Management of Natural Resources in a Changing Environment

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UASBR: An Effective Wastewater Treatment Option to Curb Greenhouse Gas Emissions

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Introduction

Anaerobic digestion is used for treating high strength organic wastewater. Since late seventies, anaerobic digestion has experienced an outstanding growth in research and full scale application, particularly for the treatment of food and beverage industry effluent and to a lesser extent for municipal wastewater (Hulshoff-Pol et al., 1998; Yu et al., 2004; Fountoulakis et al., 2004; Filik-Iscen et al., 2007). Anaerobic digestion is a complex, natural, and multi-stage process in which organic compounds are degraded through a variety of intermediates into methane and carbon dioxide, by the activity of a consortium of micro organisms. Interdependence of the bacteria is a key factor in the anaerobic digestion process (Parawira et al., 2005) and the deciding factor for quality of treated effluent as well as gas generation.

The upflow anaerobic sludge blanket reactor (UASBR) is a reactor of upflow where the organic material on its way through the covering of sludge composed of a large population of anaerobic bacteria begins its biodegradation. The reactor is composed of three essential parts: a zone of digestion, a zone of sedimentation, and a separator of gas-solids-liquids. These are integrated into one column where the primary sedimentation process, the bio-digestion of the sludge and the secondary sedimentation is done simultaneously as a primary and secondary treatment of residual waters, achieving efficiency in the removal of organic material up to 85% (Sponza, 2001). Anaerobic digestion treatment is one of the technologies being considered to provide a solution to the treatment of high strength organic wastewater and maximum amount of biodegradable fraction can be converted into useful energy end product in the form of biogas and fertilizer in the form of digestate (Fernandez et al., 2001; Saravanan et al., 2004; Song et al., 2004). The upflow anaerobic sludge blanket process is one of the most commonly used wastewater treatment system, with several installations treating industrial wastewater (Techobanoglous et al., 2004).

Ion exchange resins consist of a polymeric matrix and a functional group with a mobile ion. The most common synthetic structures are: cross linked polystyrene, cross linked polymethacrylate, phenol-formaldehyde etc. The manufacture of ion exchange resins involve the preparation of a cross linked copolymer followed by sulfonation in the case of strong acid cation resins, or chloromethylation and amination of the copolymer for anion resins (Dow, 2000). The production process involves use of variety of chemicals like styrene, divenyl benzene, ethylene glycol dimethacrylate, isobutyl alcohol, formaldehyde, methanol, ethylene dichloride, trimethyl amine, dimethyl amine, methacrylates, polyvinyl alcohol, oleum, etc. The unused solvents and chemicals make the effluent from the manufacturing process high in organics, total dissolved solids, and low in pH. The presence of different chemicals in the wastewater makes the treatment challenging and requires a cost effective as well as robust process with minimum GHG emissions to meet the international commitments.

The objective of the work was to study the anaerobic treatability and possibility of utilizing UASBR in order to optimize the operational cost, reduce green house gas emissions and convert waste into useful end products.

Methodology

Pilot Scale Digester

The UASB reactor was constructed from MS-FRP sheet with 2 m length, 1 m width and 4 m height. The working volume of the reactor was 7 m^3 (Fig. 1). Sampling ports were provided for the collection of samples. A centrifugal pump (Grundfos, Chiu) of capacity 5 m^3/hr was used for feeding wastewater into the reactor. A HDPE tank of 500 L capacity was utilized as buffer tank.

Seed and Inoculation

The reactor was initially seeded with inoculum from an anaerobically digested sludge of a sewage treatment plant. On subsequent days, jaggery solution along with urea and DAP was added to obtain the desired mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) in the reactor. After achieving 4% MLSS and 0.75 MLVSS/MLSS ratio, effluent injection at the rate of 0.5 m^3/d started for acclimatization of the micro organisms. The acclimation period in this study was 60 days.

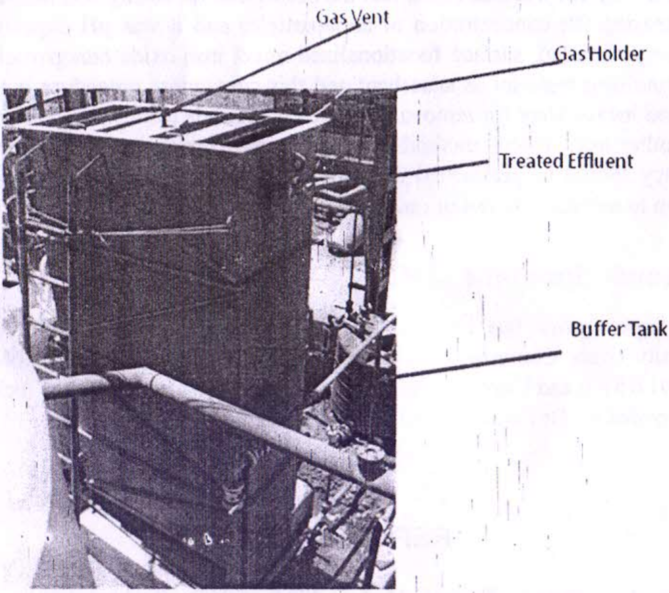

Fig. 1: Pilot upflow anaerobic sludge blanket reactor.

Sampling and Analysis

The functioning of the reactor was monitored over a period of four months. The samples at feed, in the reactor and treated effluent were taken on regular basis to monitor the performance of the reactor. Chemical oxygen demand (COD), total suspended solids (TSS), total dissolved solids (TDS), MLSS and MLVSS were regularly analyzed for the untreated and treated effluent as well as sludge according to the standard methods (APHA, 1995).

Operating Conditions

The reactor was operated in fill, react and withdrawal mode during initial period of operation. After stabilization of the process, the reactor was operated in continuous mode for a period of three months.

Results and Discussion

Characterization of Wastewater

The pilot plant was installed in the ion exchange resin manufacturing facility located in Ankleshwar, Gujarat to understand the actual operational conditions and the associated difficulties. The manufacturing facility was already having a state of the art effluent treatment facility consisting of collection tank, solids contact clarifier, aerobic reactor based on membrane technology and hence, it was decided to install the pilot plant after clarifier (Fig. 2) in order to get rid of suspended solids which are polymeric in nature and non-biodegradable and replicate the future condition. Hence, the samples were collected from the outlet of solids contact clarifier and the characterization is given in Table 1. The effluents were rich in organics with high COD (7000-8000 mg/L), BOD (2500-3500 mg/L) and TDS (15000-25000 mg/L) values. Presence of high organics in the wastewater was due to unused chemicals and washing of reactors. Apart from these harsh parameters, the BOD/COD ratio (0.3-0.35) is not very much favourable for biological treatment.

Table 1: Wastewater characteristics

Sr. No.	*Parameters*	*Unit*	*Inlet*
1	pH	–	7.0-9.0
2	Total dissolved solids	mg/L	15000–25000
3	Total suspended solids	mg/L	100-200
4	Volatile suspended solids	mg/L	50-150
5	COD	mg/L	7000-8000
6	BOD	mg/L	2500-3500
7	Oil and grease	mg/L	< 30

UASBR Performance

Acclimatization of micro organisms for the wastewater was judged from the analysis of MLSS and MLVSS in the reactor. MLVSS represents the micro organisms in the reactor, responsible for biodegradation of organics. The organic loading rate (OLR) was increased or decreased based on the MLVSS in the reactor. During start up phase, ups and downs were observed in the MLVSS value. If sharp reduction of 25% in MLVSS value was observed during acclimatization period, part of wastewater feed was replaced with jaggery solution in order to maintain 0.5 food/micro-organism (f/m) ratio. The process stabilized in 60 days and after that continuous increase in MLVSS was observed (Fig. 2).

OLR was always maintained above 1 kg COD/m^3/d by combination of organics supplied from process effluent and jaggery. Initial OLR from effluent was kept as low as 0.5 kg/m^3/d and increased in a stepped manner to 4.5 kg/m^3/d over a period of 75 days (Fig. 3). The process was found stabilized at this point and the system was operated for almost one month with this OLR. Consistency in the treated effluent was observed during this period.

Upflow velocity is regarded as one of the key parameter significantly affecting microbial ecology and characteristics of UASBR. It also helps in flushing the hazardous gases thereby keeping the system in healthy condition. The optimum upflow velocity for the wastewater and the system under

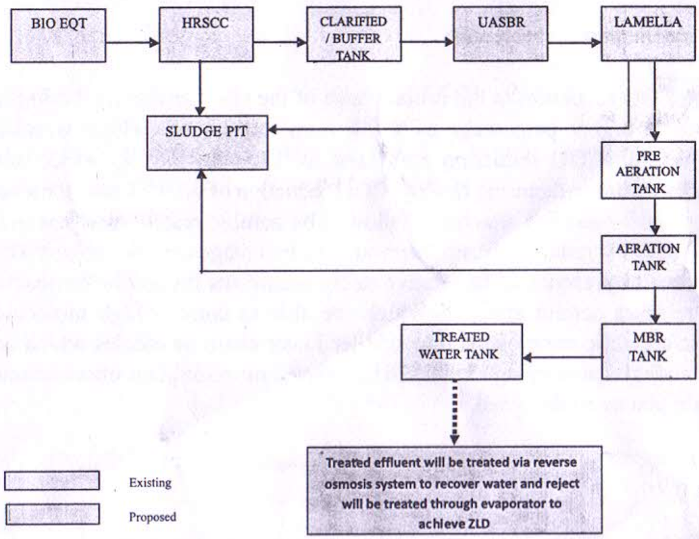

Fig. 2: Schematic diagram of effluent treatment plant for resin manufacturing facility.

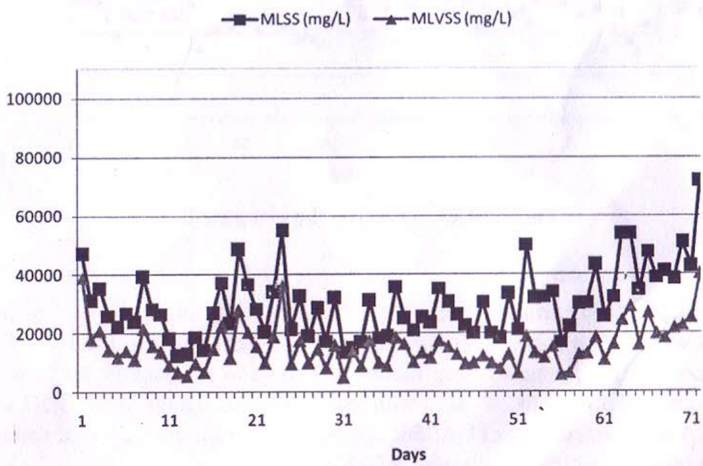

Fig. 3: MLSS and MLVSS trend.

study was found to be 0.5 m/h. In order to maintain the desired OLR and upflow velocity, the feed to UASBR is 4-5 times of the influent and hence the same was recycled back to buffer tank/UASBR feed tank. This also helps in minimizing the toxicity and shock load to UASBR.

The COD reduction in the initial phase of the start up was on the higher side due to higher percentage of COD from the jaggery which is easily biodegradable. COD reduction stabilized to 47-50% (Fig. 4) which was desired by the manufacturing facility. COD reduction of 90-95% was achieved with the combination of anaerobic followed by aerobic reactor, whereas only 85-90% of COD reduction was observed with two-stage aerobic reactor. This may be due to presence of facultative micro organisms present in the reactor which releases certain enzymes which are able to convert high molecular aliphatic/aromatic compounds into smaller linear chain molecules which are easily biodegradable (Singh et al., 2012). Based on pilot plant observations, full scale plant was designed.

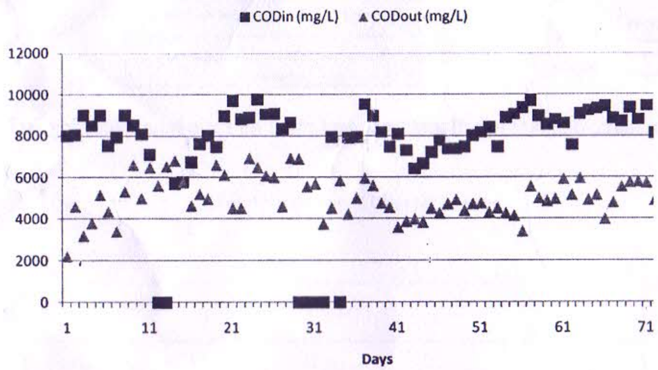

Fig. 4: COD profile over the trial period.

Cost Economics

The manufacturing unit was planning to increase the production of IX resins, which will lead to increase in flow as well as organic load to the ETP. The expansion of the manufacturing facility will lead to increase in the flow to ETP from 180 m^3/day to 240 m^3/d with marginal or no change in the COD and BOD. A cost comparison of UASBR against installation of an aerobic reactor was carried out which is presented in Table 2.

Extra investment in case of UASBR = (88.18 – 84.70) Lacs INR
= 3.48 Lacs INR
Savings in operating cost = (11.02 – 1.70) Lacs INR
= 9.32 Lacs INR
Pay back period = 3.48/9.32
= 0.37 yr = 4.5 months

The capital cost associated with the installation of anaerobic reactor is more than that of aerobic reactor for achieving almost similar reduction in organics but the operating cost is almost six times less which makes the UASBR a better choice for developing countries.

Table 2: Cost comparison for aerobic reactor versus UASBR

Sr. No.	*2-Stage Aerobic Reactor*		*Anaerobic followed by Aerobic Reactor*	
1	Mechanical Equipments			
	AT Blower (2 × 1200 m^3/hr)	5,60,000	UASBR feed pump (60 m^3/hr)	68,000
	Sludge pump (2 × 10 m^3/hr)	50,000	Sludge recirculation pump (1 m^3/hr)	50,000
	Sec. clarifier mechanism	1,80,000	Lamella clarifier	5,00,000
	Diffuser (100)	4,50,000	UASBR Internals + Gas flare system	40,00,000
	Total	**12,40,000**		**46,18,000**
2	Civil Equipments @ 6000 INR/m^3			
	Aeration tank (1145 m^3)	68,70,000	UASBR tank (700 m^3)	42,00,000
	Sec. Clarifier (60 m^3)	3,60,000		
	Total	**72,30,000**		**42,00,000**
	Grand Total (1+2)	**84,70,000**		**88,18,000**
3	Operating Cost @ 4.5 INR/kWh (INR/Annum)			
	AT Blower	10,08,000	UASBR feed pump	1,41,000
	Sec clarifier mechanism	52,000	Sludge pump	29,000
	Sludge recirculation pump	42,000		
	Total	**11,02,000**		**1,70,000**

Reduction in GHG Emissions

The degradation of organics by anaerobic bacteria results in methane and carbon dioxide. Methane is a source of energy which can be utilized for heating requirements or power generation. Generation of methane and reduction in operating cost results in huge reduction of GHG emissions.

(a) Methane generation and power production

COD reduction in the reactor = 3500 mg/L × 240 m^3/d/1000

= 840 kg/d

Approx. methane generation @ 0.30 m^3 CH_4/kg COD reduced

= 0.30 × 840 = 252 m^3/d

= 10.5 m^3/hr

Power production = (Vol. of methane × cal. value × engine eff.)/860

= 10.5 m^3/hr × 9500 kcal/m^3 × 0.35/860

= 40.6 kWh = 974 kWh/d

(b) Power consumption of 1494 kWh/d can be achieved due to installation of UASBR in place of aerobic reactor as provided in Table 3. This reduction is due to elimination of aeration tank blowers which are major power consumer in effluent treatment plant. Considering 330 days of manufacturing facility operation, the annual saving in power consumption results to 4,93,020 kWh.

(c) Total savings in power consumption (a+b) = (3,21,420 + 4,93,020)
= 8,14,440 kWh/annum

(d) Considering, one tonne CO_2 is released with generation of 800 kWh electricity (www.carbonfootprint.com), reduction in GHG emissions for 8,14,440 kWh consumption is 1020 tonnes per annum CO_2 emissions.

(e) To offset 1020 tonnes of CO_2 emissions, 6,50,000 – 10,00,000 INR should be invested in clean energy and reforestation.

Table 3: Power consumption comparison for aerobic reactor versus UASBR

Sr. No.	*Equipments for aerobic reactor*	*Power consumption (kWh/d)*	*Equipments for UASBR*	*Power consumption (kWh/d)*
1	AT blower	1536	UASBR feed pump	85
2	Sec clarifier mechanism	35	Sludge pump	20
3	Sludge recirculation pump	28		
	Total	**1 599**		**105**

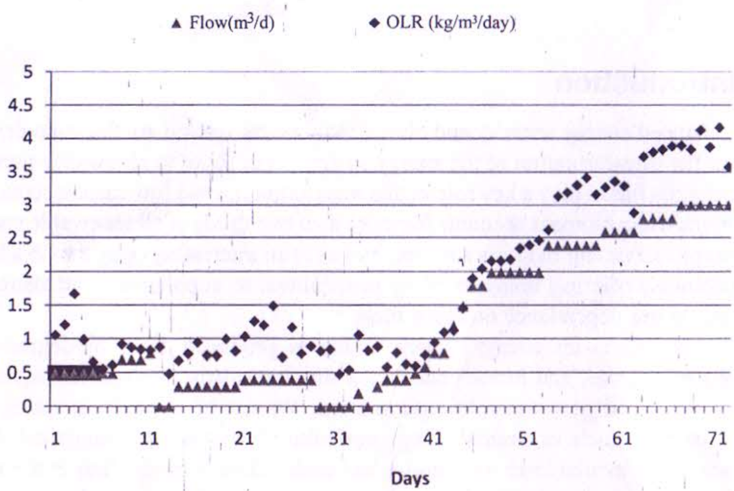

Fig. 5: Flow and OLR profile over the trial period.

Conclusions

The results of the study reflect that UASBR is a cost effective option for the treatment of IX resin manufacturing facility wastewater. The process is able to degrade high molecular weight compounds through action of consortium of micro-organisms. The optimum COD removal efficiency of reactor was 50% corresponding to HRT and organic loading rate of three days and 4.5 kg/ m^3/d respectively which is expected to improve over the extended period of operation. The stabilization/acclimatization period for the system is 60 days with sludge recycling option for reducing hazardous gases and to minimize shock loading. UASBR along with EASP results in COD reduction up to 95%. Cost benefit analysis indicates that UASBR is a better choice if compared to extended aerobic reactors. Moreover, UASBR is helpful in reducing green house gas emissions and a natural option to minimize global warming.

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