An overview: Treatment of wastewater by UASB reactor and Hybrid UASB reactor

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Abstract: The whole planet is facing serious water scarcity problems. So in order to this problem, a literature review study was performed on the anaerobic treatment of wastewater using UASB and HUASB reactor as the core component. The merits of aerobic and anaerobic process are discussed along with the comparison of UASB and HUASB technology on the basis of their performance parameters like temperature, pH, upflow velocity, sludge granulation, HRT and OLR. Although both the technologies give good results but the study supports HUASB reactor as the better option for the treatment of wastewater.

1. Introduction

The whole world is facing severe menace due to water pollution problems. Access to safe drinking water is not guaranteed to a majority of the population. Mostly in developing countries like India it is very vital to maintain the quality of surface water sources (Banu *et al*., 2007; Trivedi *et al*., 2013). According to the Census 2011, the demand for fresh water for increasing population will become unmanageable. As per Indian Infrastructure report 2011, millions of small-scale farmers in urban and peri-urban areas depend on wastewater or polluted water sources to irrigate high-value edible crops for urban markets because they have no other source for irrigation. In 2015, it was computed that the sewage treatment capacity was only 22,963 MLD in contrast to municipal wastewater generation of 61,754 MLD in the India itself (CPCB Bulletin, July 2016). So, it can be concluded that there is a large void between generation and treatment capacity. As per CPCB Bulletin, July 2016, around 38,791 MLD of untreated sewage (62% of the total sewage) is dumped directly into nearby water bodies. The demand for water supply is incomparably raising due to increase in industrialization and urbanization. The total number of cities and towns in India has increased from 2,250 to 5,161 and 7,936 in 1991, 2001 and 2011 respectively. Discharges of inadequately treated municipal wastewater may have a great impact on natural water sources i.e. surface and underground water bodies or land. And when is directly discharged into rivers, canals, ponds in developing countries can damage the aquatic life and the quality of the water sources. Due to hike in BOD and COD, eutrophication happens due to heavy amount of organic material and nutrients. So, due to all these reasons, there is a great need for treatment of municipal wastewater in order to save our natural water resources from contamination or depletion and also for the fulfillment of the water demand. So with the help of wastewater treatment system, this problem can be figure out and the treated water can be reused for various purposes like industrial, agricultural, aquacultural and municipal purposes. The treatment of wastewater has been an issue of high antecedence in most of the developing countries and they have therefore reached a very satisfactory quality of their wastewater discharges.

Primarily two types of wastewater treatment systems exists i.e. aerobic and anaerobic. Free or dissolved oxygen is required to convert organic matter of wastewater into biomass and CO_2 in aerobic treatment, while in anaerobic system convoluted organic matter is converted into methane, CO_2 and H_2O through steps like hydrolysis, acidogenesis including acetogenesis and methanogenesis in the oxygen free environment. For achieving high degree of treatment efficiency aerobic treatments are used while for resource recovery & utilization, anaerobic treatment are used but objective of controlling pollution is yet to be achieved (Seghezzo *et al*., 1998). There has been a keen interest in recent years in anaerobic and advances in the anaerobic treatment of municipal wastewater offer a promising technology including Upflow Anaerobic Sludge Blanket reactor (Lettinga and Vinken, 1980; Lettinga, *et al*., 1980). Anaerobic reactors were counterfeited to be fewer stable under fluctuations, expensive installation and a long start-up time as correlated with aerobic reactors, but the belief was due to narrow knowledge of the treatment and reactor design.

Nowadays the historic failings of the anaerobic treatment have subtracted significantly. In the last three decades, the application of anaerobic treatment in industrial and municipal wastewaters has elevated. Due to of substantial dominance, anaerobic treatment has come forwarded as a practical and economical alternative to aerobic treatment. As per a report published on 23rd March, 2015 in Times of India, nearly 37,000 MLD of 'untreated' sewage water flows into rivers across the country and thus depraving the fresh water resources. So, due to all these reasons, there is a great need for treatment of municipal wastewater in order to save our natural water resources from contamination or depletion and also for the fulfillment of the water demand.

2. Anaerobic digestion process

Anaerobic digestion is a convoluted process which transforms organic matter into methane with the help of tons of microbial populations allied by their individual substrate and product specificities and this process also illustrate the direct and indirect symbiotic association between different groups of bacteria. A balance is formed with the help of a chain mechanism in which the product of one bacterium is substrate for other and in this way the substrate concentration is maintained. However this biological conversion takes place in four steps i.e. hydrolysis, acidogenesis, acetogenesis and methanogenesis. All the steps are described below:

a) **Hydrolysis:** Hydrolysis is the first stage which is slowest among all the four stages. Complex organic substances are converted into liquified monomers and polymers by bacteria i.e. proteins into amino acids, carbohydrates into monosaccharides and lipids into fatty acids. As the particulate organic materials are too large to be absorbed by plants, so it is important to convert higher mass organic molecules into basic structural building blocks by extracellular enzymes. This basic structure building block is used as a substrate or food source.

b) **Acidogenesis:** Soluble organic monomers of sugars and amino acids are indoctrinated to ethanol and acids like propionic and butyric acid, acetate, H_2 and CO_2 by acidogenic bacteria. Ammonia is being originated from the disintegration of amino acids.

c) **Acetogenesis:** This is a stage in which long chain fatty acids, volatile fatty acids and alcohols are indoctrinated into hydrogen, acetic acid and carbon dioxide by acetogenic bacteria. BOD (biological oxygen demand) and the COD (chemical oxygen demand) are both reduced and the pH decreased during the reaction. Low partial pressure is needed to thermodynamically allow the conversion of all the acids and hydrogen play a momentous role in this reaction. The low partial pressure is provided by hydrogen degrading bacteria and H_2 concentration is an indicator of its "health".

d) **Methanogenesis:** In this final step, methane gas and CO_2 are formed from the transformation of hydrogen and acetic acid by methanogenic bacteria. Organic loading rate, feed composition and temperature are some factors which impinge the several conditions in the reactor. The end product mainly consists of methane (CH_4) and carbon dioxide (CO_2), but also encompasses several other gaseous "impurities" such as hydrogen sulphide, nitrogen, oxygen and hydrogen. The higher the CH_4 content the higher the energy value of the gas and biogas with methane content higher than 45% is flammable.

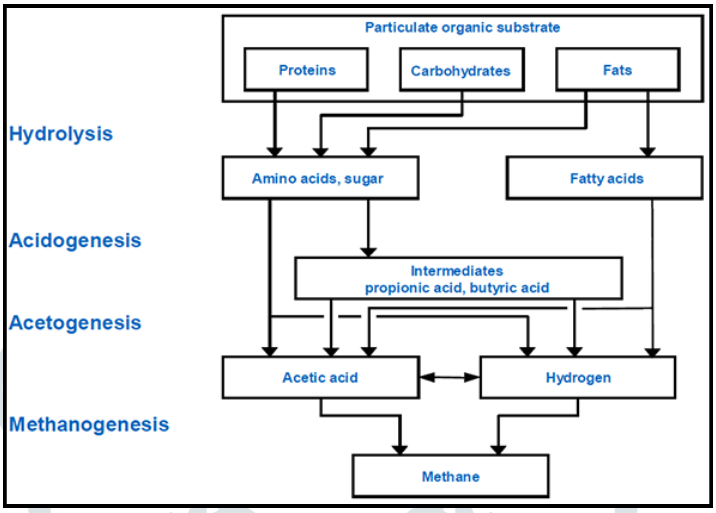

Fig.1. Anaerobic microbial digestion process (adapted from Seghezzo, 2004)

3. Factors affecting anaerobic process:

The anaerobic treatment has numerous advantages and a workable choice for the treatment of wastewater. For the treatment of sewage both in tropical and subtropical countries, the UASB and HUASB technology also proved economically more attractive than facultative ponds and oxidation ditches. Factors like hydraulic retention time (HRT), organic loading rate (OLR), temperature, pH, granulation, phase separator design, seed sludge, sludge aging, degree of mixing, nutrient requirements and the presence of toxic compounds in the influent distress the performance of the anaerobic treatment process. Some of them are discussed below:

(a) Temperature: Temperature of the reactor is the factor which highly affects the anaerobic process. Generally the microorganisms' health, growth and continuity is temperature based. There are three ranges of temperature i.e. psychrophilic, mesophilic and thermophilic and anaerobic treatment is feasible at all three stages but there is recession in the specific growth rate and methanogenic activity at psychrophilic ranges (Azbar *et al*., 2009; Bodik *et al*., 2000). The methanogenic activity at psychrophilic range lowers to 10-20 times than the activity at mesophilic range. This requires an hike in the biomass in the reactor (10–20 times) or to operate at higher sludge retention time (SRT) and hydraulic retention time (HRT) in order to achieve the same COD removal efficiency as that obtained at 35^0C (Foresti, 2001; Kalogo and Verstraete, 2001; Mahmoud, 2002).

(b) pH: pH range of 6.3-7.8 seems to be most affirmative condition for the methanogenesis process (Yasar and Tabinda, 2010). Due to buffering capacity of the acid base system in an anaerobic digester, during the treatment of domestic wastewater, the pH remains in this range without inclusion of any other chemical. The methanogenic bacteria perform at pH close to 7.0 but the most selected range for the whole group is 6.0 to 8.0. At low pH acid fermentation may preponderate over methanogenic activity because acidogenic bacteria are very less sensitive to pH variations. The degradation of fatty acids especially propionate takes place at pH less than 6 due repressions of methanogenesis of acetates. Therefore, the system must have adequate buffering capacity to neutralize the origination of volatile acids and carbon dioxide for the effluent of industries.

(c) HRT (Hydraulic Retention Time): This is the most important which usually distress the performance of UASB reactor during the treatment of municipal sewage (Vieira and Garcia, 1992). HRT is that time in which wastewater remains in the reactor and is calculated as:

$$HRT = \frac{\text{Reactor volume}}{\text{Wastewater flow}}$$

HRT is the factor which affects the COD reduction rate and important parameter with respect to the aimed degradation rate. The HRT should not be less than 2 hours. According to the study by Trnovec and Britz, 1998 during the treatment of a carbohydrate-rich effluent of the canning industry with UASB reactor, it was reported that COD removal performance was higher than 90% at an HRT of 10 h. As per an investigation done by Fang in 2000 at 37ºC, the impinge of HRT on acidogenesis of dairy wastewater and HRT stretching from 4 to 24 h and by escalating HRT from 4 to 12 h, it was reported a boost in the acidification i.e. from 28 to 54%. But however, it is also reported by some scientists that there is no distinct effect of HRT on the treatment efficiency of UASB reactor (Halalsheh, 2002; Vieira and Garcia, 1992) and this disparity of opinion in scientific community is may be due to the difference in the reactor design, operating procedures and range of HRT.

(d) Upflow Velocity (V_{up}): Direct related with HRT, upflow velocity has a vital role in capturing of suspended solids. The efficiency of the system gets boosted when there is a decrease in V_{up} and hence enhance the hydraulic retention time (Liu *et al*., 2010; Rajakumar *et al*., 2011; Van Haandel and Lettinga, 1994). Upflow velocity affects the contact time between the sludge and wastewater and it gets dwindled by elevated Vup which results in demolishing of sludge granules & higher washout of solids and therefore the COD reduction efficiency of the UASB rector decreases. (Leitao, 2004; Mahmoud, 2002; Nkemka and Murto, 2010).

(e) Sludge Granulation: The success of the reactor depends upon the establishment of the granular bed at the basement of the UASB reactor. The washout of the sludge from the system is curtailed by the formation of sludge bed which is basically formed by the gathering of suspended solids and bacterial population into flocs and granules. The treatment system shows a very gratifying performance due to granulation of sludge at high organic loading rates. It is very sympathetic in reducing the reactor size and hence makes the system cost effective. Sludge granulation sustainability is greatly distressed by the parameters like temperature and upflow velocity. Many researchers reported that sludge granulation takes place at an upflow velocity (V_{up}) of 0.478 m/h and ambient temperatures (19-28ºC). Spherical granules were detected by them after one month operation of the system. It was also examined that, spherical granules were formed after a period of 9 months. As per study by Yasar *et al*., 2010, hike in VSS/TS ratio is associated with the development of sludge granules during the treatment of combined industrial wastewater. When the increase in VSS/TS ratio becomes subsidiary after 90 days, it simply concludes that it takes around 3 months for the proper granules formation of sludge.

4. Upflow Anaerobic Sludge Blanket (UASB) reactor

The use of anaerobic process in the main biological step in the wastewater treatment system was very rare till the development of UASB reactor. The UASB process was developed by Lettinga and co-workers in the late 1970's (Lettinga *et al*., 1980).

Initially the reactor was designed to treat concentrated industrial wastewater and its application was later extended to sewage treatment. Nowadays, the UASB reactor is extensively used for the treatment of several types of wastewater, forming part of the high-rate anaerobic technology (Kavitha and Murugesan, 2007). The UASB scheme basically consisted of Influent tank, peristaltic pump, cylindrical UASB reactor, Gas/liquid/solid separator, effluent outlet, gas collection system. The figure 2 showing the basic scheme of the UASB reactor. Antecedents of the UASB reactor can be found in the so-called anaerobic contact process studied by Simpson (1971); Pretorius (1971). 'Biolytic tank', a similar system to UASB reactor was observed to be used by in 1910. So, for the treatment of various types of wastewater, UASB technology can be utilized (Hulshoff Pol & Lettinga, 1986; Kato *et al*, 1994; Lettinga, 1995, 1996 a,b).

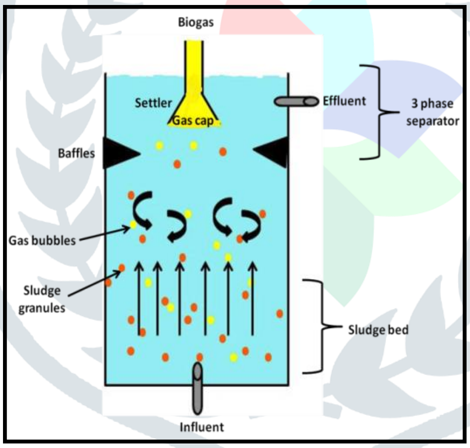

Fig.2. Upflow Anaerobic Sludge Blanket Reactor

Development of dense granular sludge bed at lowest part of the reactor where all biological digestion mainly takes place depicts the success of the UASB reactor. Incoming suspended solids and bacterial growth gets accumulated for the configuration of sludge bed. According to some studies, flocs and granules gets naturally aggregated by bacteria under convinced conditions in upflow technologies (Hulshoff Pol *et al*., 1983; Hulshoff Pol, 1989). Under practical reactor conditions, these granules have excellent settling property and hence non-susceptible to wash out from the system. A UASB reactor facilitates good treatment at higher OLR rates due to of retention of active sludge, either granular or flocculent within the reactor. A pleasant contact between biomass and the wastewater is imparted by the natural turbulence facilitate by the influent flow and the biogas production. However, due to these positives, high organic loads can be applied in the UASB systems which cannot be provided in the aerobic process (Kato, 1994). Therefore, a reduced amount of the reactor space and volume is required and additionally paramount energy is produced as biogas. Several transformations can be done in a wastewater treatment plant which includes UASB technology in terms of sand trap, screens for coarse material, and drying beds for the sludge. The primary settler, the anaerobic sludge digester, the aerobic step (activated sludge, trickling filter, etc.), and the secondary settler of a conventional aerobic treatment plant can be redeemed by UASB reactor. Due to all these leverages, the effluent from UASB reactor devoir further treatments like stabilization ponds, activated sludge plants, and others in order to remove remnant organic matter, nutrients and pathogens. The economics of anaerobic treatment in UASB reactors were thoroughly discussed by Lettinga *et al*., (1983b).

Various researchers worked on the treatment of wastewater by UASB reactor and give their valuable outputs in the light of this technology. Zhao *et al*., 2014 investigated the capacity of the UASB reactor for the treatment of salts contaminated wastewater at a controllable HRT of 12h. They noticed that the UASB reactor efficiency was 83.3% at 1% influent salinity in terms of COD and it changes a very little to 87.6% and 85.2% when salinity was changed from 2 to 3% respectively. The amputation rate of NH_4^+-N and PO_4^{3-}

P also changed little when the influent salinity of the reactor increased from 1% to 3%. Their study clearly showed that activated anaerobic sludge of UASB reactor had a very good aptitude for salt tolerance.

Kavitha and Murugesan in 2007 investigated the treatment of fish processing effluent through UASB reactor. After proper acclimatization of the reactor and adaptation of the fish processing effluent to the sludge granules, the COD reduction rate was found to be 96% at the high organic loading rates of 150 mg l^{-1} d^{-1} to 2,200 mg l^{-1} d^{-1}. The methane content was found to be 748 l kg^{-1} COD^{-1}. The sludge granules size was 1-3 mm with very good settleability and the efficiency of methane and the whole process was found to be increased with an increase in the organic loading rate.

Ganesh *et al.*, 2007 studied the UASB technology for the treatment of low-strength effluents and application to dairy industry wash waters. Their results showed that the reactor achieved 75-85% removal efficiency in terms of COD ranging from 1200-2000 mg/l and the reactor which contaminated accidently with the acid recovered fastly. Inspite of this, the reactors showed a very good treatment efficiency and able to stand with the shock-loads. They also focused on the fact that the UASB reactors can produce a large volume of low-strength wastewaters, which are often disposed untreated due to high costs and potential of stabilizing the organic wastes by producing valuable energy as byproduct.

In 2013, Tanksali scrutinized the UASB reactor for the treatment of wastewater of the sugar industry. A laboratory scale 8.4 ltrs of the UASB reactor was fed with the non-granular sludge from the septic tank and the working temperature was 26-39^{0}C. The study was conducted in two phases. The 1st phase dealt with increase of OLR and decrease of HRT from 1g COD/l.d to 6 g COD/l.d and 48 to 12 hrs respectively and on 42nd day granules were observed. The disintegration of granules was observed at 12 hrs HRT. The second phase started with the restabilization at 61st day that dealt with an increase of HRT (24 hrs to 18 hrs) and decrease of OLR (2g COD/l.d to 4.67 g COD/l.d). The granules visibility was felt on a very period of 14 days and COD removal efficiency was from 80 to 96 %. The COD removal rate linearly increased with increase in OLR. The ratio of VFA to alkalinity was varied between 0.14 to 0.3 during the treatment. Maximum volumetric biogas production was 13.72 L/ d. at OLR of 6 g COD/L. d. The methane content in the biogas was found to be 71% at steady state conditions. The startup was successful within 100 days of the study.

Kumar and Bishnoi, 2017 investigated the performance of the UASB technology for the treatment of sugar industry wastewater and found a very good removal efficiency for COD, phosphate, sulphate, Ca, Mg and total hardness. As the food industry wastewater contains high pollution load and may cause severe health problems if discharge untreated.

The UASB (Upflow Anaerobic Sludge Blanket) technology is known to be the energy conservative technology. It is a viable technology for the reduction of organic pollution loads and requires very less skills, hence it's cost effective too. With the inoculation of non-granular sludge, the UASB system faces confronts for the treatment of low-strength wastewaters.

Venkatesh *et al.*, 2013 studied the effect of digested non-granular sludge on the establishment of the UASB reactor for the treatment of low strength wastewater with the COD for 700-1000 mg/l. At the ambient temperature of 24-35^{0}C, a lab scale reactor of an effective volume of 9.97 L was operated for the start-up which lasted for 84 days. The reactor achieved 90.8% COD removal with biogas evolution of 4.72 L/d (457 L / kg COD removal) at an organic loading rate of 1.293 kg COD/ m^3 d. The steadiness of the reactor was substantiated by volatile fatty acids (VFA)/ alkalinity ratio at 0.184.

5. Hybrid Upflow Anaerobic Sludge Blanket (HUASB) reactor:

In the recent times, due to pros over UASB technology, HUASB (Hybrid Upflow Anaerobic Sludge Blanket) reactors are used to treat wastewaters (Govindaradjane and Sundararajan, 2013). The hybrid Upflow anaerobic sludge blanket (HUASB) reactor is a new concept which is the hybridized version of an UASB reactor with a random packing medial support media at the top of the reactor. HUASB reactor has several advantages over UASB reactor such as:

(1) Higher efficiency in the treatment of a variety of waste waters including high strength waste water at high OLR and lesser HRT

(2) Increased retention of granular sludge and prevention of washout of microbial population etc.

The HUASBR process is seemed as one of the most cost effective & efficient anaerobic treatment. In HUASB reactors, there are so many materials which are used as a support media, especially synthetic material like polymers have been used predominately. Synthetic materials like plastic pall rings, polyurethane rings, polypropylene pall rings, polyethylene cascade rings, nylon fibers etc. have been used as a supporting media. Natural materials have also been used like blast furnace slag, volcanic rocks, ceramic rasching rings have also been used, but barely.

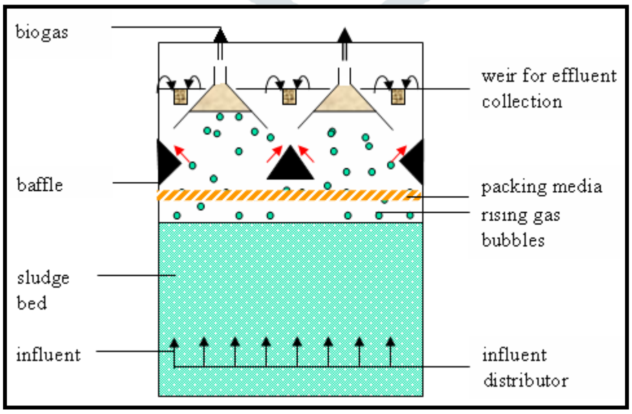

Fig.3. Hybrid Upflow Anaerobic Sludge Blanket Reactor (Khanal, 2002)

The main objective to be achieved in the start-up of any high rate anaerobic reactor is to accomplish a satisfactory and consistent immobilization of anaerobic organisms. Start-up regime of the above reactor can be considered as the second influential part of the continuous-mode of operation, the first one being the acclimatization in the batch-mode of operation. A usually low volumetric loading rate is recommended for the primary start-up of HUASB reactor.

Govindaradjane and Sundararajan, 2013 studied the comparative performance of the UASB and HUASB reactor and they ended up with the following conclusions that the steady state condition is achieved 14 days before as it is achieved in UASB reactor means the former has prevenient start-up which is advantageous from operation of the treatment process and it was also noted that COD removal efficiency of the reactor has not distressed by the early start-up. Both the UASB and HUASB reactors found to be having alike trend for OLR and COD removal (%) for the considered experimental ranges of HRTs and influent COD concentrations. Though, 78.32% and 83.10% are the maximum COD removal in UASB reactor and HUASB reactor respectively which is higher in the latter one at the consistent influent COD and HRT. Also, the bio-gas yield and COD removal (%) trend is also found matching in both the reactors. But HUASB reactor gives slightly better results than UASB reactor, as the maximum gas yield equals to 0.30 m3/kg.COD removal at identical HRT and VLR, but at an OLR of 0.155 kg.COD/kg.VSS.day. 54-56% is the range of methane content in biogas generated from HUASB & UASB reactor and it is found almost same in both the reactors. The higher biomass concentration is supported by HUASB reactor is 23.21 to 32.06 g.VSS/l which is more than the UASB reactor i.e. 20.1 to 30.11 g.VSS/l which is may be due to facilitation of microbial growth supported by media at the top of the HUASB reactor. Thus, the HUASB reactor contemplated in the present study is presumed to be capable of handling still higher influent COD concentrations than the experimental range of values of the present study.

In another study done by Herumurti *et al*., 2008 for the treatment of non- penicillin wastewater of pharmaceutical industry. Two reactors i.e. UASB and HUASB were seeded with the aerobic treatment's sludge and devaluation in organic load was observed. 93% was the highest COD deportation rate for the UASB reactor and 94% was for HUASB reactor at a HRT of five days and the strength of wastewater was very high. At HRT of 4 days, hybrid UASB enacted the highest methane production.

Lavanya and Jodhi, 2016 observed a very good performance of the hybrid reactor during different parameters i.e. rainy and winter season. A pilot model of 8 lt was taken for the treatment of dairy effluent. The reactor was operated with varying operating condition of flow rate of 33.83, 41.66, 59.51, 83.33, 138.83 ml/min, influent COD of 1599.88, 2091.98, 2564.46 mg/l. OLR for rainy season was 0.025, 0.031, 0.036 kg/COD/m^2 day and for winter season it was 0.018, 0.026, 0.032 kg/COD/m^2 day. The HRT interpreted was 6.00, 10.00, 14.00, 20.00 and 24.00 hrs. The COD removal was observed for minimum of 78.10% starting from 78.86% for rainy season and maximum of 79.10% from 80.61% COD removal for winter season.

Banu and Kaliappan (2007) studied the advantages of Hybrid UASB coupled with fixed film for the treatment of tannery wastewater. The treatment lasted for 370 d with two different HRT's i.e. 2.5 d and 2.9 d with maximum OLR of 2.74 kg.COD/m^3/d and 3.14 kg.COD/m^3/d respectively. The reactor was fed with influent concentration of COD of 14000 mg/l and tannin of 1987 mg/l. They also investigated that OLR beyond the above mentioned lead to a gradual decrease in COD removal efficiency of the reactor. The degradation of inhibitor substance such as tannin during the anaerobic digestion was also found and it was in the range of 65-91% at the HRT of 2.9d.

6. Advantages and disadvantages of anaerobic process:

The various merits of both treatments are highlighted in Table 1, and both systems are capable of achieving high organic removal efficiency.

Table 1: Comparison of aerobic and anaerobic treatment

FEATURE	AEROBIC	ANAEROBIC
Organic removal efficiency	High	High
Effluent quality	Excellent	Moderate to poor
Organic loading rate	Moderate	High
Sludge production	High	Low
Nutrient requirement	High	Low
Alkalinity requirement	Low	High for certain industrial waste
Energy requirement	High	Low to moderate
Temperature sensitivity	Low	High
Start up time	2–4 weeks	2–4 months
Odor	Less opportunity for odors	Potential odor problems
Bioenergy and nutrient recovery	No	Yes
Mode of treatment	Total (depending on feedstock characteristics)	Essentially pretreatment

(Adapted from Chan *et al*., 2009)

7. Conclusion

This study was based on the review literature for the performance of the UASBR (Upflow Anaerobic Sludge Blanket Reactor) and HUASBR (Hybrid Upflow Anaerobic Sludge Blanket Reactor). From the studies, it was concluded that both the technologies had a very good efficiency during the batch study but HUASB reactor was more efficient when an aerobic pre or post- treatment was given to the whole treatment process. As the whole world is facing serious water scarcities problems, the treated water could be a best solution for the reuse purposes like gardening, flushing the toilets etc.

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