original article

Treating municipal solid waste leachate in a pilot scale upflow anaerobic sludge blanket reactor under tropical temperature

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ABSTRACT

Aims: The objective of this study was to investigate an Upflow Anaerobic Sludge Blanket (UASB) reactor efficiency in treating municipal landfill leachate, under tropical temperature.
Materials and Methods: A 30-liter pilot-scale UASB reactor was used to treat the municipal solid waste leachate, under tropical temperature, for 230 days. The reactor was inoculated with 10 liters of anaerobic sludge from an anaerobic digester, in an agro industry's wastewater treatment plant. The Volatile Suspended Solids (VSS) of sludge were 65 g/L, with volatile suspended solids to suspended solids (VSS/SS) ratio of 0.74. The reactor was operated in mesophilic (34 – 39ºC) temperature.
Results: After reaching a stable operation, the reactor was exposed to raw leachate, with mean chemical oxygen demand (COD) concentrations of 35 g/L. The leachate was diluted to 9 – 10 g/L at Organic Loading Rates (OLRs) of 2, 6, 12, 15 g COD/L.d and decreased again to 12 g COD/L.d, resulting in 45, 76, 84, 68, and 79% removal efficiency and increased again to 87% removal efficiency for COD, at Hydraulic Retention Times (HRTs) of 6, 1.6, 0.83, and 0.67 days, respectively, in the UASB. In the reactor used in this study, the heavy metals were removed by adsorption on biomass, and the maximum removal rate was 68% for Zinc (Zn).
Conclusions: It was concluded that the optimum OLR for diluted leachate up to 10 g COD/l, was 12 g COD/L.d at an HRT of 0.67 day (16 hours).

Key words: Anaerobic system, heavy metals, leachate treatment, methane production, UASB reactor

INTRODUCTION

Solid waste landfills may cause severe environmental impacts if leachate and gas emissions are not controlled. Leachate generated in municipal landfill contains a large amount of organic and inorganic contaminants,[1] including a high concentration of metals and some hazardous organic chemicals. The removal of organic material based on COD, Biochemical oxygen demand (BOD), and ammonium from leachate is the usual prerequisite before discharging the leachate into natural waters.[2] Anaerobic treatment methods are more suitable for the treatment of concentrated leachate streams. Anaerobic treatment methods offer lower operating costs and produce usable biogas products, with production of a pathogen-free solid residue, which can be used as the cover material in landfills.[1,2] Since its introduction in the early 1980s, the Upflow Anaerobic Sludge Blanket (UASB) system has gone through a lot of improvement in both design and operational details and has been used to treat a variety of industrial effluents.[3]

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High-rate anaerobic processes such as UASB and an anaerobic filter were found to be efficient in the treatment of leachate having a COD higher than 800 mg/L and a BOD/COD ratio higher than 0.3.[4] In an investigation, the UASB reactor was operated at 37 – 42ºC, with an organic loading rate variation of 4.3 – 16 g COD/L.d, in a COD concentration of 5.4 – 20 g/L, and with an 80% COD removal in OLR of 16 g COD/L.d. The percentage of methane in biogas produced in the first and second UASB reactors was 64 and 43% respectively, with 9.5l/d biogas.[5]

Kennedy and Lentz,[6] found that treatment of the municipal landfill leachate, using the continuous flow UASB reactor was more favorable than the sequencing batch reactor at higher OLRs, and was very similar at low and intermediate OLRs. Nitrification of anaerobically pretreated municipal landfill leachate on a laboratory scale–activated sludge reactor was investigated through aerobic post-treatment, to produce effluent with 150 – 500 mg/L COD, less than 7 mg/L BOD, and an average less than 13 mg/L NH_4-N.[7] Nitrogen can also be removed effectively from landfill leachate using a nitrifying upflow biofilter, with waste material as a filter medium, combined with subsequent denitrification of the nitrified leachate in the landfill body.[8] Lin *et al*.[9] examined the operating parameters and treatment efficiency in the digestion of septage, with landfill leachate, by using four laboratory scale anaerobic CSTR digesters. The septage and leachate were mixed in the ratio of 1: 0, 1: 1, 2: 1, and 3: 1 on the basis of COD for each digester, the Sludge Retention Time (SRT) was controlled at 20, 10, and 5.3 days. For the same SRT, a higher ratio of septage increased the removal efficiencies of COD, ammonia nitrogen, and total phosphorus. The methane yield was increased with increasing septage fraction. Torkian and Amin *et al*., succeeded in obtaining 85 – 90% efficiency in COD removal from a medium-sized traditional slaughterhouse's effluent by a pilot scale UASB reactor, in a temperature range of 25 – 29°C.[3]

In a study by Jianyong *et al*.,[10] the leachate from pretreated municipal solid waste was treated by an expanded granular sludge bed (EGSB) bioreactor under mesophilic conditions and 88 – 97% COD removal was obtained under normal operation conditions.

Castrillon *et al*.,[11] studied the removal of COD from an old municipal solid waste leachate with a COD between 11000 and 16000 mg/L by anaerobic treatment and obtained 80 – 88% COD removal for an OLR of 7 g COD/L.d and around 60% for an OLR of 1 g COD/L.d, as leachates had lower COD (4000 – 6000 mg/L).

Jiexu *et al*.,[12] in an investigation, obtained 82.4% of COD removal at an OLR of 12.5 g COD/L.d, under mesophilic conditions, with an UASB reactor, when treating fresh leachate from the municipal solid waste incineration plant with high COD (70390 – 75480 mg/L).

The objective of this study was to investigate the UASB reactor efficiency in treating municipal landfill leachate, under tropical temperature (34 – 39ºC), in Ahwaz city, south of Iran. This investigation focuses on the treatment of leachate and finding the optimum flow rate in such a reactor, when working in a tropical temperature. It has been performed on a laboratory scale, according to the conditions in Ahwaz city.

MATERIALS AND METHODS

The rectangular section dimensions of the UASB reactor used in this study were 20 × 25 cm^2, 70 cm height, and an efficient volume of 30 liters. Figure 1 shows a schematic of the UASB reactor used in this study. Three evenly distributed sampling ports were installed along the reactor's front wall. The temperature of the reactor was maintained at 35 ± 1ºC in winter, by an internal heater supported by thermocouple. The temperature was variable between 33 and 39ºC, because of the change in the ambient temperature during spring, summer, and autumn. Flocculated sludge (10 liters) from the anaerobic treatment plant of an agro industry (Shooshtar, Iran), which was treating sugarcane wastewater, was inoculated into the UASB reactor. The Volatile Suspended Solids (VSS) concentration of the seed sludge was 65 g/L. The biomass was periodically sampled from the reactor for analysis of the VSS concentration. The raw leachate produced in the municipal solid waste collection vehicles and transport trucks were used for feeding the UASB reactor in this study. The raw leachate with pH between 3.5 and 5 was neutralized by using lime and potassium hydroxide. The COD concentration of raw leachate was in range of 18 – 42 g/L. Thus, it was diluted to optimum concentration and pH. The diluted leachate with a COD range of 7 – 12 g/L and a pH of about 7 – 8 was continuously fed into the UASB reactor. Table 1 represents the characteristics of the leachate used in this study.

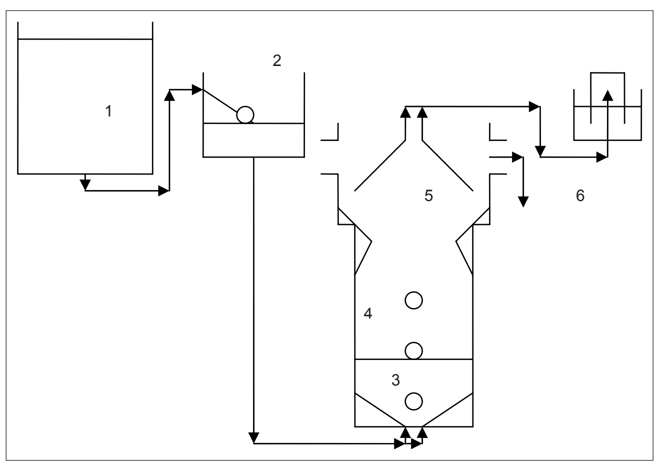

Figure 1: Schematic of a UASB reactor used in this study: (1) Leachate reservoir, (2) neutralization reservoir, (3) biomass zone, (4) liquid–solid zone, (5) gas–liquid separator, (6) effluent, and (7) gas measuring system

Table 1: Characteristics of municipal solid waste leachate of Ahwaz

Raw leachate	Average	Range	Number of measurements
COD, mg/L	32500	18000–42000	80
BOD_5, mg/L	23000	12500–27000	27
pH	4	3.5–5.5	200
Diluted leachate (reactor influent)			
COD_{in}, mg/L	9480	7000–12000	80
pH_{in}	7.5	7-8	200

The initial COD loading rate of the reactor was 3 g COD/L.d after the startup period, which corresponded to three days of Hydraulic Retention Time (HRT). The loading rate was increased by increasing the daily inflow rate of the reactor, and decreasing the HRT, and the COD removal efficiency exceeded 75%, and the biogas production rate was consistent in the three consecutive analyses. For measuring biogas, a simple handmade measuring system, consisting of two conversely small buckets, with efficient volume of 1.5 liters, was used, which worked on the basis of gas–liquid transfer.

The COD removal efficiency was determined on the basis of soluble COD, after filtering the samples through a filter paper (Whatman No. 41, Category 1441125). The COD samples were collected from the influent and effluent of reactors, twice a week, and were digested for two hours, using a COD digester (AQUALytic, AL31). Then the digested samples were analyzed through a spectrophotometer (AQUALytic, AL282).

Suspended solids (SS), Volatile Suspended Solids (VSS), and soluble COD were determined according to the *Standard Methods* (1998).[13] For SS analysis, 100 ml, filtered and weighted samples were heated in a plate till dry and then kept in an oven for one hour, at 110°C. The SS was calculated from the difference between the wet and dry weight of the filtered samples. The VSS analysis was performed by burning the samples in a furnace at a temperature of 550°C.

The leachate samples were collected and digested with nitric acid (Merck, Germany) for detection of heavy metals.[13] The digested samples were analyzed using the Perkin Elmer 3030 Atomic Absorption Spectrophotometer (PerkinElmer, Inc., Massachusetts, USA).

RESULTS

Chemical oxygen demand removal in the upflow anaerobic sludge blanket reactor

Tables 2 and 3 illustrate the operation parameters of the UASB reactor used in this study. Figure 2 shows the efficiency of COD removal and OLR throughout the study. The HRT was decreased stepwise from 72 – 0.67 days after the startup period. The COD removal efficiency was between 76.5 and 79.7%, which corresponded with OLRs of 3 to 15 g COD/L.d.

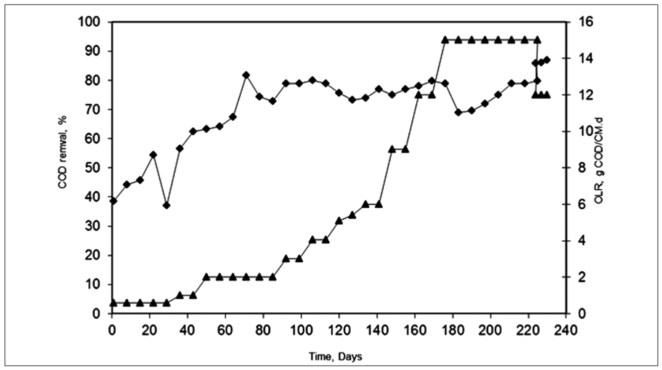

Figure 2: OLR and efficiency of COD removal

In the recurrence period the OLR was decreased from 15 to 12 g COD/L.d by decreasing the COD concentration from 10 to 8 g/L, with 45l/d inflow rate, so that the HRT (0.67 d) did not change by decreasing the OLR. The COD removal efficiency was increased to 87% after returning the OLR to 12 g COD/L.d, which was the highest COD removal efficiency obtained in this study.

Temperature of reactor

The reactor temperature was controlled between 33 and 39ºC. In winter, by means of a heater, the temperature of reactor was controlled at 35 ± 1ºC. In spring, summer, and autumn, the temperature of reactor was affected by ambient temperature, and it was varied between 33 and 39ºC. Figure 3 shows that the highest performance of the reactor in removing COD was obtained at the maximum temperature (39ºC) in this study.

Heavy metal removal

The performance of the reactor was investigated in removing heavy metals (Zn, Pb, Ni, Cd) from MSWL (Municipal Solid Waste Leachate). Table 4, illustrates the quantity of metal concentrations in the influent and effluent of the reactor, and compares these concentrations with the metal concentrations in the raw leachate. The highest metal removal efficiency based on the concentration of metals in diluted leachate was 68% for Zn and the lowest removal rate was 4% for Cd.

DISCUSSION

The COD concentration variations in this study and the COD removal efficiencies of the UASB reactor exhibit similar results, with the data obtained by Kettunen *et al.*,[1] Osman Nuri and Teresa Sponza,[5] Kennedy and Lentz,[6] Lin *et al.*,[9] and Shin *et al.*,[14] but in some instances, this study obtained higher efficiencies in COD removal. For example in a study carried out by Kettunen *et al.*,[1] the COD removal was between 85 and 90% for the sequential anaerobic–aerobic system, and the COD removal efficiency for the anaerobic stage was only 60%, while in this study only for one stage in the UASB reactor the COD removal efficiency was 87%.

Table 2: Operation parameters of the UASB reactor used in this study

Operation Days	Temperature °C	Loading rate			Retention time	COD	
		Q in l/d	CODin g/L	OLR g COD/L.d	HRT, day	Removal, %	gCODrem/gVSS.d
Startup period							
1 – 86	34.5	2.5 – 8.5	7 – 12	0.6 – 2	3.5 – 12	75	0.06
Steady state operation periods							
87 – 105	34.7	10	9	3	3	79	0.095
106 – 128	35.3	13.5-17	9	4-5	1.8-2.2	80	0.13 – 0.15
129 – 148	36.5	18	10	6	1.6	78.5	0.18
149 – 162	38.7	27	10	9	1.1	78.5	0.28
163 – 179	38.4	36	10	12	0.83	83.5	0.38
Maximum organic loading period							
180 – 219	38.5	45	10	15	0.67	79.7	0.49
Return period to lower OLR							
220 – 230	39	45	8	12	0.67	86.9	0.43

Table 3: Data, averages, and standard deviations obtained from operation of the UASB reactor used in this study

Days	pH -	Temperature °C	COD_{in} g/L	COD_{out} g/L	COD_{rem} %
1–30	7.45 (0.52)*	33.82 (0.6)	7 (0.02)	3.67 (0.58)	47.51 (8.27)
31–49	7.17 (0.41)	34.83 (0.75)	12 (0.018)	4.96 (0.62)	58.69 (5.13)
50–86	8 (0.3)	34.83 (0.39)	9.92 (0.26)	3.24 (1.23)	68.34 (4.78)
87–105	7.17 (0.52)	34.5 (0.84)	9 (0.21)	1.94 (0.08)	78.41 (0.92)
106–118	7.25 (0.5)	34.75 (0.5)	9 (0.2)	1.85 (0.04)	79.41 (0.45)
119–131	7.88 (0.25)	35.63 (0.48)	9 (0.33)	2.25 (0.05)	75.05 (0.57)
132–153	7.5 (0.5)	36.79 (0.99)	10 (0.25)	2.52 (0.19)	74.76 (1.91)
154–163	6.5 (0.58)	38.75 (0.5)	10 (29)	2.52 (0.29)	74.78 (2.94)
163–183	7 (0.29)	38.67 (0.52)	10 (0.35)	2 (0.28)	79.98 (2.81)
184–219	7.33 (0.57)	38.67 (0.49)	10 (0.27)	2.55 (0.46)	74.47 (4.63)
220–230	8 (0.41)	39 (0.35)	8 (0.23)	1.1 (0.04)	86.29 (0.52)

*Average (standard deviation)

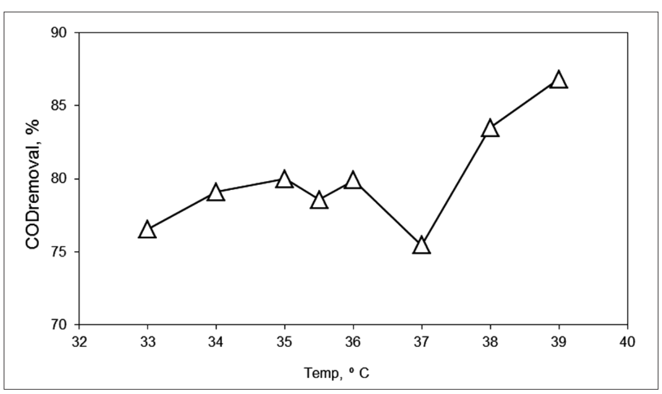

Figure 3: Relation between Temperature and COD removal efficiency

The highest performance of the reactor in removing COD was obtained at the maximum temperature (39ºC) in this study.

Table 4: Metal concentrations (mg/L) in raw leachate, influent, and effluent of reactor

	Zn	Pb	Ni	Cd
Raw Leachate	4.6	0.72	0.38	0.07
Influent				
First month	0.48	0.6	0.19	0.059
Second month	0.53	0.51	0.18	0.051
Third month	0.5	0.61	0.23	0.063
Effluent				
First month	0.19	0.47	0.17	0.051
Second month	0.17	0.35	0.17	0.049
Third month	0.35	0.49	0.21	0.058
Allowed Concentration	2	1	2	0.1

All units are (mg/L)

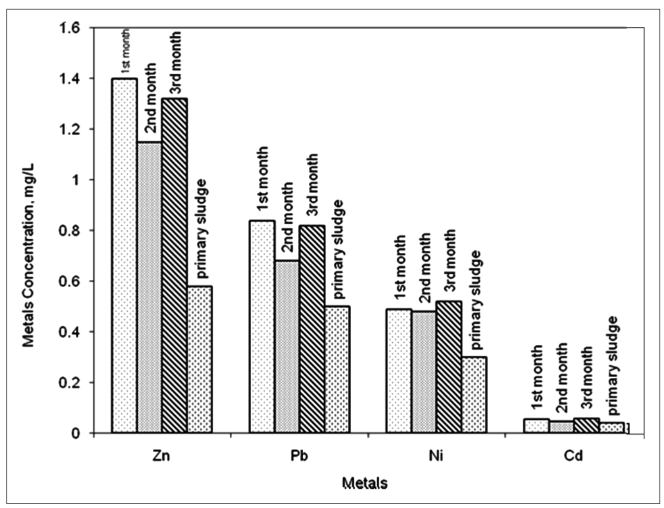

Figure 4: Metal concentrations in primary and reactor sludge

This shows the positive effect of increasing temperature on the performance of the UASB reactor in tropical regions, such as the Ahwaz city (with an annual average ambient temperature range of 30 – 50°C), in the south of Iran.

Figure 4 shows that the concentrations of metals in the biomass are higher than their concentrations in the primary sludge, after three months. Therefore, it can be interpreted that the metals removed physically accumulated in the biomass of the reactor. The reactor is controlled for prevention from reduction of sulfate to hydrogen sulfide and also for the chemical precipitation of metals, by adjusting the pH between 7 and 8. Thus, it is obvious that the removal of heavy metals is not because of chemical precipitation. It can be assumed that the heavy metal removal is physical removal, in the form of adsorption on the microbial surfaces. It is because of the interactions between the metal ions and the negatively charged microbial surfaces. In the maximum organic loading rate period, the washout problem appears due to the high organic loading rate and low HRT. Also, because of the washout of sludge, with the content of concentrated metals, their concentrations are decreased in the sludge of the reactor in the second month [Figure 4].

CONCLUSION

It was concluded that the UASB reactor could receive high organic loading rates to treat diluted (10 g COD/l) MSW leachate (CODavg., 30 g/L) with high efficiency (87%) under tropical temperature (maximum reactor temperature, 39°C), in the optimum organic loading rate of 12 g COD/L.d. Therefore, the UASB reactor was a feasible process for treating MSW leachate in the tropical city of Ahwaz (with maximum annual ambient temperature of 50°C), in the south of Iran. Using high organic loading rates in the design of the UASB reactor would help to reduce the efficient volume of the reactor, and thereby, save the costs of reactor construction and operation.

The effluent COD concentration of the UASB reactor in this study was 1050 mg/L, which did not pass the effluent standards, based on the fifth article of the Water Pollution Prevention Act of the Iran Department of Environment (DOE). So, it was necessary to use an aerobic process after the UASB reactor.

The heavy metal analysis showed that in the reactor used in this study, the heavy metals were removed by physical adsorption on the microbial surfaces. The reactor was controlled for prevention of reduction of sulfate to hydrogen sulfide, so chemical precipitation could not be predominant in the mechanism for heavy metal removal. The maximum removal rate was for Zn, which was equal to 68%.

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