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EFFICIENCY OF UPFLOW ANAEROBIC GRANULATED SLUDGE BLANKET REACTOR IN TREATING FISH PROCESSING EFFLUENT

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Key words : Fish processing effluent, UASBR, Granulation, COD reduction.

ABSTRACT

The UASB Reactor concept represents a very promising proposition for the anaerobic treatment of a variety of industrial wastes and even of domestic wastes. In the present study, after careful acclimatization, the granules were found to be well adapted to fish processing effluent and the COD reduction was upto 96% at organic loading rates from 150 mg l^{-1} d^{-1} to 2,200 mg l^{-1} d^{-1}. The biogas production was 748 l kg^{-1} COD^{-1}. The process efficiency and biogas generation was found to be increased with an increase in the organic loading rate. The size of the granules was 1-3 mm and exhibited good settleability

INTRODUCTION

Waste water from the industries may be treated following the primary, secondary and tertiary treatments methods. The physico-chemical processes comes under primary treatment and generally accepted as expensive treatment methods (Gohil, 1995; Kavitha *et al*. 2003). To overcome these problems, the secondary biological treatment method has been received much attention and considered as an efficient, low cost treatment system (Sastry, 1995; Kavitha *et al.* 2002). It includes aerobic and anaerobic processes. Due to high energy requirements, operation, heavy cost as well as constraints in stable maintenance, the aerobic biological treatment technologies cannot be replicated in developing countries and in industries of low turn over rates

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(Rajamani *et al*. 1995; Rintala, 1991).

Anaerobic Technologies is considered as the waste treatment and management solution for the 21st century. Out of a variety of anaerobic reactor configurations currently available, UASB reactors are the most effective one (Young and McCarty 1969; Lettinga *et al*. 1980; Lettinga and Hulshoffpal, 1991; Anwar khursheed, 1997; Sundarajan *et al*. 2000). The modified version of the conventional anaerobic digester is called as UASB process where the waste water is applied in upward direction through a dense blanket of anaerobic sludge (Dhahadgaka and Mhaisalka, 1996; Panesar *et al*. 1999). The high rate reactors, the upflow anaerobic sludge blanket reactor has been successfully used in treating various food processing, fermentation industrial wastes land fill leachates and sewage (Lettinga *et al*. 1984; Wang *et al*. 1985; Saropj Sayed *et al*. 2002). Hundreds of full scale plants based on this technology are operating worldwide. The granulation process greatly enhances the amount of retained viable biomass thus establishing very long solid retention time (SRT) at low hydraulic retention time (HRT). In order to protect the environment from pollution, the high rate reactors are employed and so the advantages of UASB reactor are high removed capacity, short retention time, high COD removal efficiency, low energy demand, no need of supporting media, simple reactor construction, long experience in practice (Weiland *et al*. 1991; Harendranath *et al*., 1998). The treatment efficiency of various effluents has been proved by the UASB reactors. Rajamani *et al*., (1995) had established a pilot scale UASBR to treat the tannery effluent (60%). Sunita Sastry and Kaul (1996) treated Dairy effluent treatment using the UASBR and got 80% treatment efficiency. Evaluation of high rate anaerobic digesters was carried out by Kasturi Bai *et al*. (1997) and they have suggested the UASBR for the treatment of domestic wastewater. Kalyuzhnyi *et al*. (1997) had received 95% of treatment efficiency in high strength cheese-whey waste water in UASB reactor. It is evident that limited works have been undertaken in fish processing effluent using UASB reactor. Fish processing units are mostly situated near the coastal area and the waste waters are directly discharged into the sea which will affect the aquatic life drastically (Jorgenson, 1968). To protect the world from aquatic pollution, strict environmental legislations were amended and the industries are forced to recover and treat the effluents properly to a greater extend than they do now. Under these circumstances, this investigation on the anaerobic treatment of sea food processing effluent has been undertaken.

MATERIALS AND METHODS

A laboratory scale UASB reactor was fabricated with a capacity of 3.58 L total volume and 0.58 L for separator volume by means of PVC pipe. The internal diameter of the reactor was 0.78 L and the aperture area was 20% of the cross sectional area. Provision for gas collection was made on the top of the reactor. Four sampling ports at a distance of 100 mm were provided to study the sludge profile at every stage. The Gas-Liquid-Solid (GLS) separator is the key element of the UASB reactor (Schellingkout and Collazis, 1988) and it was fixed on the top of the reactor, where gas was separated and collected in the gas collector, liquid was left in the reactor and solids were also separated and settled down due to their higher density (Lettinga, 1980). Sludge washout was regularly done for efficient treatment. A feed inlet point, of two numbers to ensure complete mixing with a common feed distributor, was connected to a peristaltic pump by means of silicone tube of 4 mm diameter. The capacity of the peristaltic pump (McLins-20) was 2 mL to 10L hr^{-1}. To keep the sludge blanket under suspension, upflow velocities in the range of 2.3 ft h^{-1} have been used (Lettinga and Hulshoff Pol, 1991). The top of the anaerobic reactor was tightly closed to maintain the stringent anaerobic condition. The over all experimental set-ups were given in Fig 1. During the experimental period, the treatment efficiency of the UASB system at various organic and hydraulic loading rates was studied. The inlet and outlet waste water was tested in terms of chemical oxygen demand, suspended solids, VFA, TVS and alkalinity. The biogas produced from the UASB reactor was measured using a wet gas flow meter (APHA, 1995).

Start Up of the UASB reactor

The purpose of the start-up of the high rate anaerobic processes is to cultivate and to retain high concentration of active biomass in the reactor. The first start-up of an anaerobic process is considered critical as it may require long period of time and may result in the failure of the process. The start-up is affected by factors such as the seed sludge, the mode of process operation, wastewater characteristics and environmental factors (De Zeeuw *et al*. 1984; Fang *et al*. 1994) in the reactor. This is a time consuming and delicate process. This period is considered as base pillar for the development of first macroscopic sludge granules which will shoot up the treatment efficiency of the substrate. About 34% of the reactor volume was filled with a well digested suitable inoculum such as cow dung cum fish processing sludge mixed slurry (Lettinga *et al*. 1986). The nutrient solution was also added with the effluent which includes the nitrogen, phosphorous source in addition to trace elements (Luonsi and Rintala, 1984; Shen *et al*. 1993). The addition of nutrient solution will motivate the granular biomass in the initial state of the granulation process (Alibhai *et al*. 1986; Van den Berg, 1980; Praveen, 1995).

Granulation of UASB reactor

Good performance of UASB reactor depends mainly upon the formation of a bed of well settling and highly active granular sludge; with a low Sludge Volume Index and a high methanogenic activity (Gatze Lettinga *et al*. 1980). A well digested sludge from the secondary settling tank of M/s Amulya sea food, Tuticorin had been collected in polythene carboys and brought to the laboratory. The sludge was kept in the anaerobic digester which had 15 litres of working volume for two weeks. The methanogenic activity of the sludge was tested by connecting the gas outlet of the digester to the gas flow meter and measured. After the specific methanogenic activity test, about 37g l^{-1} of volatile solid content sludge was filled in the UASB reactor, upto the height of 33% and the reactor was started for the granulation process. To induce granulation process a small quantity of anthracite powder and crushed granules from the UASB reactor were added before the start-up of the reactor. The favourable environmental conditions were provided for the growth of anaerobic bacteria. Shock loading was avoided to prevent the loss of microbial biomass (Routh, 2000; Shivayogimath, 2003). The substrate used for granulation purpose was, the fish processing effluent. During granulation process, the suitable operational conditions were strictly followed (Table 1).

The granulation process was started with the flow rate of 60 mL h^{-1} using the peristaltic pump. The flow rate was maintained and the retention time of the effluent in the reactor was 60 hours. The experiment was started with the organic loading rate of 150 mg L^{-1} and continued with the same flow rate for about 25 days, so as to obtain the COD reduction of 80%. The flow rate and the COD loading rate were increased to 300, 600, 1200, 1600, 2000 and 2,200 mg L^{-1}, after confirming 80% reduction of COD at every stage. Since the upflow velocity was recommended as 0.9 to 1.5 m hr^{-1} it was maintained as 1.25 m hr^{-1}. The experiment was continued for 120 days.

RESULTS AND DISCUSSION

The characteristics of fish processing effluent are given in Table 2. The effluent was found to be acidic in nature and the COD was 2,280 mg L^{-1} while the total dissolved solids content was 2,000 mg L^{-1}. The treatability studies of the effluent was conducted by UASB granulated bed reactor by providing various organic loading rates like 150, 300, 600, 1,200, 2,200 mg L^{-1} in terms of COD. Various hydraulic loading rates include 60, 120, 200 and 300 mL hr^{-1}. The stability of the reactor was measured in term of VFA and alkalinity ratio which was found from 0.44 to 0.55 overall the process.

pH

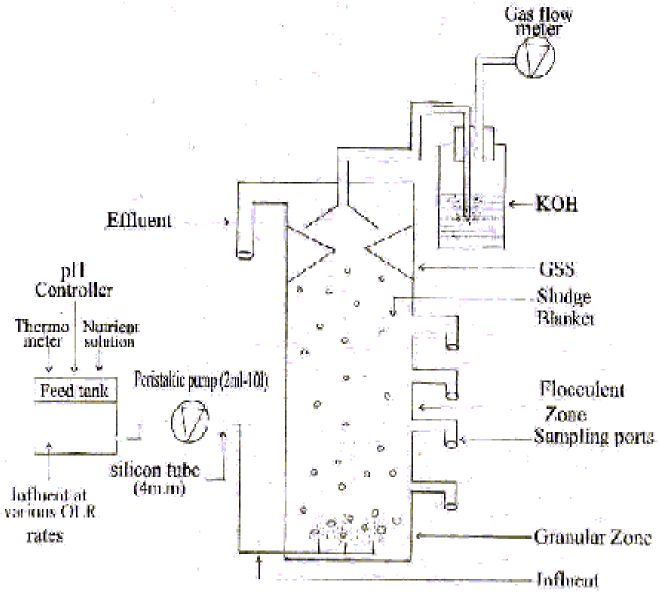

Fig. 1 Schematic diagram of experimental set up.

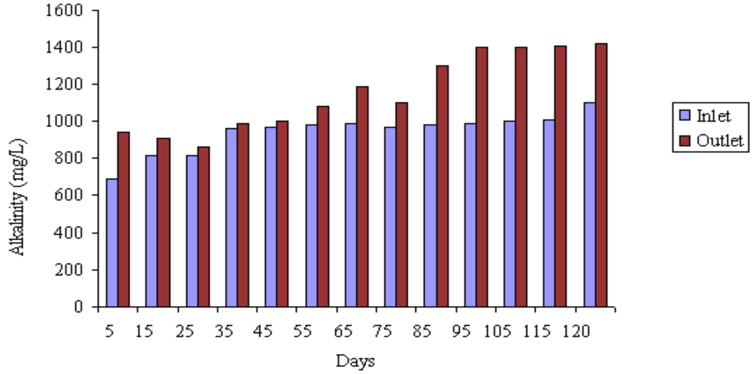

Fig 2. Alkalinity of fish processing effluent (mg/L)

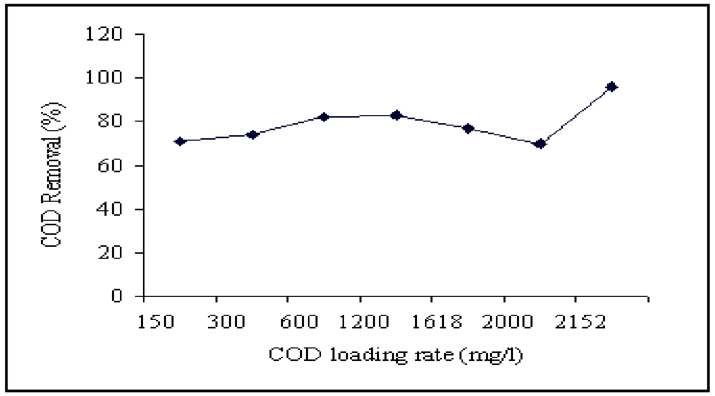

Fig 3. Removal of COD at various loading rates before and after the granulation period

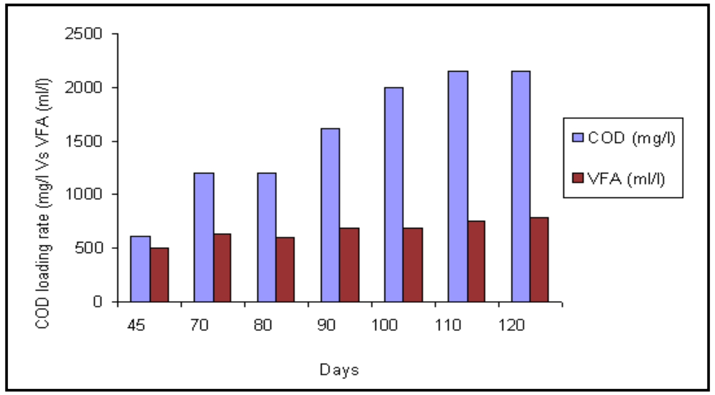

Fig 4. COD loading rate Vs VFA in fish processing effluent

The pH is a very important variable in the UASB process. When the pH in the reactor is too low (<6.0), the consumption of fatty acids gets strongly inhibited. If the pH is too high (>8.0), the bacteria are limited in their growth by the low concentrations of unionised fatty acids (Bolle *et al*. 1986). The pH determines the growth of both methanogens and acidogens (Lettinga and

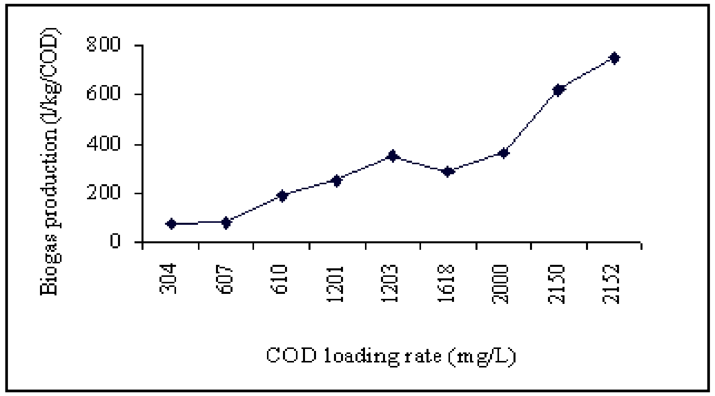

Fig 5. Biogas production in fish processing effluent at various COD loading rates

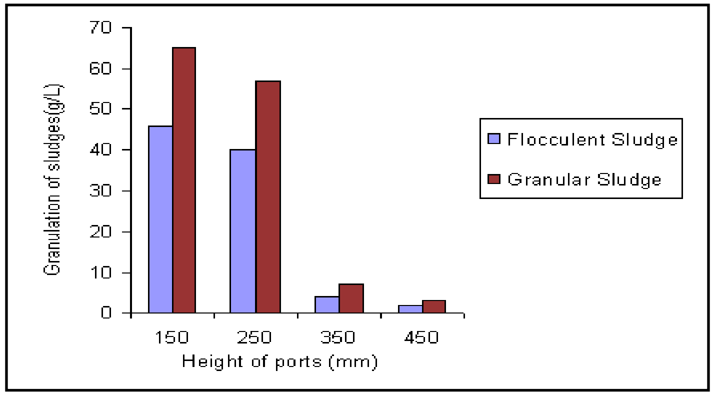

Fig 6. Sludge Profile: Flocculent and Granular bed

Hulshoff Pol, 1991). So, the pH of the effluent in the inlet and outlet during the granulation and after the granulation period was maintained between 6.5 and 7.6. On the 5th day the inlet and outlet pH were 6.71 and 7.17, while it was 6.91 and 7.30; 6.97 and 7.25; 6.90 and 7.40; 6.9 and 7.6 in the 30th, 60th, 90th and 120th days respectively. A decrease in pH (6.5) was observed on 75th day and was due to the less dosage of sodium bicarbonate given in the inlet. Moreover, the pH was maintained from 6.5 to 7.6 which favoured the growth of long filamentous bacteria and increased the reactor efficiency by forming granular biomass. Sodium bicarbonate was added to maintain digester pH for the proper regulation of the reactor (Alberto Dalla Torre *et al.* 1986). Maximum pH was deserved (7.6) on the 105th and 120th day (Table 3). The increase in pH of the outlet was due to the conversion of stronger acids, ie., volatile fatty acids to a weaker carbonic acid. The analysis of the effluent coming out of the UASB reactor showed that the pH was within the safe limits in this experiment. Failure of the digester due to VFA accumulation can be controlled by maintaining the pH.

Alkalinity

Table 1
Operational conditions for granulation process

Sr No.	Parameter	Amount (mg /L)
1.	pH	6.5 - 7.8
2.	TSS	50 - 100
3.	COD	150 - 160
4.	Alkalinity	700 - 1200
5.	VFA	350 - 700
6.	VFA:Alkalinity	0.5 - 0.58

Note: All parameters are expressed in mg/L except pH

Table 2
Characteristics of fish processing effluent

S.No.	Parameters	Quantity (mg/L)
1.	Flow	95
2.	pH	6.5-7.5
3.	Suspended Solids	300-350
4.	BOD (5 days 200 c)	800-850
5.	COD	1500-2280
6.	TDS	1900-2000
7.	Residual chlorine	0.5-1.0
8.	Ammonical nitrogen	15-30
9.	Kjeldhal nitrogen	30-50

Note : All parameters are expressed in mg/L except pH

With an increase in pH, there was an increase in the alkalinity of effluent. In the inlet it was between 690 and 1,100 mg l^{-1}. The alkalinity in the outlet was 940 to 1,420 mg l^{-1} throughout the process with an increase in organic loading rate. This will enhance the growth of granular biomass. Increase in alkalinity during start-up period was the indication of well maintenance of anaerobic condition. But there was a decline in the trend from 820 to 860 mg l^{-1} on 25th day. The change in alkalinity from 20 to 40 days was mainly due to the growth of microbial biomass which had to be acclimatized. After 40 days of the start-up, the alkalinity increased in the outlet and this indicates the stable condition of the anaerobic digester. The alkalinity was mainly based on the pH of the substrate. Alkalinity in the form of sodium bicarbonate was available as a result of the anaerobic biodegradation of the substrate in the reactor (Simpson *et al*. 1960). Fig 2. showed that the reactor was in the balanced state throughout the course of the study.

Efficiency of COD Removal Before Granulation

The COD removal efficiency was strictly depends upon the organic loading rate in terms of COD. The initial COD level was maintained as 150 mg L^{-1} until the COD reduction reached to 80%. After attaining 80% reduction, the COD loading rate was increased to 300, 600, 1,200, 2,200 mg L^{-1} respectively. During the start-up period the reactor was fed with a very low loading rate from 150 mg^{-1} d^{-1} and poor removal efficiency (20%) was observed. This may be mainly due to the slow microbial growth in the reactor. Under low loading rates the COD removal efficiency was not upto the expected level mainly because of the insufficient mixing provided by the biogas generated (Jayantha *et al*, 1994). The COD removal efficiency of 72% was reached on the 20th day. The removal efficiency slowly increased throughout the study except on shock loading. This was due to the slow growing nature of the anaerobic micro organisms and relatively long period required for start-up and acclimation of anaerobic systems (Lucy Pugh *et al*. 1987). This initial period was mentioned as "stabilization period" or "acclimatization period". This period was considered as more essential for the better development of compact biogranules (Herbert,

Table 3

pH of fish processing effluent during the granulation period of UASB reactor

Day	Inlet	Outlet
5	6.71	7.71
10	6.72	7.25
15	6.60	7.30
20	6.48	7.41
25	6.97	7.45
30	6.91	7.31
35	7.05	7.30
40	6.85	7.27
45	6.90	7.25
50	6.92	7.50
55	6.95	7.52
60	6.97	7.25
65	6.64	7.30
70	6.68	7.31
75	6.50	7.25
80	6.75	7.33
85	6.82	7.48
90	6.90	7.40
95	6.91	7.50
100	7.05	7.55
105	7.10	7.6
110	6.9	7.4
115	6.8	7.4
120	6.9	7.6

1985). The initial decrease in COD removal efficiency at high organic loading rates was due to the inability of the methanogenic population to remove the volatile acid intermediates (Dhabadgoankar and Mhaisalkar, 1996). On the 41st day, the removal efficiency was very low (3%) which was due to the sudden increase in the organic loading rate and this may be retained after few days of same organic loading rate. It was observed that, the percent removal of COD was increased to 82% on 110th day, which indicate the onset of the formation of granules (Fig 3.).

Table 4

Ratio between Alkalinity and VFA during the treatment of fish processing effluent after granulation

	Alkalinity (mg/L)		VFA (ml/L)		VFA/Alkalinity
Days	Inlet	Outlet	Inlet	Outlet	
60	990	1125	285	500	0.44
65	990	1190	280	609	0.51
70	1000	1250	303	630	0.50
75	970	1100	300	580	0.53
80	980	1155	293	593	0.54
85	980	1300	290	700	0.54
90	990	1350	308	690	0.51
95	990	1400	310	760	0.54
100	980	1300	298	683	0.53
105	1000	1400	306	786	0.56
110	973	1384	303	748	0.55
115	1010	1409	320	772	0.55
120	1100	1420	318	780	0.55

Table 5

Performance of UASB reactor using fish processing effluent after granulation

Day	pH	COD (mg/L)		VFA		Alkalinity (ml/L)		VFA/Alkalinity (mg/L)		
Days	In	Out	In	Out	% Removal		In	Out	In	Out
60	6.97	7.25	610	112	82	285	500	990	1125	0.44
65	6.64	7.30	1209	600	50	280	609	990	1190	0.51
70	6.68	7.31	1201	490	59	303	630	1000	1250	0.50
75	6.50	7.25	1200	338	72	300	580	970	1100	0.53
80	6.75	7.33	1203	200	83	293	593	980	1155	0.54
85	6.82	7.48	1598	960	40	290	700	980	1300	0.54
90	6.90	7.40	1618	812	50	308	690	990	1350	0.51
95	6.91	7.50	1608	525	67	310	760	990	1400	0.54
100	7.05	7.55	2000	995	50	298	683	980	1300	0.53
105	7.10	7.6	2000	600	70	306	786	1000	1400	0.56
110	6.9	7.4	2150	385	82	303	748	973	1384	0.55
115	6.8	7.4	2140	200	91	320	772	1010	1409	0.55
120	6.9	706	2152	80	96	318	780	1100	1420	0.55

Efficiency of COD Removal After Granulation

The substrate degradation was faster at the initial stage and most of the substrate was consumed by bacteria near the bio granule surface (Fang, 1995). The granular bed formed after 60 days of the commencement of the process. The shape of the granules was found to be symmetric in nature. Methanogenic bacteria appear to be extremely sensitive to environmental factors like pH, temperature and pressure. Among them *Methano sarcina* would provide a higher substrate utilisation rather than *Methanothrix* (Noike *et al*. 1985). Each gram of granule in the reactor was capable of converting a daily maximum of 0.86 of COD into methane (Herbert *et al*. 1995). Granulation was observed on the 60th day onwards. The concentrated biomass can withstand more organic loading rate. On the 80th day the organic loading rate was increased upto 1203 mg L^{-1} d^{-1} COD, the maximum efficiency observed was 83%, which was considered as higher than the flocculated bed reactors. This was the indication of the presence of stabilised biomass in the form of compact granules. The present study proved that using UASB reactor 96% removal of COD was possible in fish processing effluent. The COD reduction was observed to be a steady state from 80% to 96% for different organic loads, like 150, 300, 600 and 2,200 mg L^{-1} (Fig. 3). The maximum removal efficiency (96%) in fish processing effluent was due to the formation of well settling granules. From this study it was concluded that the COD removal efficiency of the UASB reactor depend mainly on the COD loading rate and it was not sensitive to either the hydraulic retention time or COD of the waste water.

In the UASB process, after it get stabilised the micro organisms attach themselves to each other or to small particles of suspended matter to form agglomerates of highly settleable granules and an active sludge blanket was formed at the bottom of the reactor (Fang *et al.* 1994). The gas produced cause sufficient agitation to keep the bed fully mixed (Dhabadgaonkar and Mhaisalkar, 1996). Gas recirculation provides mechanical agitation at the gas-liquid interface in the digester compartment and was useful to prevent the accumulation of biodegradable waste solids in the lower part of the reactor and/or to ensure a good contact between the bacteria and substrate Ute Austermann-Haunn *et al*. 1997). Active anaerobic sludge can be preserved unfed for many months without deterioration under proper conditions (Lettinga, 1979a).

The granular character of the sludge in UASB reactor has three distinct engineering advantages over flocculent sludges: 1) the micro organisms are densely packed, no space is lost for inert support. Also the spherical granules provide high micro organisms to space ratio 2) granules show excellent settling properties because of their large size 3) granules have a higher specific activity and thus can take higher Organic loading (Grotenhuis, 1991; Schmidt and Ahring, 1995, 1996; Harendranath and Singh, 1996).

Volatile Fatty Acid

The VFA alkalinity ratio after granulation was shown in Table 4 and it was maintained between 0.44 and 0.55. The volatile fatty acid concentration found in the effluent varied from 500 to 780 mL^{-1} at different organic loading rates. It's concentration in the effluents was mainly depend upon the COD loading rates (Fig 4.). Low volatile fatty acid indicate the presence of methanogenic granular bed in the reactor and it was not the rate limiting step at these conditions (Gujer and Zehnder, 1983; Hulshoff Pol 1989).

The UASB system can withstand high volatile fatty acids load than any other anaerobic systems of waste water treatment. Lesser organic loading rate decreases the volatile fatty acids concentrations (Jayantha, *et al*. 1996). The initial increase in VFA indicated higher amount of acidogens than the rate of methanogens, which influence the formation of the steady state granules (Table 4). For the development of high strength granules the VFA and alkalinity ratio was strictly maintained from 0.44 to 0.55 (Kavitha and Murugesan, 2004).

Biogas generation

After 40 days of start-up period, the biogas was produced by the granules and it was recorded on every five day still the end of the study. One kg of COD removal had produced 350 L of biogas. The biogas production rate was observed as significant in various COD loading rates during this study. The biogas generation was generally increased with an increase in organic loading rates (Fig 5.). This was because of the maximum substrate utilization by the organisms in the reactor (Subramaniam and Sastry, 1988). During this process each gram of methane entitled corresponded to four gram of COD removal. The rate of gas production increased gradually at a peak of 748 L kg^{-1} COD^{-1}. The sharp reduction in the biogas production on the 85th day was mainly because of the sulphate reduction and in addition to that some quantity of gas escaped along with the effluent. The gas production rate reached a steady state from 100 to 120th day. At this junction, it has been ascertained that the granulation process was vigorous and the experiment was continued for further treatment. The quality of gas recovered was considerable and it may be utilized as valuable fuel (Jayantha *et al*. 1994).

Sludge Profile

The sludge accumulation in terms of VSS mass during the entire experimental period can be best expressed by the sludge profile measured over the height of the reactor (Anwar *et al*. 1997) as shown in Fig 6. The samples were collected from four ports regularly on the 10th, 30th, 60th, 90th, 120th days and analysed.

At the bottom of the reactor three types of zones were formed according to the size of the particles. They are flocculent zone, settler zone and granular zone. The sludge in the bottom zone was observed to be granular in shape and had well and undigested material smell. The middle zone or blanket zone also had a granular sludge but of smaller size and smelled like well digested material. The top zone had sludge of dispersed and flocculent nature and smelled like well digested material. The sludge had a pH of 6.8-7.2 and registered an increasing trend from bottom to the top. Similar trend was noticed in alkalinity too. This was due to the production of CO_2 during the process in which the waste water developed contact with biomass (Pathe *et al*. 1990). The low activity of the biomass was observed at the bottom while the middle, upper part had higher activity (Calliviguarelli *et al*. 1990).

The sludge concentration from the bottom of the reactor was increased upto 65 g L^{-1}, which indicated the stabilised granulated bed formation of the reactor. The well developed and properly designed UASB reactor had a high concentration of solids in the bottom and relatively low at the top. The fairly formed sludge concentration gradient was 3.1, 7.2, 56.8 and 65 g L^{-1}. The sludge concentration increased along with the increasing loading rates. The increased sludge concentration tends to enhance the treatment efficiency and granulation process (Wu *et al*. 1985). On the 60th day a sudden decrease in the sludge concentration from 32.23 to 32 g L^{-1} was observed. This may be due to the washout of sludge. The expanded bed and the cross sectional area of the reactor was influencing the sludge biomass (Surtzen han and Jewell, 1980). It was evident that the concentration of the biomass was 55 to 60 percent higher in granular bed than the flocculent bed. This higher sludge (granular) clearly indicated that the granular sludge bed accommodates more biomass than the flocculent bed and reduce more organic loads (Murugesan *et al*. 2000). It was also significant that the treatment efficiency was higher than the flocculent bed reactor. From this investigation we came to a conclusion that the granular bed had higher sludge concentration when compare to the flocculent bed. This provide further scope for conducting more small scale and pilot scale experiments with different retention time, upflow velocity, temperature etc.

Performance Efficiency of UASB reactor

The performance efficiency of the UASB reactor was given in the Table 5. From this we came to a conclusion that the UASB reactor can be well used for the treatment of fish processing effluent. The reactor can able to retain high biomass concentration without sludge washout even at high substrate loading rates. The change of feed (OLR) affected the performance of the reactor for a short period and the biomass adapted to the new substrate after a short acclimatization period. The overall treatment efficiency in terms of the COD removal was 96% and the biogas production was 76 to 748 L kg^{-1}.

CONCLUSION

The application of an UASB reactor for the treatment of fish processing effluent had proved to be a very cost-effective method. The extensive research and experience that is nowadays available on UASB reactors no doubt renders the process, one of the most suitable for the treatment of low and high strength wastewater. The application of UASB reactor help the industries to install a compact anaerobic treatment system to accommodate a large quantity of high organic effluent because the high rate anaerobic UASB reactor requires less space and cost effective. Energy is produced in anaerobic treatment. The produced biogas can be used as a fuel in the industrial sector. The high conversion rates made the UASB system compact compared to most aerobic systems.

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