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Application of UASB Reactor in Industrial Wastewater Treatment – A Review

K.Kaviyarasan

Abstract: The contents presented in this paper focuses on the performance of UASB (Upflow Anaerobic Sludge Blanket) reactor for treating various industrial and domestic wastewaters at various operating conditions. The reactors can be used conveniently for the treatment of tannery, distillery, food processing, metal mining, dairy, domestic wastewater etc. The performance of the reactor mainly depends on the OLR and HRT. The author highlighted to enhance the start-up and granulation in UASB reactors, biogas (methane and biohydrogen) production, coupling with post-treatment and the reactors to overcome the temperature constraint and pH, improving the removal efficiencies of the organic matter, nutrients and pathogens in the final effluent. Kinetics, models and hydraulic characteristics are useful to verify the experimental data and also helpful for the further research.

Key words: biogas, hydraulic characteristics, UASB, Wastewater, Organic loading rate (OLR), Hydraulic retention time (HRT)

1 Introduction

1.1 About UASB Reactor

UPFLOW Anaerobic Sludge Blanket (UASB) reactor also called as anaerobic reactor was used to treat various industrial wastewaters like petroleum [1,10], distillery [2, 11], Canning industry [3], Heavy metals [4], Paper and Pulp [5], Tannery [6,7], Pharmaceutical [15], domestic waste water [8] etc. The sludge blanket in the UASB comprised of microbial granules, i.e. small agglomerations (0.5 to 2mm in diameter) of microorganisms and because of their weight able to resist being washed out in the upflow. Bacteria living in the sludge, break down organic matter by anaerobic digestion and transforming it into biogas. The rising bubbles mix the sludge without the assistance of any mechanical parts. Sloped walls push down the material that reaches the top of the tank. The gas that rises to the top is collected in a gas collection dome and can be used as energy (biogas) [9].

1.2 Factors Influencing Reactor's Performance

1.2.1 pH

The bacteria responsible for hydrolysis are acid-producing bacteria and methane producing bacteria. The acid-producing bacteria commonly tolerating a low pH, but the optimum pH range is 5-6. The methane producing on bacteria work better in a pH range 6.7-7.4. If the reactor goes out of 6-8 range, the activity of methane producing bacteria is reduced and these causes negative influence the reactor's performance.

- *Assistant Professor, Department of Civil Engineering, Dr.Paul's Engineering College, Vanur, Villupuram, Dist., Tamil Nadu, India. PH - 0413-2677006/07 E-mail: kaviyarasanmtech@gmail.com*

1.2.2 Temperature

Temperature plays a key role on the anaerobic process in UASB technology, to enhance the microorganisms ability to produce biogas from digestion. The suitable temperature provides the microorganisms with a less viscosity and good degradation. Since the operating conditions of UASB reactor are under mesophilic or thermophilic conditions, under these conditions of sludge handling, storage etc. prior to carrying out biodegradability, activity tests. Thermophilic reactor sludge is particularly susceptible to low temperatures. If the sludge sample is stored at a low temperature, activity tests may present long lag phases in order to achieve a re-acclimatisation of the sludge population to the thermophilic test temperature.

1.2.3 Hydraulic Retention Time (HRT)

HRT is considered as an important for operating parameter which controls the performance of UASB reactor. Very long HRT will affect adversely on the process of sludge granulation in UASB reactor and very short HRT is disadvantageous due to the fact that the biomass may move out with effluent.

1.2.4 Organic Loading Rate (OLR)

This is another important parameter to control the performance of UASB reactor. Increase of OLR will cause an operation problem. OLR is an important factor for the removal of COD.

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The Schematic diagram of UASB reactor with all components is

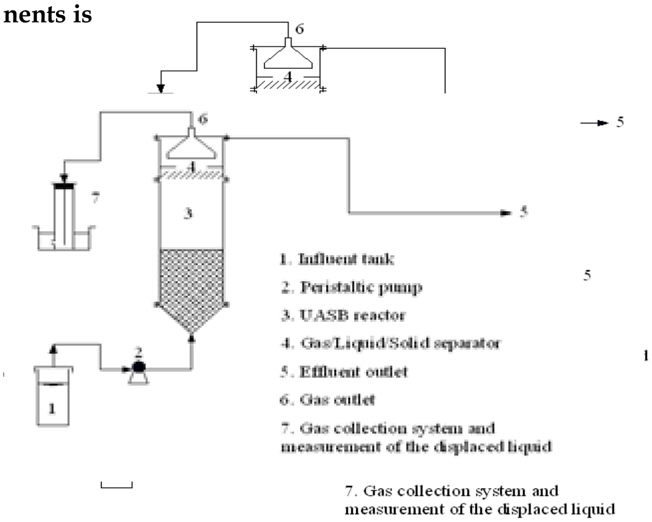

Fig.1. The Schematic diagram of UASB reactor

1.3 Advantages:

- Low land demand, can be constructed underground with locally available material.
- No aeration system required
- High treatment efficiency for high-strength wastewater.
- Low sludge production, treated sludge is stabilized (can be used to enrich soil).
- Effluent is rich in nutrients and can be used for agricultural irrigation.
- Biogas can be used for energy (but usually requires scrubbing first).
- Reduction of CH_4 and CO_2 emissions.
- Low odour emissions in case of optimum operation.

1.4 Disadvantages:

- Require skilled staff for construction, operation and maintenance
- Treatment may be unstable with variable hydraulic and organic loads.
- UASB effluent requires treatment to remove pathogen.
- Long start-up phase.
- Not resistant to shock loading.
- Constant source of electricity and water flow is required.
- Not suitable in cold climate regions. [10]

2. Earlier Work by Various investigators

2.1 Treatment of Industrial Waste water using UASB reactor

Two laboratory scale UASB reactors were operated in parallel at ambient room temperature of 25-29°C for the treatment of petroleum refinery wastewater. Each reactor volume was 2.36L and fed the biomass obtained from local palm oil mill effluent. The flow rate was adjusted to 1.4L/h & HRT maintained 40 hrs. The reactors were operated for a period of 120 days. With low organic loading rate (OLR) of 0.58, 0.89, 1.21 and 2.34 kg/m^{3}d, the COD removal efficiencies were found 78, 82, 83 & 81% respectively. The maximum efficiency was found to be 83% at the OLR of 1.21 kg/m^{3}d. [11]

The UASB reactor was used to treat sugar industry waste water at varying loading rates of 0.5 - 16g COD/L and operating period 200 days. The reactor volume was 7.95 L and sludge from septic tank (size < 1mm) was used as seed with an initial concentration of 16.6 g VSS/L. The authors achieved the maximum COD removal of 89.4% and volumetric biogas production of 4.66 L/L.d at HRT 6 hrs and ambient temperature 29-37°C. The VFA /alkalinity ratio was varied between 0.19-0.33. [12]

Municipal sewage was treated using UASB reactor and inoculated with 0.5 m^3 digester sludge. The reactor volume was 1.15 m^3 operated at HRT of 8h and sewage temperature ranged between 10.6-27.7°C for more than 1100 days. The COD and SS removal efficiencies were 63±13% and 66±20% respectively. Cellulose was used as a substrate to develop degradable bacteria Bacteriodetes and Firmicutes phyla. The authors noticed during the winter season (<15ºC), methane gas production was reduced. [13]

The high organic content waste with biological technologies was studied by Sureshkumar et.al (2011). The UASB reactor was used for the degradation of cyanide and phenol under continuous mode operation. The seed sludge was a mixture of anaerobic sludge from food processing waste water, digested cattle dung and sludge acclimated to phenol in the ratio 50:25:25. The phenol concentration was 100-500 mg/L and operated for 48 h. The phenol is degraded by 98% in the absence of cyanide. The presence of cyanide concentration 30mg/L, affect of phenol degradation was insignificant. When the cyanide concentration 40 mg/L, the phenol degradation was totally suppressed. [14]

Two start-up strategies of UASB reactors were used to treat the pharmaceutical wastewater (Chloromycetin). The total volume of reactor was 1.50L and operated for 88 days. The seed was inoculated with digester sludge (1L) at pH 6.91. The reactors were operated in parallel at around 30ºC. In reactor 1, the COD removal was observed as 97.2% with volumetric COD loading rate of 4.50 g/L.d and volumetric biogas production 2.18 L/L.d for 10 days. The ratio of synthetic and chloromycetin wastewater gradually reduced from 2:1 to 1:2 and HRT also slowly shortened from 2 days to 1day. For 30 days operation the COD removal was 84.5% with volumetric COD loading rate of 4.78 g/L.d and volumetric biogas production 2.01 L/L.d. In the same reactor chloromycetin wastewater fed for 30 days, the average COD removal was 78% and volumetric biogas production 1.82 L/L.d at volumetric COD loading rate 4.79 g/L.d. Reactor 2 chloromycetin wastewater fed with influent COD concentration 4762 mg/L at HRT 1 day, the COD removal was 77.7% and the volumetric biogas production 1.84 L/L.d. [15]

The anaerobic degradation of coconut husk leachate using UASB reactor was observed by Neela et al (2007). The volume of reactor was 13.51 L and seeded with 5.1L mixture of dairy wastewater treatment plant sludge and canteen waste digester sludge. With the HRT of 7.776 /day, the COD was reduced from 1091.2 - 264.16 mg/L. It was reported that about 25gCOD/kg of husk was leached out and about 81.9% of COD converted to biogas. The methane content of the biogas was found to be 75%. [16]

The UASB reactor was used to treat the poultry manure wastewater. The reactor volume was 15.7 L and operated for 72 days at mesophilic state (32±2ºC). The temperature was controlled by using two adjustable thermostats. The authors mentioned that in order to increase the efficiency of the digestion process, seeding was recommended. Further stated that seeding with mature granules require less time for start-up compared to flocculent seed (biomass from conventional anaerobic digester). At average operating conditions i.e. pH - 7.3, HRT - 8 days and OLR - 0.76 kgCOD/m^3day, the COD removal was 90.7% on 63 day. [17]

Abbasi et.al (2013) studied the impact of treatment of aluminium (Al^{3+}) ion on sludge granulation in a UASB reactor. Al^{3+} was added in the different concentrations i.e. 100, 200 and 300 mg/L. The reactor volume was 1000ml, 150 ml sludge obtained from manure and operated at different HRT 48, 24, 12, 6 & 4, the maximum removal of COD was noticed at 24 & 12 h HRT. The results were not satisfactory at 6 & 4h. The amount of methane biogas obtained was 60-66%. [18]

The influence of sulphate on methanol degradation and competition by using two UASB reactors operated for 80 days at thermophilic condition (55ºC) was examined by Paula et.al (2004). The reactors had 0.9 L capacity and methanol was used as substrate. The operating conditions were OLR about 20 gCOD/L.d and HRT 10h. In both reactors, methanogenesis was the dominant process with no considerable accumulation of acetate. The maximum VFA concentration in reactor R_1 measured as 173.6 mg COD/L at day 33 and acetate composition was 88% of total VFA. For the sulphate-fed reactor (R_2), the sulphate removal efficiency exceeded 95% resulting in average total sulphide concentration of 105 mg/L. Both the reactors were inoculated with 14 g VSS and the methanol removal was about 93% (R_1) and 83% (R_2). [19]

Yasar.A et.al (2007) investigated the treatment of combined industrial effluent by using UASB/ UASF reactors. The gas-liquid-solid separator (GLSS) designed with slope angle (Ø) of 60º. The reactor volume was 15.5 L. The UASB reactor was seeded with activated sludge from dairy waste treatment plant. During stabilization, the reactor fed with synthetic wastewater containing C: N: P ratio of 300:5:1. The UASF reactor was seeded with anaerobic sludge (TS – 890 g/L and VSS – 10.5 g/L) of the Hudiara drain bed (sediments) comprised of sand particles with attached microbial growth and organic matrix. The sludge age varying between 30-150 days. In both the reactors, the increase in concentration of TS was mainly due to settling of sludge while VSS concentration clearly demonstrated the production of biomass. The maximum growth rate of bacteria depends upon the food to micro-organisms ratio (F/M). The VSS/TS ratio reflects biomass growth and its quality. In UASB reactor VSS/TS ratio was gradually increased from 0.5 to more than 0.7 by adding sludge. This steady increase in VSS/TS ratio showed gradual increase in granular size. Beyond the sludge age of 90 days, the increase in VSS/TS ratio was marginal, even slightly decreased trend noted on day 150. In case of UASF reactor, VSS/TS ratio also appeared to gradual increase from 0.012 to 0.042 with increasing sludge age. Although the VSS content in the sludge age of both the reactors was comparable but the VSS/TS ratio in the case of UASF strikingly very low. This was because the characteristics of the UASF sludge which contained maximum mass of inert material. Addition of GLSS substantially improved the overall efficiency of UASB reactor at 12 h HRT. But the shorter HRT (3h) and higher upflow velocity (45cm/h) declined the overall removal efficiency. [20]

Studies on the aerobic and anaerobic (UASB) systems by treating the food processing industrial wastewater such as potato-chips and confectionery were conducted by El-Gohary et.al (1999). The authors designed two-phase UASB reactor and used PVC material for reactor fabrication and operated at ambient temperature (40ºC). Confectionary wastewater was used in phase-I UASB reactor with HRT 12h. The COD removal was around 92.4% and corresponding BOD 91.5%. Mean residual values of COD, BOD, TSS and Oil & grease in the treated effluent were 342, 187, 114 and 43 mg/L respectively. Similarly, the potato chips industry wastewater with optimum HRT 18h and OLR 2.9 kgBOD/m^3d, COD, BOD & SS removal were 86, 82 & 91%. The biogas production rate was 0.37m^3/kg COD removed. The two-stage UASB reactor was operated at 12 & 18h HRT. At 18h HRT the COD and BOD removal were 94% and 95%. Also the SS were reduced by 95%. In case of 12h HRT a slight improvement in the quality of the effluent was observed. [21]

2.2 Bio-hydrogen gas Production from wastewater using UASB reactor

The continuous fermentive hydrogen production from coffee drink manufacturing wastewater (CDMW) was observed by Jung.K et.al (2010) using UASB reactor. CDMW was tested in two different types of reactors such as a completely stirred tank reactor (CSTR) and UASB reactor. The CSTR working volume was 5.0 L and seeded with heat-treated sludge (working volume 30%) and filled with substrate. It was purged with nitrogen gas for 5 minutes to provide an anaerobic condition and agitated at 200 rpm. The initial and operated pH was maintained at 8.0 and 5.5 respectively. The UASB reactor working volume was 3.5 L. At the day 10, 1.5 L of mixed liquor of CSTR was seeded to UASB reactor. 5.0g/L of $NaHCO_3$ was added externally to provide a buffer capacity. After attaining steady state, both the reactors were operated in continuous mode under mesophilic condition. The performance of CSTR in the production of H_2 gas was limited when the biomass concentration in the blanket zone exceeds 60,000 mg-VSS/L due to the reason insufficient substrate for intrinsic LAB to survive. The hydrogen producing granules with diameter of 2.1mm were successfully formed by using actual waste as substrate. The max H_2 yield of 1.029 molH_2/mol hexose added was achieved at HRT of 6h in UASB reactor. As caproic acid is generated by consuming acetic and butyric acids, all of which are related to H_2 production. The presence of caproic acid in the broth also indicates H_2 production, yielding 1.33 mol H_2/glucose. [22]

The batch experiments of hydrogen production by heat treated UASB granule by batch and repeated batch fermentation processes were conducted by Sangyoka et.al (2007). The batch culture yielded maximum hydrogen of 0.22 ml/mgCOD. VFA produced in the repeated-batch experiments were acetic, butyric and propionic acids. Since the acetic acid has dominant species the production rate was high. Butyric and propionic acids were produced in smaller amount. The maximum amount of hydrogen production was found during acetic acid fermentation. The maximum hydrogen production rate (75%) was noticed when feed in/feed out rate 20.81%. [23]

Venkata Mohan et.al (2007) had investigated the feasibility of bioaugmentation in the process of enhancing biohydrogen production operated at a temperature of 28°C under acidophilic microenvironment (pH-6.0) using an aerobic sequencing batch biofilm reactor (AnSBBR). Parent augmented inoculum (kabamycin resistant) was acquired from the operating UASB reactor pre-treated with the chemical wastewater (altering between heat-shock treatment (100°C;2h) to eliminate the non-spore forming bacteria and to inhibit the growth of methogenic bacteria. The amount of specific hydrogen was almost doubled after augmentation from 0.297 to 0.483mol H_2/kg COD_R-day. Chemical waste water acted as primary carbon source in the metabolic reaction for the production of molecular H_2. By adjusting the influent pH between 5.0 and 6.0 (acidophilic conditions), the investigators assessed the potential of native anaerobic mixed microflora with respect to H_2 production. [24]

The conversion patterns of acetic acid, propionic acid and butyric acid in activated sludge at different heights of UASB reactor were investigated by Min et.al (2004). The VFA was used as the substrate since degradation capabilities of the microbes are decided mainly by the characteristics of the substrate. But when the mixed organic acids are used, the conversion regulations changed accordingly. Relationships of different substrates vary according to their locations. In the whole reactor, propionates conversion was restrained by acetate and butyrate of high concentration. On the top and/or at the bottom of the reactor acetate conversion was limited by propionate existing, but not by butyrate. At the midst of the reactor acetate conversion by the existing propionates and butyrate conversion is restrained. The chemical reactions (fermentation) involved in the reactor to produce hydrogen are [25]

$$CH_3CH_2CH_2COOH + 2H_2O \rightarrow 2CH_3COOH + 2H_2$$

Butyric acid water Acetic acid Hydrogen

$$CH_3CH_2COOH + 3H_2O \rightarrow CH_3COOH + 3HCO_3 + 3H_2$$

Propionic acid water Acetic acid Hydrogen

$$CH_3COOH + 2H_2O \rightarrow 4H_2 + 2CO_2$$

Acetic acid water Hydrogen Carbon-di-oxide

Flow diagram of Bio-gas (Hydrogen & Methane) production from UASB Reactor is shown in Fig. 2 [33]

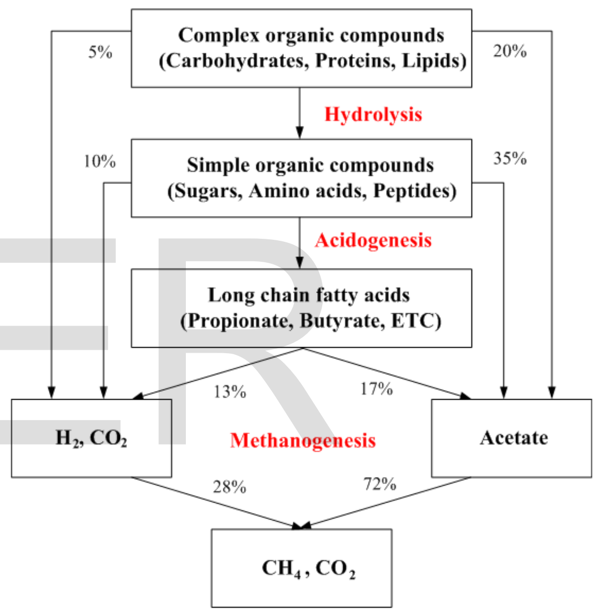

Fig.2 Flow diagram of Bio-gas (Hydrogen & Methane) production from UASB Reactor

2.3 Characteristics of UASB reactor

The hydrodynamic characteristics of UASB bioreactors operated under different OLR and hydraulic loading rates were explained by Siby John and Vinod Tare (2011). The investigators used three laboratory scale models to treat concocted sucrose wastewater. With the help of these models, the characterization of fluid flow pattern in the reactors, the correlation of the hydraulic regime with the biomass content and biogas production were studied. The empty bed reactors followed a plug flow pattern and the flow pattern changed to a large dispersion mixing with biomass and gas production. Effect of increase in gas production on the overall hydraulics was insignificant. The UASB reactor was operated under different organic loading and hydraulic loading rates. The reactor consists of two components i.e. biological dead space and hydraulic dead space. The biological dead space includes both the volume occupied by biomass and dead space that results from the interference of biomass particles in fluid flow. Hydraulic dead space tends to occur wherever the stagnant zones form. [26]

2.4 Kinetics and Models used in UASB reactor

Mathematical model was developed by Florencio et al (1996) in order to achieve the optimum alkalinity dosage for good pH stability in a reactor treating methanol. The model estimates pCO_2 and pH expected from certain stoichiometry yield of acetic acid and methane from methanol. It was mentioned that the model did not considered nitrogen and phosphorous uptake by the biomass that would contribute for loosing alkalinity. With this model it is possible to predict the pH in the reactor and the CO_2 composition of the biogas. [27]

Romli et.al (1994) investigated the effect of reducing the pH of the acidification reactor on the overall performance of a two stage anaerobic wastewater treatment system both experimentally and to simulation of a dynamic structural model. The system operated at low pH was subjected to a short-term step increase in feed concentration. The measured and the predicted dynamics responses of reactor variables to the shock load were evaluated. The dynamic response of the system to a shock load indicated a decrease in effluent quality during the disturbance. But the system was recovered quickly as soon as the shock load terminated. The comparison between the experimental and the simulation results demonstrated the feasibility model that can be applied for reactor design and operational evaluation purposes. [28]

The sulfide toxicity effects are studied by Paula and Foresti (2009) using kinetics of a UASB reactor. The two lab-scale UASB reactors (10.5L) were used and operated in continuous mode for 12 months. The reactors were fed with synthetic waste using glucose, ammonium, acetate methanol and nutrient solution. The authors reported that one of the reactors received the increasing concentration of sodium sulfide. Both the reactors were operated at the substrate COD of 2000mg/L, HRT 15.6h, the COD removal was observed as 98%. The overall kinetic parameters obtained with the bench scale UASB reactor operated under progressive increase of total sulfide concentration at pH in the alkaline range. Sulfide toxicity could be expressed with the following equation.

$$q_i = \frac{0.4}{36+S} * \frac{S}{1+i/1462}$$

q_i - specific substrate utilization rate (d^{-1})
S – substrate concentration (mg/L)
i – concentration of total sulfide (mg/L) [29]

A model was developed by Gomez.R et.al (2013) to predict the behavior of UASB reactors to treat the sugarmill wastewater. The important aspect in their paper was development of model taking into consideration of mass transfer through the film around the granules, the intra-particle diffusion and the degradation reaction. The model enables the determination of the removal efficiency of the substrate and the increase of both the height of the sludge bed and the granule size with time. The major concentration of substrate was degraded at the lower part of the UASB reactor where the major concentration of biomass present. A better removal of COD occurred at the lowest upflow velocity, due to the longest time of contact between the substrate and the microorganisms. The authors concluded that the model developed (model of CSTRs in series) could be used to improve and control existing UASB reactors. [30]

2.5 Technical problems in UASB operation

Aiyuk et.al (2010) highlighted the technical problems coming up from UASB reactor application in domestic wastewater treatment without pre-treatment. The average total COD of the wastewater was 522 mg/L. The reactor was able to remove 80% of the organic matter. Due to the delicate balance of the methanogens in anaerobic reactors, perturbations of the miobiota arose following the sludge extraction and promote the reactor imbalance. This further a decrease the reactor performance and hence the general sustainability of the UASB process when treating domestic sewage directly. In addition, the UASB reactor could not remove the macronutrients (nitrogen and phosphorous) and SS. It caused due to rapid rise in sludge bed height and frequent sludge removal. The high rate sludge production causes accumulation of SS. The removal of sludge caused inactive solids to decrease the reaction zone and increase the disturbance to microbial growth [31]. When the loading rate was increased to 24gCOD/L.d. by reducing HRT to 4h, the reactor performance was deteriorated. [31]

3. CONCLUSIONS

- UASB reactors are highly efficient to remove organic pollutants like BOD, COD, and SS etc.
- These reactors can be operated at both mesophilic and thermophilic conditions
- The UASB system can solve the environmental problems economically.
- The models and kinetics of the existing UASB reactors can be used to improve the performance of reactor design, biomass concentration, treating the heavy metals and biogas production.
- Compare to other conventional methods, the cost involved in construction and maintenance is low. No costs arise other than desludging costs and the operation of feeding pump.

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