ISBN 978-93-86878-04-5
7th International Conference on Chemical, Agriculture, Environment and Natural Sciences (CAENS-2017)
Kuala Lumpur (Malaysia) Nov. 20-21, 2017

Studies on Efficiency of UASB Reactor during Sludge Granulation

Chandra Sekhar. Matli[1] and A Randheer Reddy[2]

[1] Professor in Civil Engineering, Water & Environment Division, National Institute of Technology, Warangal - 506 004, INDIA. E-mail: 380mcs@gmail.com

[2] Post Graduate Student, National Institute of Technology, WARANGAL - 506 004, INDIA.

Abstract: *Wastewater treatment is becoming ever more critical due to pollution of fresh water resources, increasing wastewater disposal expenses and stringent discharge regulations that have lowered permissible contaminant levels in waste streams. The ultimate goal of wastewater management is the protection of the environment in a manner commensurate with public health and socio-economic concerns. Understanding the nature of wastewater is fundamental to design appropriate wastewater treatment plant and technologies. Research in the field of anaerobic wastewater treatment emphasizes the importance of sludge granules in anaerobic biodegradation process. It is believed that the development of anaerobic granules is reflecting an important role on the performance of reactor. This paper presents an overview on the concept of up-flow anaerobic sludge bed (UASB) reactor operation and the results of the studies on factors influencing the efficiency of the reactor. Anaerobic granulation theories like physical, microbial and thermodynamic theories, mechanism of granule agitation inside the reactor are also discussed in this paper. Experimental studies were designed to study the efficiency of the UASB for removal of Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), Volatile suspended solids (VSS), Total suspended solid (TSS), Volatile fatty acids (VFA), Sulphates for different sludge ages. Attempt is made to investigate the process of sludge granulation using anaerobically activated sludge as seed sludge at various sludge ages. Maximum granulation was observed at sludge age of 150 to 180 days. At this sludge age the diameter of granules is about 0.6 mm at which the efficiency of reactor is high because of well matured dense granules. At early stages, the granules formed will wash out from the reactor very frequently. Reduced efficiencies of the preparatory processes of hydrolysis, acidogenesis and acetogenesis, rather than methanogenesis itself are the cause of poor performance at short sludge ages. Hence the removal efficiency of reactor is poor at an early stage. The success of these reactors is related to their capacity for biomass accumulation by settling without need of a carrier. Density of granules was highly dependent on VSS/TSS ratio of influent and effluent conditions of reactor. Good settling properties are obtained through the flocculation of the biomass of in the form of dense granules with diameters up to several millimeters.*

Keywords: *UASB, Sludge age, Efficiency, Sludge granulation, VSS, TSS.*

1. Introduction

For developing countries, the anaerobic treatment offers an attractive prospect. With many options available for treatment of municipal and industrial effluents, the anaerobic treatment process stands ahead because of minimum sludge formation and production of energy in the form of methane. For the past several decades the research on fundamentals of anaerobic digestion was going on and the total duration of digestion process has come down with the advancement of high rate anaerobic processes (Amatya, 1996; Abdullah, 2007; Lettinga and Hulshoff, 1991). The relative size of these high rate digesters is quite small and the space occupied is also less. Instead of flat and short reactors as used earlier, tall reactors are being applied. The loading rates for high rate anaerobic digesters are comparatively high, because of the retention of active granular settle able sludge in the reactor. The basic studies of the microbiological and biochemical aspects of anaerobic digestion have revealed many of the characteristics and nutritional requirements of individual and groups of anaerobic bacteria, while pilot and full scale engineering studies have demonstrated the operational requirements and instabilities often encountered in the process.

The granular biomass from the existing Upflow Anaerobic Sludge Blanket (UASB) reactor can be used as inoculum material to start-up new UASB reactor. When such material is not available, non-granular material such as anaerobic digested sludge, waste activated sludge and cow dung manure can be used as inoculum. Granular sludge can be developed using non-granular material for inoculation. Although, there are reports of wastewaters containing high-suspended solids being successfully treated in UASB reactors without primary sedimentation, the separation of suspended solids is still suggested, especially for reactors having non-granular configuration (Habeeb, 2011; Tiwari, et al., 2005; Liu et al., 2003).

The granulation of sludge enables the treatment system to show good treatment performance at high organic loading rates. It also leads to the reduction in the reactor size, which renders the treatment system cost effective. Nevertheless, parameters like temperature and upflow velocity substantially affect the sludge granulation (Chen and Lun, 1993; Gangrekar, et al., 2005). The introduction of proper phase-separator design into the conventional UASB can significantly improve its treatment efficiency under comparable conditions. This paper presents the results of studies on the process of sludge granulation with different sludge age and the effect of phase separator design on the treatment efficiency of UASB reactor.

2. Salient Features of UASB Reactor and Methodology

Studies are carried out for the UASB reactor commissioned in Amberpet, Hyderabad for treating 339 MLD domestic wastewater. The characteristics of domestic wastewater are given in Table 1. Primarily treated wastewater is allowed into the UASB reactor with design features listed in Table 2.

TABLE I: Characteristics of Domestic Wastewater

S No	Parameter	Influent value
1	pH	7.17
2	Dissolved Oxygen	0.50 mg/l
3	Biochemical oxygen demand (5 days @ 20^0 C)	274 mg/l
4	Chemical oxygen demand	490 mg/l
5	Total suspended solids	330 mg/l
6	Volatile suspended solids	106 mg/l
7	Feacal coliforms	4.96*10^5 MPN/100ml
8	Temperature	24.8^0 C
9	Volatile fatty acids	108 mg/l

Wastewater characteristics, namely, Chemical oxygen demand (COD), Biochemical oxygen demand (BOD), Total suspended solids (TSS), Volatile suspended solids (VSS), Volatile fatty acids (VFA) and sulphate are determined as per Standard Methods for the Examination of Water and Wastewater (APHA, 2005). Sludge samples were collected at different sludge ages at three different points of UASB as given below.

- Inlet point of UASB reactor
- Outlet above sludge blanket portion (Gas-Liquid-Solid Separator - GLSS portion)
- Final outlet of reactor

An average of ten sludge samples were analysed for different parameters during the study for sludge age of 60, 90, 120, 150 and 180 days. Using these experimental results, removal efficiencies of the UASB w.r.t different parameters is determined during granulation of sludge inside the reactor.

A mathematical algorithm developed by Vlyssides, et. al. (2007), was used to estimate the size distribution of a sludge sample from the UASB using the VSS/TSS ratio of each fraction, assuming spherical granules.

$$d = -8*10^{-4}\log\left[1-\frac{VSS/TSS}{97.27}\right]$$

where - d = diameter of granules; VSS=Volatile suspended solids; TSS=Total suspended solids

TABLE II: Design Features of UASB Reactor

S No	Parameter	Influent value
1	Height	5.80 m
2	Free board in reactor	0.50 m
3	Total Height	6.30 m
4	Gas collector height	2.10 m
5	Feed inlet point distance	2.00 m
6	Hood width	0.44 m
7	No of Reactors	24
8	Size of reactor	32*28*5.8m
9	Peak flow	28,250 m^3/hr
10	Avg flow	14,125 m^3/hr
11	Hydraulic Retention Time	8.88 hr (avg. flow); 4.44 hr (peak flow)
12	Solids Retention Time	33 days
13	Sludge bed concentration	60 kg/TSS/m^3
14	Max Sludge bed height	80% of height of gas collector
15	Avg upflow velocity	0.65 m/hr
16	Max upflow velocity	1.30 m/hr
17	Max Aperture velocity	2.50 m/hr
18	Angle of gas collector	50^0
19	Settling Zone Surface	75% of total
20	Sludge produced	1380 m^3/day
21	Gas Produced	6423 m^3/day
22	Manure	165 m^3/day

3. Results and Discussion

***Performance of UASB* -** The removal efficiency of the UASB reactor at different stages of sludge digestion for different sludge ages is presented in Table 3 and Fig. 1. The removal percentage of all parameters that are considered for the present study is higher in the sludge blanket portion when compared to that of GLSS portion. The overall removal efficiency of the reactor is maximum for 150 days sludge age and beyond that the efficiency of removal is declining. For efficient performance of the UASB, the sludge age needs to be maintained as 150 days.

Variation of SS in Sludge – The average concentration of Volatile Suspended Solids (VSS) and Total Suspended Solids (TSS) in sludge samples collected at different sludge ages are given in Table 4. VSS/TSS ratio reflects biomass growth and its quality. VSS/TSS ratio is helpful in determining the granule size. Density of granules was highly dependent on VSS/TSS ratio of influent and effluent conditions of reactor. From Table 4, it is observed that VSS/TS ratio gradually increases from 0.3 to about 0.8 with increasing sludge age. This steady increase in VSS/TS ratio also reflects a steady increase in the granules size. The TSS and VSS of the reactor contents increased with increasing granule size, indicating a corresponding increase in the biological solids inventory, VSS/TSS ratio range varies in the order of 0.31 to 0.80. After the sludge age of 150 days VSS/TSS ratio was constant. The amount biomass wash-out had likely exceeded with increasing organic loading rate. The better retention of sludge in the reactors could be attributed to higher settleability and strength of granules developed in the reactors.

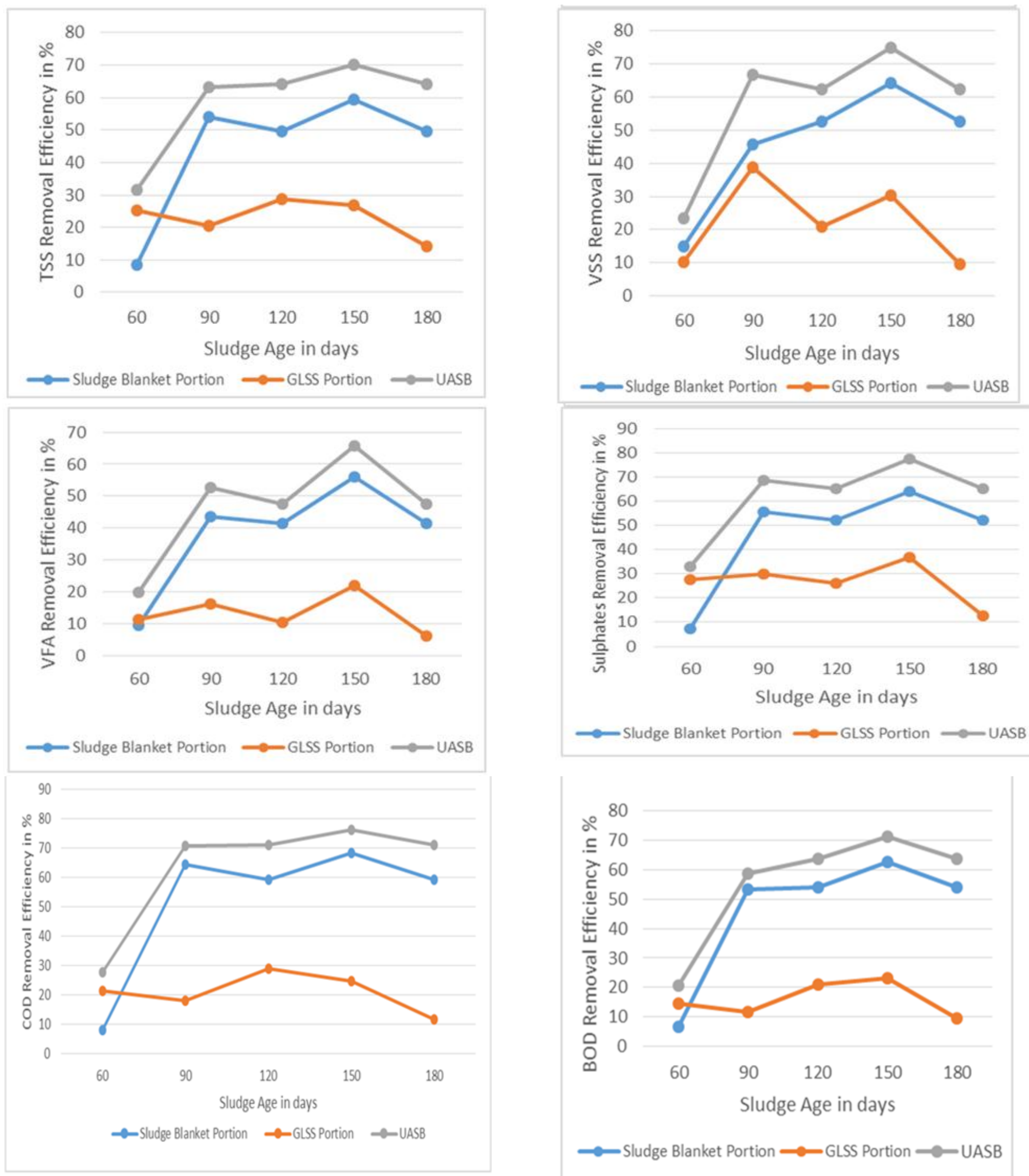

Fig. 1 Performance of UASB at Different Stages

Table 4 indicates that the size of sludge granule increases with sludge age upto 150 days and after that there is no increase in size of the sludge granules. Minimum start up time required for UASB reactor by using anaerobically activated sludge as seed sludge is 45 days because from then the VSS/TSS ratio is above 50%. Steady increase in VSS/TSS ratio also reflects a steady increase in the granules size .The TSS and VSS of the reactor contents increased with increasing granule size, indicating a corresponding increase in the biological solids inventory, VSS/TSS ratio range varies in the order of 0.31 to 0.80.

Maximum size of granules was observed at sludge age of 150 to 180 days. At this sludge age efficiency of reactor is high because of well matured dense granules. During early stages, the granules formed will escape from the reactor very frequently. Hence the removal efficiency of reactor is less at an early stage and maximum when sludge age is 150 days. The removal efficiencies of BOD, COD, TSS, VSS, VFA and Sulphates indicated in Table 3 and Fig. 1 comply with this result.

4. Conclusions

The key factor for the successful operation of UASB reactor is mainly formation of granules and the same is reported in this paper. The performance of the reactor is assessed using sludge age as a fundamental parameter. The performance of UASB reactor was maximum in terms of removal efficiency of BOD, COD, TSS, VSS, VFA and Sulphates during the sludge age of 150 to 180 days. The removal efficiency in sludge blanket portion is significant when compared to that of GLSS portion. The GLSS portion improved the overall efficiency by 10-20% in the UASB reactor. Maximum size of granules was observed at sludge age of 150 to 180 days. At this sludge age efficiency of reactor is high because of well matured dense granules. Good settling properties are obtained through the flocculation of the biomass to form of dense granules with diameters up to several millimetres. For want of time, factors influencing size of sludge granules and sludge composition could not me attempted in this study.

5. References

[1] Abdullah Yasar (2007) - Sludge granulation and efficiency of phase separator design, Journal of Environmental Sciences (JES), Vol. 19, pp. 553–558.

[2] Amatya P L, (1996) - Anaerobic treatment of industrial wastewater by upflow anaerobic sludge blanket (UASB) reactor, M. Sc. Thesis. Asian Institute of Technology, Bangkok, Thailand.

[3] Chen, J and Lun, S.Y. (1993) - Study on mechanism of anaerobic sludge granulation in UASB reactors. Water Science Technology, Vol. 28 (7), pp.171–178.

[4] Ghangrekar, M, M, Asolekar, S, R, and Joshi, S, G (2005). Characteristics of sludge developed under different loading conditions during UASB reactor start-up and granulation. Water Res, Vol. 39, pp. 1123–1133.

[5] Habeeb S A (2011) - Granules initiation and development inside UASB Reactor and the main factors affecting granules formation process, International Journal of Energy and Environment (IJEE) Volume 2, Issue 2.

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

[7] Liu Y., Hai-Lou X., Shu-Fang Y., Joo-Hwa T. (2003) - Mechanisms and Models for Anaerobic Granulation in Upflow Anaerobic Sludge Blanket Reactor. Water Research 37: pp.661–673.

[8] Tiwari, M, K, Guha, S, Harendranath, C,S, and Tripathi, S (2005) - Enhanced granulation by natural ionic polymer additives in UASB reactor treating low-strength wastewater. Water Res, Vol. 39, pp. 3801– 3810.

[9] Vlyssides A G (2008) - Simple estimation of granule size distribution and sludge bed porosity in a UASB reactor , Global NEST Journal, Vol 10, No 1, pp 73-79, Copyright© 2008 Global NEST.

TABLE III: Removal Efficiency (in %) of UASB for Different Sludge Age

Sludge Age	COD Removal			BOD Removal			TSS Removal			VSS Removal			VFA Removal			Sulphates Removal		
	Sludge Blanket Portion	GLSS Portion	UASB	Sludge Blanket Portion	GLSS Portion	UASB	Sludge Blanket Portion	GLSS Portion	UASB	Sludge Blanket Portion	GLSS Portion	UASB	Sludge Blanket Portion	GLSS Portion	UASB	Sludge Blanket Portion	GLSS Portion	UASB
60	7.98	21.42	27.69	6.86	14.73	20.58	8.41	25.17	31.46	14.84	10.09	23.43	9.48	11.42	19.82	7.31	27.63	32.92
90	64.37	18.12	70.83	53.12	11.66	58.50	54.11	20.51	63.25	45.61	38.70	66.66	43.63	16.12	52.72	55.55	30.00	68.80
120	59.42	28.90	71.15	53.95	21.09	63.66	49.71	28.81	64.20	52.67	20.75	62.50	41.37	10.29	47.41	52.08	26.19	65.16
150	68.43	24.84	76.27	62.58	23.07	71.22	59.35	26.98	70.32	64.16	30.23	75.00	55.97	22.03	65.67	64.15	36.84	77.35
180	59.42	11.84	71.15	53.95	9.70	63.66	49.71	14.14	64.20	52.67	9.75	62.50	41.37	6.07	47.41	52.08	12.57	65.16

TABLE IV: Variation in TSS and VSS in Sludge Samples at different sludge ages

Sludge age (days)	30	45	60	90	120	150	180
VSS(g/l)	9.6	26.4	32.4	42.6	49.8	58.3	60.5
TSS(g/l)	30.3	42.1	50.6	59.8	65.9	72.4	75.4
VSS/TSS (%)	31	62	64	71	76	80	80
Diameter of Sludge Granules (mm)	0.137	0.352	0.414	0.457	0.528	0.600	0.600