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Review

A simple anaerobic system for onsite treatment of domestic wastewater

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The use of anaerobic process for domestic wastewater treatment would achieve lower carbon footprint as it eliminates aeration and generate methane. Among several anaerobic treatment processes, high rate anaerobic digesters receive great attention due to its high loading capacity and chemical oxygen demand removal rate. Up-flow anaerobic sludge blanket reactor (UASB) is getting wide acceptance among several anaerobic processes. However, its application is still limited to industrial wastewater treatment. There are some unresolved problems to be accepted it in developing countries with lower temperature conditions for domestic wastewater treatment. Several studies have been carried out for the performance of UASB reactor but there is still lack of updated information especially on the issue of low temperature domestic wastewater treatment. Considering the gravity of the issue, an attempt have been made to compile updated information so as to help engineers, researchers and practitioners in the selection of reactors and future prospects of research.

Key words: Wastewater, anaerobic, up-flow anaerobic sludge blanket reactor (UASB), carbon footprint.

INTRODUCTION

Domestic wastewater refers to the wastewater from toilet, bathroom and kitchen of household. Anaerobic treatment of organic material proceeds in the absence of oxygen and the presence of anaerobic microorganisms. It is the consequence of a series of metabolic interactions among various groups of microorganisms which ultimately converts waste into a renewable energy, that is, biogas along with other useful byproducts.

Anaerobic wastewater treatment system is considered to be a sustainable and suitable process for on-site (individual or cluster) treatment due to its low or no energy consumption, low space requirement and relatively simple reactor design (Zeeman et al., 2000). This is partly explained by the elimination of aeration.

The important advantages of anaerobic wastewater treatment are production of methane and bio-fertilizer, reduce carbon dioxide (CO_2) emission and more importantly improve sanitation and public health, while the excess sludge production is low as compared to aerobic processes. Also, the excess sludge is highly stabilized and generally its dewaterability is excellent which eliminates the costs for aeration (Lettinga, 1996;

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Hammes et al., 2000; Luostarinen and Rintala, 2005).

A recent study in Nepal shows that an estimated biogas production potential from urban wastewater is about 22 million m^3/year equivalent to 14.5 MWth, at the sametime, the carbon dioxide (CO_2) emission reduction potential is about 2460 tons per year (Lohani et al., 2013). This may directly relate with financial benefits, however, it also has several economic benefits for instance reduction of indoor air pollution, improvement in public health due to improved sanitation and greenhouse gas reduction. This indicates that anaerobic treatment of wastewater could be a sustainable solution due to its vast economic and environment benefits for developing countries like Nepal. Despite enormous benefits, its use is usually limited to high strength industrial wastewater with soluble substrates (Lew et al., 2011).

Domestic wastewater has generally low concentration of chemical oxygen demand (COD) and relatively high concentration of suspended solids with low specific methane yield that requires initial hydrolysis to convert the suspended solids into soluble substrate. Hydrolysis is often the limiting step, especially at low temperature conditions (Lew et al., 2011). Hence, operation of anaerobic reactors for domestic wastewater with a high content of suspended solids is therefore, only feasible at higher ambient temperature or with external heat supply. Nevertheless, standard septic tanks are useful for removal of inert solids, preliminary hydrolysis of particular organic matter, though optimized fermentation and hydrolysis depends on its design (Richard et al., 2005). Therefore, combination of a septic tank, serving as the primary treatment step, combined with a pulse fed UASB reactor as secondary treatment could be a suitable low cost and effective onsite sanitation option. Pulse feeding UASB was found to be simple and effective (Nadais et al., 2005). In addition, it stimulates the development of granular sludge with both improved settling and degradation properties (Franco et al., 2003; Rocktäschel et al., 2013).

For the purpose of anaerobic treatment of domestic wastewater, various technologies have been developed which are core sustainable wastewater treatment (Mahmoud et al., 2003; Luostarinen et al., 2007). Recent reviews mostly focus on anaerobic digestion (Aiyuk et al., 2004; Gomec, 2010) and enhance the start-up and granulation in UASB reactors (Chong et al., 2012). However, there is still lack of information and documentation on the enhancement of treatment efficiency and energy recovery from high rate anaerobic digestion treating domestic wastewater at low temperature climatic condition. Hence, the goal of this study is to compile up to date information of commonly used anaerobic systems with focus on the UASB and septic tank-upflow anaerobic sludge blanket (ST-UASB) reactors, which may serve as background information for perspective research direction.

The information regarding UASB reactor pilot/field operation is given emphasis so that future improvement on reactor process control would be possible.

TECHNOLOGIES FOR ANAEROBIC TREATMENT

Two types of digesters are used in the anaerobic digestion process which are batch and continuous process. In batch process, all the constituent is put in the reactor in the beginning and is removed completely after the reaction is complete, whereas in continuous process fresh influent is fed into the reactor and effluent is regularly drawn out (Ostrem et al., 2004). Most commonly continuous type reactors are used for domestic wastewater treatment.

Septic tank and soak-away system

The most commonly used anaerobic system for pre-treatment of domestic wastewater in on-site application is septic tank. The conventional septic tank is the oldest anaerobic treatment system still widely employed in developing countries and isolated residential locations in developed countries (Coelho et al., 2003). Septic tank has simple design of horizontal flow mode with one-two baffles between the inlet and outlet. But there are certain problems like short circulation in the tank and dissolved oxygen input through inlet (Arceivala and Asolekar, 2007). Moreover, performance of the septic tanks is rather poor due to the horizontal flow mode of the influent sewage despite its lengthy hydraulic retention time (HRT) (Mgana, 2003). About 30-50% COD and about 60% total suspended solids (TSS) removal can be achieved in septic tank treatment system. Thus, septic tank effluent requires further processing in a post-treatment system to meet environmental standards, which would increase the cost and complexity of the system.

Soak-away system is another treatment process in which dispersal of wastewater is done through soil purification process and ground water recharge. As it is basically used for post treatment of septic tank effluent, the performance is dependent on the treatment efficiencies of the septic tank, wastewater distribution and loading to the soil infiltrative surface (Foxon et al., 2004).

Among the anaerobic digesters, high-rate digesters are popularly used in sewage treatment. This is because, unlike the conventional low-rate anaerobic digesters such as anaerobic ponds and septic tanks, high-rate anaerobic reactors are designed to operate at short HRT and long solids retention times (SRT) to incorporate large amounts of high-activity biomass, thus allowing improved sludge stabilization and higher loading capacity (Sperling and et al., 2001). For the treatment process to be considered as high rate, two conditions must be fulfilled which are to retain high concentration of sludge under high loading rate and ensure proper contact between wastewater and retained sludge (Lettinga et al., 1987). Some of the examples of high rate digesters are anaerobic baffle reactor, upflow anaerobic sludge blanket reactor and expanded granular sludge bed reactor as described below.

Anaerobic baffle reactor

Anaerobic baffle reactor (ABR) is a reactor which uses a series of baffles in which the water is forced to rise upward and simultaneously drop downward which ensures good solid retention and more contact between biomass and organic substrate therefore achieving good organic removal rates (Barber and Stuckey, 1999). This technology has been used in the treatment of a variety of wastewater types; however most studies were focused on high strength wastewater with soluble biodegradable material (Barber and Stuckey, 1999). Studies on domestic wastewater have been limited to laboratory scale using synthetic wastewater, or at full scale with limited investigation of internal reactor dynamics (Singh and Viraraghavan, 1998; Foxon, 2004). The ABR functioned as solids retention device where particulate material retained through settling in the first compartment, forming a gel-like matrix and anaerobic conversion to CH_4 and CO_2 reduced the amount of solid (Foxon, 2004). For the smooth operation of ABR, initial loading rates should be kept low to prevent overload of slow growing micro-organisms along with gas and liquid up-flow velocities to encourage flocculent and granular growth (Barber and Stuckey, 1999). According to Henze and Harremoes (1983) approximately 1.2 kg COD/m^{3}d is recommended for start-up period. But for the treatment of dilute wastewater, it is recommended to start-up with high biomass concentration (> 3 gVSS/l) so that sufficiently high sludge blanket and improved gas mixing could be obtained in short time (Barber and Stuckey, 1999).

Expanded granular sludge bed (EGSB) reactor

EGSB is the latest amongst high-rate anaerobic treatment systems which has also become increasingly popular, mainly because of very high loading potential (Lettinga, 2001) with high superficial velocity of 5-10 m/h (Lettinga, 1995). The high surface velocities of the liquid in the reactor are achieved through the application of a high effluent recirculation rate, combined with the use of reactors with a large height/diameter ratio of 20 or more (Kato, 1994; Lettinga, 1995). A practical case of high up-flow velocity in EGSB reactor results in a significant reduction in the area required and this is interesting in the case of treatment of soluble effluents from industries.

The EGSB process use granular anaerobic biomass and have the operation principles as UASB, but differ in terms of geometry and process parameters (Zoutberg and Eker, 1997). In the EGSB process, granular biomass is expanded by the high gas and liquid up flow velocities and hence only granulated sludge is retained at the bottom of the reactor whereas, significant amount of sludge remains in fluidized state at higher levels (Parawira, 2004). Small granule and dispersed biomass are washed out leading to retaining of mainly well structured granular sludge. Advantages like higher OLR up to 40 kgCOD/m^3 is achieved depending on the type of wastewater but drawbacks like granule disintegration, washout of hollow granules and occurrence of fluffy granules are prominent in this reactor (Parawira, 2004). However, in one such study, use of tall reactors with effluent recirculation resulted in EGSB reactor with high superficial velocity and granular sludge bed expansion eliminating dead zones and better sludge-wastewater contact (Man et al., 1986). This prevented the accumulation of excess flocculent between sludge and sludge granules (Van der Last and Lettinga, 1992) with efficient removal of soluble pollutants.

Up-flow anaerobic sludge blanket (UASB) reactor

The UASB reactor was developed by Gazte Lettinga in 1972 during a laboratory study on anaerobic treatment of beet sugar wastewater (Lin and Yang, 1991). Among all high-rate anaerobic digesters UASB reactors have been most widely used (Chong et al., 2012). It is a reactor which operates without any power requirement and is like an inverted septic tank which is more efficient than conventional septic tanks for removal of pollutants and production of biogas (Arceivala and Asolekar, 2007). This has rather become successful due to the presence of solid liquid gas (SLG) seperator on the top for the prevention of solid loss and absence of fixed bed which otherwise would have induced clogging (Foresti et al., 2006). The critical elements of UASB reactor are the influent distribution system, gas-solid separator and effluent withdrawal design (Metcalf and Eddy, 2003). Lin and Yang (1991) concluded UASB to be better performing than other advanced anaerobic systems in terms of having high specific activity (rate of reaction), handling high organic rate, retaining high concentration of biomass due to relatively slow upward flow velocity and good COD removal. The key feature of the reactor that makes it popular high rate anaerobic digester (especially in tropical countries) is the availability of granular or flocculent sludge due to its upflow mode of operation, high COD removal efficiency and the ability to apply high volumetric COD loading rate as compared to other anaerobic processes (Crites and Tchobanoglous, 1998). Due to the granulation and blanketing in a UASB reactor, the solid and hydraulic retention time can be independent as a result, the reduction in treatment time from days to hour is possible (Hickey et al., 1991). The UASB reactor eliminates the need of mixing as rising gas bubbles and upflow mode of operation is enough to provide required mixing, this lowers energy demand for the plant operation.

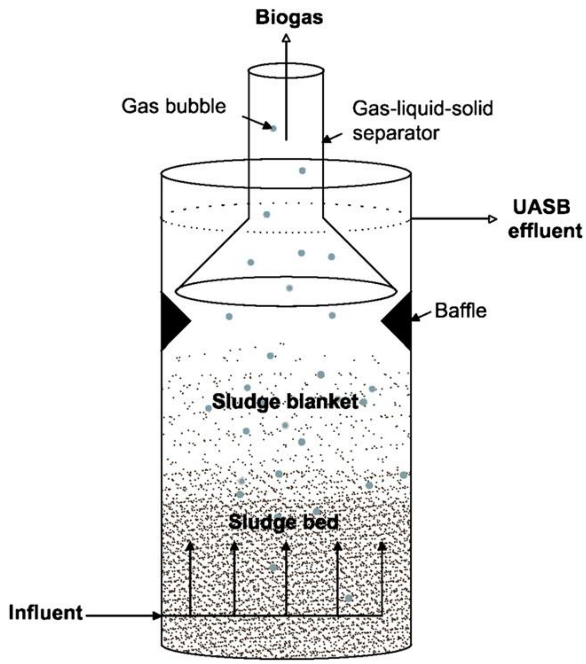

Figure 1. Schematic representation of UASB reactor (Chong et al., 2012).

Working of UASB

A UASB reactor is divided into four components which are sludge bed, sludge blanket, gas-solid separator and settlement compartment as shown in Figure 1. The biomass present at the bottom of the tank is the sludge bed whereas sludge blanket lies above the sludge bed where the suspended particles are found. Gas-solid separator is present at the top for the gas and solids separation and it helps for scum removal as well. The settlement compartment is where settlement of solid into the sludge blanket occurs (Lin and Yang, 1991). The UASB reactor is initially seeded with inoculums such as digested, anaerobic, granular, flocculent and activated sludge. Wastewater is passed from the bottom of the reactor which comes in contact with the inoculums and the biological reaction occurs throughout the sludge bed and sludge blanket (Chong et al., 2012). The baffles prevent wash-out of the viable bacterial matter or floating granular sludge by sliding the settled solids back to the reaction zone. A quiescent zone is created in the settlement zone where heavier sludge settles down and the light and dispersed ones are washed out as effluent. During the upward movement of wastewater, the soluble organic compounds are converted to biogas bubbles consisting of mainly methane and carbon dioxide which are separated by GLS.

Studies show that internal mixing is not sufficient in a pilot-scale UASB reactor treating sewage at temperatures ranging from 4 to 20°C as it may produce dead space in the reactor (Man et al., 1986). Better influent distribution is then required which can be attained by different inlet devices, more inlet feed or high superficial velocities.

Start-up and granulation in UASB

UASB start-up is a time-consuming and delicate process as it begins from the initial feeding to the stage until when stable sludge preferably granular sludge is obtained (Ling and Yang, 1991). This initial start-up is responsible for the overall effectiveness and stability of a UASB reactor which is affected by numerous physical, chemical and biological parameters (Ghangrekar et al., 1996), for instance wastewater constituents, operating conditions, availability and growth of active microbial populations in the inoculum (Chong et al., 2012). Experiences show that the main drawback of UASB reactor is start-up process. It takes long start-up time and is mainly susceptible to temperature and organic loading rates (Lew et al., 2011). The start-up period can take from 2 to several months (Vlyssides et al., 2008) and therefore is a major disadvantage for its applications. An inoculation with seed sludge helps reduce the acclimatization period required before applying the designed organic loading rates. Although a UASB reactor can provide efficient performance without granules, granules formation during start-up would be an advantage for reducing start-up period and has given importance in it (Hulshoff Pol et al., 2004; Liu et al., 2002). Furthermore, the use of septic tank as preliminary treatment step combined with a pulse feed UASB as secondary treatment could shorten the start-up period reducing effect of temperature and granular formation (Richard et al., 2005; Franco et al., 2003; Rocktäschel et al., 2013).

Digested sewage sludge is commonly used as inoculum while other types have also been used (Lin and Yang, 1991). Although, there are many advantages of using UASB, certain processes like interference of particles with flocculation, dead space, bed disruption due to vigorous gas production and speedy inflow rate could hamper the working of UASB (Parawira, 2004).

DOMESTIC WASTEWATER TREATMENT IN UASB REACTOR

The use of UASB reactor for domestic wastewater treatment is usually limited to tropical regions because of low COD concentration and relatively high particulate matter concentration (Lew et al., 2011; Sperling and Oliveira, 2009; Khan et al., 2011?). This needs an initial pre-treatment (hydrolysis) step to convert particulate matter into soluble substrate particularly at low temperature condition which otherwise accumulate in UASB reactor and inhibit anaerobic process. Few studies from various authors on application of UASB reactor for domestic/municipal wastewater treatment are shown in Table 1.

Table 1. Summary of UASB performance results at varied operating conditions.

Temperature (°C)	HRT (h)	OLR (kg COD/m^{3}d)	TSS, removal efficiency (%)	BOD, removal efficiency (%)	COD, removal efficiency (%)	Reference
30	8	1.2	-	-	85	Behling et al. (1997)
20	10-48	-	-	-	60-75	Singh and Viraraghavan (1998)
13-15	10-11	-	75-85	63-73	54-58	Alvarez et al. (2006)
30-35	10	2.7-3.3	-	-	54-72	Mahmoud (2008)
24	48-96	-	56-58	-	81-82	Shayad et al. (2008)
17	48-96	-	51-54	-	74-78	Jamal and Mahmoud (2009)
10-28	6	-	-	-	42-78	Lew et al. (2011)
25-30	9	-	-	77-83	79-81	Rizvi et al. (2014)
8-40	8	0.6- 6.4	65-85	65-85	65-85	Khan et al. (2015)

Behling et al. (1997) examined a pilot scale UASB reactor of 55.5 L capacity for 200 day trial. The equalization tank maintained the OLR 1.21 kgCOD/(m^3.d) with 7.2 l/h flow rate and 7.6 h HRT to feed UASB reactor. The digestion temperature was constant at 30°C. The reactor was fed 10% of the reactor volume (5.5 L) with granulated sludge as inoculum. Results show that the gas production increased steadily until it reached a constant value of about 28 l/d (0.34 m^3 methane per Kg COD removal) and the concentration of effluent COD gradually decreased from 1206 to 60 mg/l (85% COD removal efficiency) which took 60-70 days of plant operation that is when a digestion process is stabilized.

Singh and Viraraghavan (1998) studied start-up and operation of UASB reactors at 20°C for municipal wastewater treatment. They worked on two laboratory scale UASB reactors of 8 L capacity (1 m height and 10 cm internal diameter). Above 50% (4.5 L) digested sludge was seeded as inoculum in both reactors and was operated in a continuous mode. The HRT of the reactor was reduced from 48 to 10 h in about 280 days of operation. The COD concentration of wastewater was about 350-500 mg/l COD (40-50% insoluble) which in initial month of operation COD removal efficiency was in the range of 30-55%. After steady state, the average COD removal efficiency was in the range of 60-75%. But as the insoluble fraction of COD was high in the influent, it appeared that a significant amount of COD removal was due to entrapment of suspended solids in the sludge bed resulting in a significant increase in volatile suspended solids to suspended solids (VSS/SS) ration from 0.5 to 0.8. The high accumulation of particulate matter in the sludge bed seemed to be fine initially because of the fair removal of pollutants but in the long run it, creates disturbance and inhibition of anaerobic digestion in the reactor resulting in diminishing performance of the reactor.

Alvarez et al. (2006) also studied on start-up alternatives and performance of an UASB pilot plant treating diluted municipal wastewater at low temperature. His reactor was a metallic cylinder of total volume 34.9 m^3 (7.1 m height and 2.5 m diameter) and active volume of 25.5 m^3. Three different start-up procedures of an UASB digester were carried out in which start-up A was without inoculum, B was done with inoculation of 10 m^3 digested sludge while C used sludge developed in 50 days of operation of B type digester as its inoculum. Start-up of digester without inoculums (start-up A) was for about 120 day. However, it reached 75-85% TSS removal, 54-58% total chemical oxygen demand (CODt) removal and 63-73% biological oxygen demand (BOD_5) removal at influent concentrations of 240-340 mgCODt/l at temperatures of 13.5-15°C and hydraulic retention times (HRT) of 10-11 h. While in experiment B, start-up period was 75 days, digester efficiencies were 58, 41 and 54% for TSS, CODt and BOD_5 removal, respectively, working at 169 mg CODt/l input at temperature of 14°C and HRT of 11 h. The sludge bed developed and stabilized quickly while using a hydraulically adapted inoculum in experiment C, but CODt and BOD_5 removals remained as low as 43 and 46%, respectively with volatile fatty acids (VFA) accumulation in the effluent.

Luostarinen et al. (2007) studied three pilot scales UASB–septic tank (modified septic tank) reactor of 1.2, 0.2 and 0.2 m^3 capacity used for treating blackwater. The first reactor was inoculated with 100 L granulated methanogenic sludge and operated for 13 years. The flow of the system varied from 1-2 persons for the first year of operation and 3-4 persons in the 13th year. The second reactor was inoculated with 80L sludge obtained from 1.2 m^3 UASB system and maintained at 15°C whereas the third reactor was not inoculated and maintained at 20°C. The performance of the 1.2 m^3 UASB-septic tank was monitored for 52 weeks during the 1st year and for 13 weeks during the 13th year of operation, while others two 0.2m^3 reactor were monitored for 51 (15°C) and 47 weeks (25°C) from the start-up. Comparisons between the gas production in warm and cold season of these reactors showed that higher conversion of COD into methane was in warm season. However, most of the COD washed out as dissolved COD and suspended COD in warm season had been settled in sludge bed in the cold period. This is because with the increase in temperature, hydrolysis of accumulated solids apparently started and dissolved compounds were formed.

Mahmoud (2008) studied high strength sewage treatment in a UASB reactor and an integrated UASB digester system of working volume of 140 and 106 L, respectively. The one-stage UASB reactor was operated at 10 h HRT at ambient temperature for more than a year in order to assess the system response to the Mediterranean climatic seasonal temperature fluctuation. Afterwards, the one-stage UASB reactor was modified to a UASB-digester system by incorporating a continuous stirred tank reactor (CSTR) digester operated at 35°C with continuous mixing at 60 rpm. Pre-treated influent (screens and grit removal) was pumped into a holding tank (200 L plastic container) for about 5 min. The reactor was operated for about a year in which the first 42 days was considered to be start-up. The sludge bed of the UASB reactor was discharged more than two to three times a week to keep its content below 40 cm and that discharge was immediately fed into the digester with the help of peristaltic pump. At that very moment, the digester effluent was pumped out and re-circulated to the lower part of the UASB reactor at 10 cm from the bottom. The whole system operated for 107 days with 57 days as a startup period. The OLR of one stage UASB reactor was 3.35 and 2.73 kgCOD/(m^3.d) for hot and cold six months respectively, whereas it was 2.84 kgCOD/(m^3.d) for the reactor in the UASB digester system. The achieved COD removal efficiency was 54% during the first warm six months of the year, and achieved only 32% over the following cold six months of the year. The modification of the one-stage UASB reactor to a UASB reactor-digester system had remarkably improved the overall performance as the COD removal efficiency of digester alone was 72%.

Shayad and Mahmoud (2008) studied start-up of an UASB-septic tank for community on-site treatment of strong domestic sewage of COD_t concentration of 1189 mg/L. The two pilot scale UASB-septic tank reactors R1 and R2 with two and four days HRT with 0.8 m^3 working volume were operated in parallel for a period of 6 months (October to March) with sewage temperature of 24°C. Domestic sewage was pretreated with screens and grit removal chamber and collected in holding tank (200 L). The UASB reactor was inoculated with anaerobic sludge from cesspit and operated in parallel at ambient temperature. Steady state was considered after 80 days of operation due to poor results in the first 60-80 days. However, methanogenic activity increased with sludge bed development as methane gas began to produce after 30 days. Increase in biogas production was a result of COD conversion likely due to better mixing conditions created by intense gas production along with the bio-conversion. Methane gas production is strongly influenced by the development of sludge bed and the ambient temperature. This experiment resulted in the average removal efficiencies for COD_t and TSS as 56% (1267-56 mg/l) and 81% (623-116 mg/l) for 2 days and 58% (1267-530 mg/l) and 82% (623-113 mg/l) for 4 days HRT which does not have much differences and makes 2 days HRT more adequate and economical.

Jamal and Mahmoud (2009) researched on community onsite treatment of cold strong sewage (average influent COD_t 905 mg/l) in a UASB-septic tank system (up-flow septic tank). They experimented on two pilot scale UASB septic tank reactors R1 and R2 with 2 and 4 days HRT, respectively, with 0.8 m^3 working volume. They were operated in parallel for a period of cold 6 months (October to March) with sewage temperature of 17.3°C. Domestic sewage was pretreated with screens and grit removal chamber and collected in holding tank (200 L). The tank was inoculated with anaerobic sludge from cesspit and operated in parallel at ambient temperature. During the monitoring period, the removal efficiencies in R1 and R2 for COD_t, and TSS were 51%, 74 and 54%, 78, respectively. The difference in the removal efficiencies of those parameters in R1 and R2 is marginal. The sludge filling period of the reactors is expected to be four to seven years.

Sperling and Oliveira (2009) evaluated the comparative performance of full-scale anaerobic and aerobic waste-water treatment processes in Brazil. Evaluation and comparison of 166 full-scale WWTP (both aerobic and anaerobic) operated in Brazil was done which included septic tank anaerobic filter (ST+AF), UASB, UASB-post treatment, facultative pond (FP), anaerobic pond-FP and activated sludge (AS). The results from the statistical tests confirmed that the best performance was achieved by AS followed by UASB with post treatment. These technologies presented better performance than the other processes with regard to the effluent concentration and removal efficiency of almost all constituents. The UASB reactor showed good BOD and COD removal efficiencies but was poor in TSS, FC and nutrients removal.

Lew et al. (2011) studied about an integrated UASB-sludge digester for raw domestic wastewater treatment in temperate climates to improve the performance of UASB reactor treating raw domestic wastewater under such climatic conditions. An experimental UASB reactor made of plexiglass with working volume of 5.3 L was initially seeded with 2 L granular sludge from a full scale UASB reactor treating food wastewater. Domestic wastewater with COD concentration of 1576 (±376) mg/l was fed at temperatures of 28, 15 and 10°C for 2 months each with 6 h HRT. Gas collector was used to collect and measure the gas produced, sludge degradation as mg COD/l was calculated using the theoretical specific methane production per kg COD (350 L CH4 per kg COD). Results show declining removal efficiencies with decreasing temperatures, that is, COD removal decreased from 78% at 28°C to 42% at 10°C with highest methane production of 6.19 L CH_4/day to nil, respectively. This decline was attributed to low hydrolytic activity at lower temperatures that reduced suspended matter degradation resulting in solids accumulation at the top of the sludge blanket. Solids removed from the upper part of the UASB sludge were treated in an anaerobic digester. The anaerobic digester of 2 L working volume was designed for that purpose working in 15°C and increasing temperatures. Result shows gas production increase with rise in temperature reaching up to 4.1 L CH_4/day at 30°C which indicates that non-degradable fraction of sludge decreases with increasing temperature. Maximum utilization of COD was also observed at 30°C which accounted to about 60% (17.9 to7.16gCOD/l) COD removal.

Rizvi et al. (2014) studied start-up of laboratory scale UASB reactor treating municipal wastewater and effect of temperature, HRT on its performance. It was found that the start-up period was about 120 days. The COD and BOD removal efficiencies were in the range of 57-62 and 61-66%, respectively at 17°C and 60 days of operation. However, the removal efficiency increased to the range of 79-81 and 77-83%, respectively at 25-30°C, 9 h HRT and 150 days of operation.

Khan et al. (2015) studied performance evaluation of UASB reactor treating domestic wastewater using 60 L pilot scale reactor. The treatment efficiencies were investigated at 8 h HRT and ambient temperature ranged from 8 to 40°C. TSS, COD and BOD removal efficiencies were found to be in between 65 to 85% under different OLR between 0.57 and 6.35 kgCOD/(m^3.d). The removal of organic matter followed a liner correlation with organic loads.

Reviewing these literatures, it can be concluded that start-up process and temperature are major issues in UASB reactor for the efficient performance of the reactor. There are lack of sufficient information and experience that the UASB reactor has successfully been operated for domestic wastewater in low temperature regions. To bridge this gap, the author has applied simple principle of combining septic tank into UASB reactor for reducing/ converting high content of organic particulate matters available in domestic wastewater into soluble solution before supplying to UASB reactor.

Moreover, to get benefit from sufficient mixing and stimulate granulation process (usually takes long time at lower temperature environment), pulse feed strategy was applied to overcome effects of lower temperature environment. The preliminary results and experience is discussed below.

Future prospect (ST-UASB combined system for domestic wastewater treatment)

In tropical countries, UASB reactors are widely accepted for domestic wastewater treatment and there are several pilot and full scale plants in operation in Japan, India, Brazil and Columbia. Studies suggest that COD, BOD and TSS removal efficiencies are in the range of 65 - 75% in these countries at HRT of 6 to 18 h (Seghezzo et al., 1998; Lew et al., 2011; Sperling and Oliveira, 2009; Khan et al., 2011?). But especially in developing countries with lower temperature conditions, there are concerns in pre-removal of particulate matters prior to anaerobic treatment in order to obtain good effluents quality and biogas production, which inhibit the widespread use of this technology (Elmitwalli et al., 2002; Chong et al., 2012). One probable easiest way to improve UASB performance in these countries are to combine it with septic tank or settling tank (usual existing systems in developing countries) to ensure preremoval of suspended solids and allow for hydrolysis of particulate organic matter to generate a feed solution that is appropriate for UASB as described in earlier. Though, there is no published information on how to integrate UASB system into existing infrastructure like septic tanks and the performance of such combined system, it could attract researchers especially from developing countries with fluctuating climatic conditions to investigate on it and find a suitable solution in a local context.

The authors have conducted a preliminary study at Kathmandu University, Nepal on septic tank-UASB combined system which shows very encouraging results. A 250 L pilot scale UASB reactor is fed with septic tank effluents and operated at ambient temperature range of 0 to 30°C. The reactor is fed intermittently 12 times per HRT and the performance is recorded for different HRTs from 18 to 4 h during 1.5 years operation. The start-up period is found to be about 2 to 3 weeks even at low temperature. The average COD hydrolysis and methanogenesis percentage are about 18 to 36%, and 23 to 36%, respectively. About 22 to 37% of influent COD are converted into methane, 12 to 19% accumulated in the reactor while 44 to 62% remained in the effluent. The COD removal efficiency of UASB reactor is in the range of 38 to 56%, while the performance of the combination of septic tank and UASB is 55 to 72% at all HRT except for 4 h. At this HRT, all parameters are significantly lower, because the removal efficiency collapsed. This also shows good pollutant removal efficiencies and short start-up period for reactor operating at fluctuating temperature conditions. Though it needs further long term study and as far as possible parallel study at different countries with similar low temperature conditions to establish the similarity of operation, it can be said that the combined system could be a suitable low cost and effective onsite sanitation option especially for developing countries like Nepal.

CONCLUSION

Start-up of UASB reactor was affected by various factors, most importantly temperature and OLR. In general, a long start-up period of about two months was required, which could even be longer at lower temperature. Treatment efficiency and methane conversion was strongly dependent on temperature, HRT and OLR primarily for the treatment of domestic wastewater. The high organic particulate matter content in domestic wastewater was a major issue for lower temperature conversion and therefore, a septic tank pretreatment with pulse feed UASB (ST-UASB) combined system might be worth attended for prospective research to help solve the concerns. A preliminary study on ST-UASB combined system carried out at Kathmandu University at ambient temperature range of 0 to 30°C. The UASB reactor was fed intermittently 12 times per HRT and the performance was recorded for different HRTs from 18 to 4 h during 1.5 years operation. The start-up period was found to be 2 to 3 weeks even at low temperature conditions and the COD removal efficiency of the combined system was 55 to 72% at all HRT except for 4 h. At this HRT, the removal efficiency collapsed.

Conflict of interests

The authors did not declare any conflict of interest.

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