UASB REACTOR STARTUP FOR THE TREATMENT OF MUNICIPAL WASTEWATER FOLLOWED BY ADVANCED OXIDATION PROCESS

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Abstract - The present study was done to shorten the start-up time of up-flow anaerobic sludge blanket (UASB) reactor. Two different nutrients were used during the UASB start-up period, which was designed to decrease the hydraulic retention time (HRT) from 48 to 24 and 12 to 6 hrs at average temperatures of 25-34 °C. In the first stage, start-up was with glucose for 14 days and then the reactor was also fed with macro- and micronutrients as a synthetic nutrient influent (SNI) from 15 to 45 days as the second stage. For the control, a second reactor was kept on glucose feeding from day 1 to 45. The removal efficiencies of the chemical oxygen demand (COD) were 80% and 98% on the 6th and 32nd day of the first and second stage, respectively. The maximum substrate removal rate of 0.08 mg COD mg⁻¹ VSS d⁻¹ was observed for glucose and synthetic nutrient influent (SNI) on the 8th and 40th days, respectively. When the reactor reached the maximum COD removal efficiency it was then shifted to municipal wastewater (MWW) mixed with industrial wastewater. The HRT was reduced gradually with a one week gap while treating MWW. For further cleaning, the UASB effluent was treated with 40% waste hydrogen peroxide. The whole integrated treatment process was successful to reduce the COD by 99%, total suspended solids (TSS) by 73%, total nitrogen (TN) by 84% and turbidity by 67%.

Keywords: Start-up time; UASB reactor; COD removal; Substrate uptake.

INTRODUCTION

In many countries, UASB reactors have been used since last decade to treat sewage water due to their easy handling and low operating cost. However, to shorten the start-up period, the reactor is often inoculated with active microorganisms or granules, otherwise it takes more than three months or longer to achieve full efficiency for municipal wastewater (MWW) (Lettinga *et al.*, 1993). Before direct treatment of wastewater, the UASB reactor passes through

a start-up time period with selected nutrients as substrate. The study by Zhou *et al.* (2006) proved that the substrate produced more electrolytes in the reactor, which improved the granulation and thus the treatment efficiency, as well as shortened the start-up time. An anaerobic process includes principally three metabolic phases, i.e., hydrolysis, acidogenesis and methanogenesis (Cohen *et al.*, 1982). In another study, glucose with potassium acetate mixture as organic substrate was used to increase the number of *Methanosarcina* and other bacteria distributed within

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the granules and resulted in more than 97% COD removal efficiency (Kalyuzhnyi *et al.*, 1996). Micro- and macronutrient supplementation were found to be very effective in reducing the startup period and achieving high COD removal efficiency. Ca^{2+} at concentrations from 150 to 300 mg L^{-1} enhanced the biomass accumulation and granulation process in UASB reactors (Boonsawang *et al.*, 2008). Macronutrients such as nitrogen, potassium, phosphorus and magnesium are required for activation of microorganisms. Micro-nutrients such as nickel, cobalt and iron are known for their role as biochemical cofactors for methane production (Speece, 1996). So it is possible that supplementation of macro- and micronutrients enhances the organic matter degradation during anaerobic digestion. The division of biodegradable fractions (Fb) was first introduced to explain the oxygen demand in wastewater treatment systems (Dold *et al.*, 1986). Parameters like Fb and the substrate uptake rate can be considered as wastewater parameters for evaluating treatment efficiency during reactor start-up. These biodegradable fractions are readily accessible as molecules such as glucose and acetate (Verstraete, 2005). In untreated MWW these fractions are normally found to be greater than 0.9 and should be below 0.4 after biological treatment.

There is no doubt that the UASB reactor is gaining fame over the past decade, but there still are few researches that explore a reduction of the start-up time. Some reasons for this can be ascribed to a lack of information on selection of sludge, kinetics involved during start-up of low and high strength wastewater treatment. Environmental factors can also affect process kinetics and substrate removal (Singh *et al.*, 1999). The UASB reactor is a suitable low cost wastewater treatment system in developing countries. UASB is an attractive option which combines simple design and low operating cost with efficient removal of pollutants. Many developing countries are choosing anaerobic processes for their domestic wastewater rather than aerobic treatment processes due to technical simplicity and the small

quantity of sludge production. Furthermore, inorganic components like NH_4^+ are not reduced to acceptable limits. Therefore additional integrated treatment is preferable where nutrients removal is required.

The main objectives of the present study were to shorten the start-up time of COD removal efficiency by addition of different substrates (glucose and SNI). Secondly, to treat municipal mixed industrial wastewater by an advanced oxidation process (AOP) to polish the UASB effluent.

MATERIALS AND METHODS

Start-Up of UASB Reactor

The whole treatment process was performed in the laboratory where the temperature varied from 25 °C – 35 °C over two months. Both reactor and mixing tank were connected with tubes to transfer the liquid. Two UASB reactors were constructed with 5 mm thick transparent acrylic material with inner diameter of 11.7 cm, total height 43.5 cm. The total volume of each reactor was 4.6 L with a working volume of 4.4 L and the effluent was collected from 36.5 cm in height. The reactor had five ports; three on the left side of the reactor were used for effluent collection and recycling; the other port on the right side was used for influent feed. The higher port was left for gas collection. Reactor parameters are summarized in Table 1.

Two liters of sludge was collected from a local domestic septic tank for seeding the UASB reactor (Figure 1).

Both reactors were fed with glucose for an initial 14 days; from the 15th day reactor I was shifted to SNI (stage II) containing macro- and micro-nutrients (SNI) (Tables 2 and 3) to increase the desired population of microorganisms. The control reactor (reactor II) continued the feeding with glucose solution for 45 days as a control. Glucose and SNI solutions were prepared and adjusted to pH 7.

Table 1: UASB reactor parameters.

Parameter	Value
Temperature (°C)	20-30
Volume of reactor (L)	4.6
Flow rate (L d^{-1})	2.16
Concentration of influent (mg COD L^{-1})	250-300
Mass loading rate ($\text{g COD L}^{-1} \text{h}^{-1}$)	0.14
Hydraulic loading rate ($\text{L L}^{-1} \text{day}^{-1}$)	0.47
Hydraulic retention time (h)	48
Up flow velocity (cm h^{-1})	0.05

Figure 1: Design of the UASB, P1= peristaltic feed pump, P2 = peristaltic recycle pump.

Table 2: Composition of synthetic influent (SNI).

Synthetic influent	Concentration
NaHCO ₃	1g L ⁻¹
Trace element solution	1ml L ⁻¹
MgCl ₂	1g L ⁻¹
KH ₂ PO ₄	1g L ⁻¹
(NH ₄) ₂ SO ₄	0.24g L ⁻¹

Table 3: Components of the trace element solution.

Components	Conc. (g L ⁻¹)	Components	Conc. (g L ⁻¹)	Components	Conc. (g L ⁻¹)
Na ₂ -EDTA	5	FeCl ₂ ·4H ₂ O	3.58	CoCl ₂ ·6H ₂ O	0.5
NaOH	11	MnCl ₂ ·2H ₂ O	2.5	(NH ₄) ₆ Mo ₇ O ₂₄ ·4H ₂ O	0.5
CaCl ₂ ·2H ₂ O	7.34	ZnCl ₂	1.06	CuCl ₂ ·2H ₂ O	0.14

The reactor was operated in a continuous mode and, after 39 days, the HRT was reduced from 48 to 24 hr with the same loading rate to see the effect of macro- and micro-nutrients. After achieving a stable COD removal of 99.9%, this reactor was used to treat municipal wastewater. In a previous investigation by Subramanyam and Mishra (2007), the reactor was operated with glucose at concentrations of 100 to 1000 mg L⁻¹ with 8 hrs HRT and the removal efficiency was 95% when microbial seed was collected from a fully efficient UASB plant.

Determination of the Substrate Uptake Rate, Bio-degradable Fractions and Growth Yield

The parameters substrate uptake rate and biodegradable fractions were determined after fitting the experimental data with the following equations.

$$U = \frac{(S_o - S_e)}{\theta \cdot X} \quad (1)$$

$$F_b = \frac{BOD_5}{0.65 \times COD} \quad (2)$$

$$E = \left(\frac{S_o - S_e}{S_o} \right) \times 100 \quad (3)$$

$$F_b = \left(\frac{BOD_5}{0.65 \times COD} \right) = \frac{bCOD}{COD} \quad (4)$$

where, U = specific substrate utilization rate (d⁻¹); θ = HRT (h); S_o = influent COD (mg L⁻¹); S_e = effluent COD (mg L⁻¹); X = average volatile suspended solids (VSS) concentration in reactor (mg L⁻¹); F_b = biodegradable fractions; BOD₅ = five day biochemical oxygen demand of the effluent (mg L⁻¹), COD_e = chemical oxygen demand of the effluent (mg L⁻¹), E = removal efficiency in (%), bCOD = biodegradable chemical oxygen demand (Mathiewu and Etienne, 2000; Verstraete, 2005).

The mass loading rate and hydraulic loading rate were calculated as follows:

$$\text{Hydraulic loading rate} = \frac{Q}{A} \quad (5)$$

where flow rate and volume of the reactor are indicated by Q and V respectively.

$$L_{\text{org}} = \frac{QS_o}{V} \quad (6)$$

L_{org} = mass loading rate, S_o was taken as 300 mg L⁻¹.

The up-flow velocity was calculated by using the equation:

$$\text{Up-flow velocity} = \frac{Q}{A} \quad (7)$$

where 'A' is area of the reactor.

Analytical Procedures

All the analytical procedures were adopted from the standard methods for water and wastewater analysis (APHA, 2005). Wastewater samples were analyzed prior to and after the UASB and AOP treatments. COD was determined by the closed reflux colorimetric method using a digester (HACH-LTG 082.99.40001), (APHA, 2005). The sample, digestion solution and sulphuric acid were digested in vials for two hours at 150 °C. After digestion, absorbance was measured at the wavelength of 605 nm in a spectrophotometer (Lovibond tintometer GMBH, 44287 Dortmund). The pH was measured with a pH meter (HANNA, HI-991003) immediately after collection without stirring to prevent loss of CO₂ from the sample; such losses may cause changes in pH. The H₂O₂ was collected from an industrial process after its use in a Tetra Pak® machine. The H₂O₂ concentration was measured by a hydrometer according to the procedure given by Tetra Pak® manual (Tetra Pak, 2008). For the total Kjeldahl nitrogen, including organic nitrogen and ammonia nitrogen, the semi-micro-Kjeldahl digestion method (4500-N_{org}) was performed for 1-2hr at 200 and 300 °C, followed by distillation to obtain the sum of organic and ammonia nitrogen. For NO₃ and NO₂ determination the WAGSTECH kit was used. Granule size was measured by sieving procedures with mesh sizes of 2, 0.7, 0.5 and 0.2 mm placed vertically on top of each other.

RESULTS AND DISCUSSIONS

Effect of Glucose During the UASB Start-Up Period

It was observed that, when only glucose was added as nutrient, reactor pH ranged between 7 - 7.4 during 1-6th days and decreased from 7.3 to 6.7 during days 6th-14th. The effluent pH remained higher than the influent pH until day 6 and, after 6th day, it dropped very sharply and remained below the influent value on day 14 (Figure 2) due to fermentation of glucose to acetate. Glucose served as a better carbon source for active biomass, which was easily biodegradable to form acetate. Therefore, the removal percentage of COD during the first five days of feeding with glucose were lower than 70%, but from the 6th day, as microbial growth increased, the removal efficiency increased to 80% (Figure 3), in accordance with the finding of Wang *et al.* (2014), who found that when glucose was added to the anaerobic reactor from day 105 to day 138, the total COD removal rate was increased from 23.93% to 85.71%.

Figure 2: pH_i (influent), pH_e (effluent) comparison during start-up of the UASB with glucose.

Figure 3: COD percentage removal during start-up of the UASB with glucose.

In order to check the reactor efficiency, effluent COD was compared with influent COD. In Figure 4 effluent COD decreased from 250 to 50 mg L⁻¹ during the first 5 days and after six days it remained almost the same. In the study by Subramanyam and Mishra (2007), catechol was successfully mineralized in a UASB reactor in which microbial granulation was achieved with only glucose as the substrate. The reactor showed 95% COD removal efficiency. In another study by Majumder and Gupta (2007), sodium formate, sodium propionate, glucose and methanol were used separately as four different carbon sources in the feed as co-substrate. Methanol was found to be the best carbon source, showing 95% 2-chlorophenol and 81.1% 2,4-dichlorophenol removals. In another study by Zhou *et al.* (2006), a UASB reactor was fed with three kinds of different substrates, glucose, skim milk and mixed volatile fatty acids (VFAs). Under mesophilic conditions at pH 7.4 and glucose substrate, 90% COD removal efficiency was achieved.

Figure 4: Comparison between CODi and CODE during start-up of the UASB with glucose.

In contrast, another study by Eng *et al.* (1986) used shock loads of sucrose in a lab-scale UASB reactor, treating diluted landfill leachate. Addition of shock loads of 10 g L⁻¹ sucrose and also large amounts of volatile fatty acids in diluted leachate caused the pH value of the reactor effluent to drop from 7.2 to 4.7, which inhibited methanogenesis.

Not only did organic substrates successfully remove COD, but inorganic components such as zero-valent iron were also successful in COD reduction. Liu *et al.* (2011) demonstrated that when a voltage of 1.4 V was supplied to the zero-valent iron bed, the COD removal efficiency increased to 90% and the granule size reached up to 696 mm within 38 days.

Effect of SNI During the UASB Start-Up Period

During the second stage start-up process where SNI was used in same reactor, lower pH was observed in the beginning due to glucose conversion to acid as indicated in Figure 5 and gradually moves towards neutral and slightly alkaline pH.

By the addition of SNI it was clear from Figure 6 that COD removal reached more than 97% and remained until the end. Comparing glucose and SNI (Figs. 3 & 6) during start-up showed that using glucose in the influent removed 70% of the COD. After the 14th day, further addition of SNI in the influent gave COD removal > 97% and this maximum efficiency at 48 h HRT was changed to 24 h after 39 days. After 45 days the COD was below the detection limit. Glucose in synthetic wastewater increased the specific methanogenic activity (Vadlani and Ramachandran, 2008) which helped to decrease the COD. Many studies have mentioned that UASB digesters need to be inoculated with sludge for full reactor efficiency. Without using seed culture, start-up of the reactor was considered to be feasible after 6 – 12 weeks at a HRT of 6 h and temperature above 20 °C (Lettinga *et al.*, 1993).

Figure 5: pHi and pHe comparison for SNI used for start-up.

Figure 6: Percentage removal of COD by using SNI.

58% total COD removal was reached at a temperature of 15 °C and HRT of 11 h for 120 days by Alvarez *et al.* (2006). Kalogo *et al.* (2001a) and Kalogo and M'Bassiguie (2001b) achieved a removal efficiency of up to 65% of COD in a self-inoculated reactor treating domestic wastewater. In the present study it was observed that septic tank sludge was also effective to achieve full efficiency in 32 days when glucose was added in the first stage and SNI during the second stage with full efficiency of 99%. The key role of these macro- and micronutrients was to contribute to the synthesis of protein, cell wall permeability and new cell growth. In the study by Xu *et al.* (2005), when single micronutrient zero-valence Fe was used in a UASB reactor during the start-up time, it improved the COD removal efficiency up to 21%. Predominance of active biomass was also important during start-up, which reduced the start time from 50 days to 30 days when seed sludge was taken from distillery effluent (Vadlani and Ramachandran, 2008).

Comparison of influent and effluent COD (Figure 7) shows a difference of COD concentration in the range of 300 – 50 mg L⁻¹ during the second stage with SNI substrate.

Figure 7: Comparison of COD_i and COD_e from the fifteenth day with SNI.

Substrate Uptake Rate During Start-Up with Glucose and SNI

During the initial four days, the substrate uptake rate was lower and effluent COD was higher, which gradually start decreasing (Figure 8). From the 5th day substrate uptake increased and reached a maximum level of 80% on the 8th day. During four days due to insufficient active biomass, the substrate uptake rate was low.

Addition of nutrients helped to increase the active biomass. Higher active biomass results in higher COD removal rate. With continuous feed of substrate at the same flow rate and concentration, non-active

biomass was washed out and active biomass increased and accumulated inside the reactor. The specific uptake rate was calculated from volatile suspended solids (VSS), HRT and the reactor volume. The substrate uptake rate was increased after the 4th and 30th days with glucose and SNI, respectively.

Figure 8: COD_e and substrate uptake rate with glucose.

It was observed that affinity with the substrate was very important for the maximum COD removal efficiency and to shorten the start-up period for the maximum COD removal rate. Typically bacteria with high substrate affinity are found to be less efficient than those having low substrate affinity (Verstraete, 2005). Anaerobic species in the reactor have high affinity with glucose (stage I), so a lower COD removal rate of 80% was observed, while with SNI it was 99%. After 45 days, the reactor reached its full efficiency with continuous addition of SNI (Figure 9). The maximum COD removal efficiency of 99.9% with SNI was found on day 33. The significant negative correlation of $r = -0.7$, $n = 45$ between substrate uptake rate and COD value was found, which indicates that, as the substrate was utilized, COD decreased. Initially slow uptake rate of a specific substrate utilizing bacterial species was associated with a delay in maximum COD removal.

Figure 9: COD_e and substrate uptake rate with SNI.

In the control reactor II it was observed that glucose alone was not enough to reach maximum COD removal efficiency. Macro- and micro-nutrients were used in two phases to stimulate the UASB reactor, clearly indicating that nutrients are essential for successful removal of COD.

Biodegradable Fraction Analysis During Substrate Uptake

A clear representation in Fig. 10 showed that the initially biodegradable fraction (Fb) remained the same from the 1st to 30th days and then started to decrease on day 31, in accordance with the reduction of COD. A non-significant positive correlation ($r = 0.4$, $n = 45$) was found between the COD value and Fb. Initially higher Fb might be due to the lower number of specific microorganisms, which increased with the passage of time and this may be the reason that incomplete degradation of substrate results in higher Fb in the effluent. After 30 days when growth of micro-organisms in the reactor reached the maximum number, there was more degradation of substrate and less Fb (0.4) in the effluent.

Figure 10: Glucose and SNI effects on biodegradable fraction and substrate uptake.

During the initial three days, the glucose uptake rate was less and Fb was high, because effluent may have Fb from influent and sludge washing. It was indicated that organic matter present in the effluent was reduced as the uptake rate of biomass increased; a non-significant negative correlation ($r = -0.47$, $n = 45$) was found between Fb and the substrate uptake rate. Jhung and Choi (1995) found that biodegradation and granulation influenced more with used waste than with the reactor itself. After the 6th day the substrate uptake rate remained the same from 0.07 – 0.08 per day. The decrease in Fb was also due to the granulation and settlement of organic solids.

Treatment of Municipal Wastewater After Start-Up of the UASB

After 46 days when the reactor reached its maximum COD removal efficiency with SNI, it was shifted to municipal wastewater treatment. Municipal wastewater COD ranged from 250 to 350 mg L⁻¹ during 47 to 54 days. The HRT was adjusted at 48, 24, 12 and 6 hours after 7 days working at each HRT. From days 48 to 54, the COD was below 50 mg L⁻¹. On day 47 a high effluent COD of 78 mg L⁻¹ was observed and might be due to municipal influent, but later on it decreased to 50 mg L⁻¹ up to day 54. The HRT was adjusted to 24 h from days 55 to 61. When the HRT was changed the effluent COD was 157 mg L⁻¹ and the next day it started to reduce until day 60, where the minimum COD of 30 mg L⁻¹ was observed (Fig. 11). On day 61 the HRT was reduced again to 12 h and there was again a slight rise in COD and on day 62 it was found to be 80 mg L⁻¹. The same behavior was observed after day 68 when there was again a small rise in effluent COD. It was observed that the COD of municipal wastewater was lower than 350 mg L⁻¹ during our whole experiment from days 47 to 74. During this experiment unexpected heavy rainfall caused dilution of the wastewater. Despite the small granule (0.5 mm) formation during this time period, the reactor efficiency was not affected to an unacceptable level. During this time period there was no excess sludge produced to remove from the reactor. The biogas was not analyzed due to the unavailability of the equipment in the lab, but release of gas bubbles was observed in a water jar connected to the top of the UASB reactor. This indicates that methanogenic bacteria were active during phase II. During the last seven days of experiment at 6 h HRT, the COD was between 60–70 mg L⁻¹.

Figure 11: Comparison of influent and effluent at different HRT while treating MWW.

Post Treatment of UASB Effluent with Waste H₂O₂

UASB effluent was treated with 40% waste H₂O₂ in a further step. A 2 ml L⁻¹ dose of hydrogen peroxide was found to be very effective and total nitrogen removal of 84% was achieved with combined treatments of UASB and AOP. The removals of other parameters like TSS, COD, TN and turbidity were 73%, 99%, 84% and 67.5% respectively. Ortho-P was not removed to an acceptable level of 2 mg L⁻¹ (Table 4).

In the H₂O₂ treatment step, conductivity and TDS were not significantly removed, but both were below National Environmental Quality Standards (NEQS) (Table 5). The COD was below the standard limits. After UASB treatment the VSS/TSS ratio was increased from 0.71 to 0.73 and a drastic change of 0.4 was observed with AOP treatment. This was due to the bactericidal property of hydrogen peroxide, which kills most of the microbes present in the effluent and oxidizes cell debris. Using hydrogen

peroxide as post-treatment was very attractive due to the COD removal of 99%. Although ammonia was detected (2.42 mg L⁻¹) in the raw water sample, after UASB treatment its concentration was increased to 6 mg L⁻¹ (Table 4). The increase of ammonia may be due to ammonification process inside the reactor and, after chemical treatment with hydrogen peroxide, decreased drastically (i.e., 0.1 mg L⁻¹). This showed that post-treatment with hydrogen peroxide was very effective to reduce total nitrogen to an acceptable local standard.

Ammonium nitrogen, which is toxic to aquatic species, was oxidized with H₂O₂. Table 6 showed that in UASB effluent the ammonium nitrogen concentration reached 0.1 from 0.22 mg L⁻¹ during 120 min. Nitrate concentration was 1.3 mg L⁻¹ at 0 min and, after 30 min of mixing in the presence of hydrogen peroxide, its concentration decreased to 0.78 mg L⁻¹. After 120 min of continuous mixing nitrate reached 1.7 mg L⁻¹.

Table 4: Average characteristics of raw MWW and effluent at various treatment steps.

Parameters	Raw wastewater	UASB	H ₂ O ₂ treatment	Removal efficiency
TSS (mg. L ⁻¹)	112 ± 10	42 ± 5.89	30 ± 4	73%
VSS (mg. L ⁻¹)	80 ± 10	31 ± 3.54	12 ± 4	85%
TDS (mg. L ⁻¹)	493 ± 14	421 ± 10	477.6 ± 3	3.2%
EC S/cm	993 ± 8	841 ± 7	957 ± 3	3.6%
VSS/TSS	0.71	0.73	0.4	-
COD (mg. L ⁻¹)	290 ± 6.69	31.5 ± 4.43	BDL*	99.9%
AN (mg. L ⁻¹)	2.42 ± 0.1	6.05 ± 0.80	0.1 ± 0.1	95.9%
NO ₃ -N (mg. L ⁻¹)	3.52 ± 0.4	2.47 ± 1	1.7 ± 0.2	51.7%
NO ₂ -N (mg. L ⁻¹)	2.04 ± 0.3	1.79 ± 0.5	0.26 ± 0.1	87.3%
TK-N (mg. L ⁻¹)	24 ± 2	14.58 ± 1	3 ± 0.5	87.5%
T-N (mg. L ⁻¹)	31.98 ± 1	24.89 ± 2	5.06 ± 0.4	84.2%
Ortho-P (mg. L ⁻¹)	6.87 ± 0.2	5.34 ± 1	5.51 ± 1	19.8%
pH	7.25 ± 1	7.42 ± 1	7.5 ± 1	-
Turbidity (NTU)	40 ± 3	28 ± 3	13 ± 3	67.5%

*BDL = Below Detection Limit, TSS = Total Suspended Solids, VSS = Volatile Suspended Solids, TDS = Total Dissolved Solids, EC = Electrical Conductivity, AN= Ammonium Nitrogen, TK-N = Total Kjeldahl-Nitrogen.

Table 5: NEQ Standards for effluent discharge.

	COD	BOD	Kjel-N	NH ₄ ⁺	NO ₃ ⁻	PO ₄ ⁻	TN	SS
Working Goal mg L ⁻¹	125	25	<10	1	1	2	15	35

Table 6: UASB effluent treatment with H₂O₂ at a dose of 2 ml L⁻¹.

Time	NH ₄ (mg. L ⁻¹)	NO ₃ (mg. L ⁻¹)	NO ₂ (mg. L ⁻¹)	TDS (mg. L ⁻¹)	COD (mg. L ⁻¹)	Temp °C
0 min	0.22	1.3	0.68	487	31	30.7
30 min	0.06	0.78	0.11	484	31	31.4
60 min	0.15	1.76	0.23	473	20	31.3
90 min	0.13	1.92	0.48	460	BDL*	30.6
120 min	0.1	1.7	0.26	455.5	BDL*	30.8

*Below Detection Limit

It seemed that nitrification was more dominant than denitrification. The hydroxyl radicals released from the dissociation of H_2O_2 might have caused the oxidation of ammonium to nitrate.

Some chemicals have been already used for nitrification and denitrification processes. Sabzalim (2006) reported denitrification of nitrate using Zn and sulfamic acid treating ground water.

During anaerobic treatment inorganic components such as NH_4^+ are removed to a limited extent. Many additional systems have been proposed to remove NH_4^+ from UASB effluent. Zeolite and duckweed plants were used to reduce the NH_4^+ from UASB effluent in two different studies (Aiyuk *et al.*, 2004; El-Shafai, 2007). Treatment efficiency of 99% was achieved with zeolite, but long recharging time was required (Aiyuk *et al.*, 2004). Insignificant change was observed in TDS, but COD was decreased further to 0 mg L^{-1} from 31 mg L^{-1} . One degree increase in temperature 30.7 to 31.4°C was observed after 30 min. This might be due to the exothermic oxidation of remaining pollutants. After complete oxidation of pollutants, when COD reached zero, the temperature reached 30.8°C .

Overall total nitrogen removal was 84% with 5 mg L^{-1} effluent concentration; after peroxide treatment the value was below the Pakistan NEQS permissible limit. In Fig. 12 ammonia, nitrate and nitrite were compared during reaction with hydrogen peroxide for 120 min. After 30 min maximum decrease of nitrate, nitrite and ammonia was observed. Further mixing showed a slight decrease in ammonia and rise in nitrate due to nitrification of ammonia.

Figure 12: Effect on ammonium, nitrate and nitrite after treating UASB effluent with H_2O_2 .

Different HRT, i.e., 48, 24, 12 and 6 h were tested to check the efficiency of COD removal, after completion of the start-up period in four weeks. It was observed that HRT below 24 h disturbed the settled sludge in the reactor. Therefore, no obvious granulation occurred at low HRT for five weeks, but granule size was less than 0.5 mm . Increase in uplifting velocity of influent greater than 0.1 cm h^{-1} resulted in sludge bed disturbance. It took more time to develop granules at high uplifting velocity. Average COD reduced to 31.5 mg L^{-1} at 48 h HRT with 99% removal efficiency. No change was observed in turbidity, TDS, conductivity and pH. Many other researchers have worked to see the effect on treatment efficiency at lowest HRT. Mahmood (2007) observed, at 24 h HRT, 85% nitrate removal efficiency with zero ammonia in effluent from UASB where sludge was collected from an anaerobic methanogenic reactor. In the present work, 85% total nitrogen, 95% ammonia and 83% COD removals were observed at HRT 24 h where inoculum was collected from a domestic septic tank. In contrast, Chelliapan *et al.* (2011) observed a 94% COD removal at 4 days HRT.

Many researchers have indicated that maximum COD removal efficiency related with granule formation takes three months (Yu *et al.*, 2001; Zhou *et al.*, 2006; Kalogo *et al.*, 2001). As indicated in Table 7, during start-up of the UASB reactor the maximum removal efficiency of 95% was observed with cattle manure as inoculums (Akila and Chandra, 2007). It is clear from the present research that domestic septic tank sludge achieved the maximum COD removal efficiency of 85-99% in only six weeks at HRT of 24-48 h. It is clear that domestic septic tank sludge was very effective for removal of COD from MWW. Granulation was not included in this part of the study as municipal waste water was mixed with industrial waste water.

Economic Aspects

The total cost calculation showed that an integrated UASB system with post-treatment of hydrogen peroxide has approximately 50% less cost than conventional aerobic wastewater treatment.

Important factors which make this process less costly than aerobic treatment are indicated in Table 8. As H_2O_2 was collected after its use in an industrial process, one liter of used H_2O_2 can be purchased for US\$ 0.2. This treatment option can be used for a small treatment plant for less than 10,000 residents where it would not be as expensive as the aerobic

Table 7: Comparison of UASB HRT start-up with different inoculums.

HRT	Inoculums source	COD Removal efficiency	Reference
6 d	Self inoculation	84%	Bodkhe, 2009
24 h	Granular sludge	86%	Ramakrishnan, 2007
24 h	Cattle manure	90-95%	Akila, 2007
10-11h	Digested sludge	63-73%	Alvarez <i>et al.</i> , 2006
3 h	Digested sludge	90-92%	Singh <i>et al.</i> , 1999
48h	Domestic septic tank sludge	99%	Present study

Table 8: Economical analysis of various treatment options for MWW.

Types of Costs	Aerobic treatment cost (%)	Anaerobic treatment cost (%)
Preliminary preparation	3	2
Primary and secondary treatments		
1. Pumps	7	5
2. Screen and sand trap	6	6
3. Primary decantation	5	2
4. Rainwater decantation	6	6
5. Activated sludge basin	13	8
6. Secondary sedimentation/ mixing tank	7	NA
7. Coagulant and flocculants	NA	NA
8. Waste peroxide	NA	1
Sludge treatment infrastructure		
9. Digester	10	NA
10. Pre thickener	7	NA
11. Post thickener	3	NA
12. Gas holder	5	10
13. Mechanical sludge dewatering	10	NA
14. Motors	5	4
15. Electricity	14	6
Total cost %	100	50

NA = Not Applicable

treatment cost. An average total investment cost is about US\$100 per capita in which half of the cost is for building construction and the remaining for electrical and mechanical devices, which might vary considerably. The total cost for one year of treatment is approximately US\$40 on the basis of information given in Table 8 assuming that one inhabitant produces 180 liters of wastewater per day and a treatment cost range around approximately 0.5 US\$/m³.

CONCLUSIONS

It is concluded from the present research that a self-inoculated UASB reactor with septic tank sludge achieved the maximum COD removal efficiency in 32 days with a two-step substrates feeding with glucose and SNI. Microbes in the reactor started to utilize glucose initially as readily available carbon source and after addition of SNI reactor efficiency was increased and reached more than 97%. An optimized dose of 2 ml L⁻¹ of 40% H₂O₂ was used to

treat UASB effluent. This proposed system was found to be very successful in removal of 99% COD, 67% turbidity, 95% ammonium, 85% VSS and 84% TN at low investment cost.

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NOMENCLATURE

AOPs	Advanced Oxidation Processes
HRT	Hydraulic Retention Time
H ₂ O ₂	hydrogen peroxide
COD	Chemical Oxygen Demand
BOD ₅	Biochemical Oxygen Demand
NEQS	National Environmental Quality Standards
NTU	Nephelometric Turbidity Units
Fb	biodegradable fractions

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