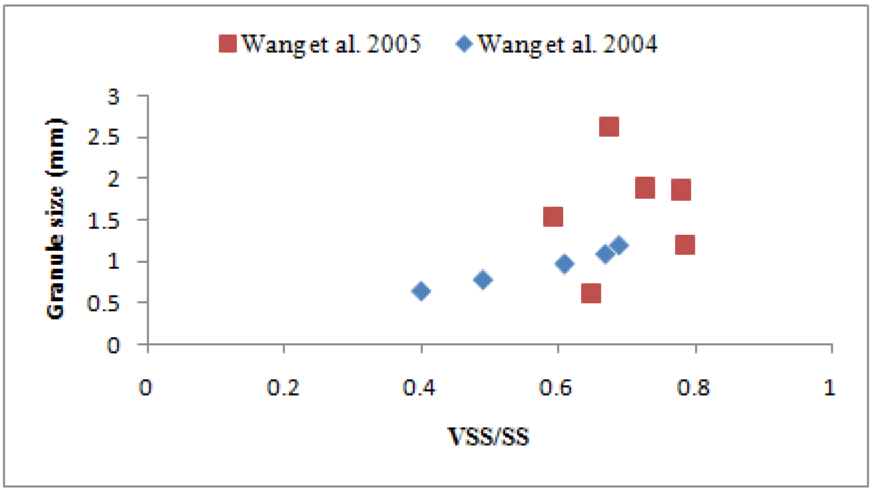

Fig.5 Variation of VSS/SS ratio with granule size

From fig. 5 when granules achieved good settling characteristics, VSS/SS ratio become constant (0.86-0.89) at different granule size [22]. The amount biomass wash-out had likely exceeded with increasing organic loading rate [23]. The better retention of sludge in the reactors could be attributed to higher settleability and strength of granules developed in the reactors. These data indicated the extent of biomass wash-out had been reduced by increasing the organic loading capacities of the reactors. As the seed sludge was taken from digested anaerobic sludge, high suspended solids content resulted in low SVI values, when microorganisms multiplied in the reactors, the VSS/SS of the sludge increases [24].

IV. CONCLUSION

In this paper described the five factors OLR, V_{up}, SVI, SMA, and VSS/SS ratio studied is on granule size development in UASB reactor. It has been informed that OLR and upflow velocity are more critical parameters controlling the granule size variations in UASB reactors. The fluctuation in VFA may arise due to fluctuation in OLR, either in form of HRT or influent COD. The optimum range of OLR and HRT can only be decided after considering the influent characteristics and other operating conditions. Layer formation in granules is due to interaction of intragranular diffusion and degradation kinetics of the substrate. SVI is an important physical parameter, was considered as an indicator of granule settleability. Low SVI values show good granule settling property. . Good settling properties are obtained through the flocculation of the biomass in the form of dense granules with diameters up to several millimetres. SMA parameter shows the metabolic property of granule, activity of granules increases with increasing granule diameter. VSS/SS ratio was also increasing with granule size, when no any shearing of granules occurs in the reactor. The evolution of size distribution is of vital importance for the monitoring of UASB reactors.

Nomenclature

OLR organic loading rate (g.COD/L.d)
V_{up} upflow velocity (m/h)
SVI sludge volume index (L/g)
SMA specific methenogenic activity (g CH_4-COD/g VSS.d)
VSS/SS volatile suspended solids/suspended solid % ratio
Q liquid inflow rate (l/d)
Q_g gas production rate (l/d)
SV settling velocity (m/h)
S_0 influent COD concentration (g/L)

V. ACKNOWLEDGEMENT

Authors are grateful to MHRD, New Delhi and the director, MNNIT, Allahabad for their help in completing and preparing this paper.

REFERENCES

[1] Fang, HHP., Chui, HK., Li, YY., Chen, T., “Microstructural analysis of UASB granules treating brewery wastewater,” Water Sci Technol, Vol. 31, 1995, 129-135.

[2] Lettinga, G., Hulshoff Pol, L.W.,. “UASB-process design for various types of wastewaters,” Water Science and Technology, Vol. 24, No. 8, 1991, 87-107.

[3] Bhunia, P., Ghangrekar, M.M.,. “Required minimum granule size in UASB reactor and characteristics variation with size,” Bioresource Technology, Vol. 98, No. 5, 2007, 994-999.

[4] Ghangrekar, M.M., Asolekar, S.R., Ranganathan, K.R., Joshi, S.G., "Experience with UASB reactor start-up under different operating conditions," Water Science and Technology, Vol. 34 (5-6), 1996, 421-428.

[5] Schmidt, J.E., Ahring, B.K., "Granular sludge formation in upflow anaerobic sludge blanket (UASB) reactors," Biotechnology and Bioengineering, Vol. 49, No. 3, 1996, 229-246.

[6] Kalyuzhnyi, SV., Sklyar, VI., Davlyatshina, MA., Parshina, SN., Simankova, MV., Kostrikina, NA., Nozhevnikova, AN., "Organic removal and microbiological features of UASB reactor under various organic loading rate," Bioresour Technol, Vol. 55, 1996, 47-54.

[7] Shayegan, J., Ghavipanjeh, F., Mirjafari, P., "The effect of influent COD and upward flow velocity on the behaviour of sulphate reducing bacteria," Process Biochem, Vol. 40, 2005, 2305-2310.

[8] Singh, RP., Kumar, S., Ojha, CSP., "Nutrient requirement for UASB process: a review," Biochem Eng J, Vol. 3, 1999, 35-54

[9] Singh, KS., Viraraghavan, T., "Impact of temperature on performance , microbiological and hydrodynamic aspects of UASB reactors treating municipal wastewater," Water Sci Technol, Vol. 48, 2003, 211-217.

[10] Fang, HHP., Chui, HK., Li, YY., Chen, T., "Degradation of phenol in wastewater in an upflow anaerobic sludge blanket reactor," Water Res, Vol. 30, 1996, 1353-1360.

[11] Kosaric, N., Blaszezyk, R., Orphan, L., "Factors influencing formation and maintenance of granules in upflow anaerobic sludge blanket reactors (UASBR)," Water SciTechnol, Vol. 22, 1990, 275-282.

[12] Kalogo, Y., M'Bassiguie´ Se´ka, A., Verstraete, W., "Enhancing the start-up of a UASB reactor treating domestic wastewater by adding a water extract of Moringa oleifera seeds," Applied Microbiology and Biotechnology, Vol. 55, No. 5, 2001, 644-651.

[13] Tiwari, M., Guha, S., Harendranath, C., Tripathi, S., "Enhanced granulation by natural ionic polymer additives in UASB reactor treating low-strength wastewater," Water Research, Vol. 39, No. 16, 2005, 3801-3810.

[14] El-Mamouni, R., Leduc, R., Guiot, SR., "Influence of the starting microbial nucleus type on the anaerobic granulation dynamics," Appl Microbiol Biotechnol, Vol. 47, 1997, 189-194.

[15] Morgan, JW., Forster, CF., Evison, LM., "A comparative study of the nature of biopolymers extracted from anaerobic and activated sludge," Water Res, Vol. 24, 1990, 743-750.

[16] Jai, XS., Fang, HHP., Furumai, H., "Surface charge and extracellular polymer of sludge in the anaerobic degradation process," Water Sci Technol, Vol. 34, 1996, 309-316.

[17] Hulshoff Pol, LW., de Castro Lopes, SI., Letttinga, G., Lens, PNL., "Anaerobic sludge granulation," Water Res, Vol. 38, 2004, 1376-1389.

[18] Liu, Y., Xu, HL., Yang, SF., Tay, JH., "Mechanisms and models for anaerobic granulation in upflow anaerobic sludge blanket reactor," Water Res, Vol.37, 2003, 661-673.

[19] Shen, CF., Kosaric, N., Blaszezyk, R., "The effect of selected heavy metals (Ni, Co and Fe) on anaerobic granules and their extracellular polymeric substances (EPS)," Water Res, Vol. 27, 1993, 25-33.

[20] Yu, H.Q., Fang, H.H.P., Tay, J.H., "Effects of Fe^{2+} on sludge granulation in upflow anaerobic sludge blanket reactors," Water Science and Technology, Vol. 41, No. 12, 2000, 199-205.

[21] Yu, H.Q., Fang, H.H.P., Tay, J.H., "Enhanced sludge granulation in upflow anaerobic sludge blanket (UASB) reactors by aluminum chloride," Chemosphere, Vol. 44, No. 1, 2001b, 31-36.

[22] Wang, Y., Show, K.Y., Tay, J.H., Sim, K.H., "Effects of cationic polymer on start-up and granulation in upflow anaerobic sludge blanket reactors," Journal of Chemical Technology & Biotechnology, Vol. 79, No. 3, 2004, 219-228.

[23] Wang, JS., Hu, YY., Wu, CD., "Comparing the effect of bioflocculant with synthetic polymers on enhancing granulation in UASB reactors for low-strength wastewater treatment," Water SA, Vol. 31, 2005, 177-182.

[24] Syutsubo, K., Harada, H., Ohashi, A., Suzuki, H., "An effective start-up of thermophilic UASB reactor by seeding mesophilically grown granular sludge," Water Sci Technol, Vol. 24, 1997, 35-59.