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ORIGINAL PAPER

Treatability of landfill leachate by combined upflow anaerobic sludge blanket reactor and aerated lagoon

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Abstract Continuous upflow anaerobic sludge blanket reactor performs more favorably at the higher organic loading rate than other anaerobic treatment. The treatment of municipal landfill leachate of Shiraz's city investigated using continuous flow anaerobic reactor and subsequently aerated lagoon. Landfill leachate has chemical oxygen demand of 45,000–90,000 mg/L and ammonia nitrogen at 1,000–2,500 and heavy metals that can impact biological treatments. Capacity of anaerobic and aerobic reactors is 10 and 20 L that operated at detention time of 2 and 4 days, respectively. Organic loading rate of upflow anaerobic sludge blanket is between 0.5–20 g chemical oxygen demand/L/day. Chemical oxygen demand removal efficiencies are between 57–87, 35–70 and 66–94% in the anaerobic, aerobic and whole system, respectively. As the entry, leachate organic loading rate increased from 1 to 20 g/L/day, the chemical oxygen demand removal efficiency reached a maximum of 71% and 84% in the anaerobic reactor and whole system, respectively, at high organic loading rate. Ammonium removal efficiency was about 54% after the aerobic stage.

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Introduction

Commercial and industrial development in many countries around the world during past decades have increased generations of urban and industrial solid waste rapidly (Lin et al. 2000). Most of the soild waste from communities is disposed in sanitary landfills, where it receives (undergoes) physical, chemical and biological alterations. Dissolved organic and inorganic substances in water create a leachate, where its treatment can be troublesome (Wu et al. 2003).The removal of COD, BOD and ammonium of leachate is the common prior condition before discharging the leachate into natural waters (Agdag and Sponza 2004). High COD and high COD/BOD ratio of the landfill leachate is the cause for the anaerobic treatment which is more advantageous when compared to aerobic treatment process (Fikret and Pamukoglu 2003). Anaerobic treatment methods are more suitable for the treatment of concentrated leachate streams, which offers lower operating costs and the production of usable biogas product and production of a pathogen-free solids residue which can be used as cover material (Park et al. 2001).

Anaerobic wastewater treatment is a recognized, well-established and proven technology for the treatment of various types of industrial wastewaters (Cakir and Stenstrom 2005). High-rate anaerobic processes such as up-flow anaerobic sludge blanket reactor (UASB) and anaerobic filter have been shown to be efficient in the treatment of leachate having a COD higher than 800 mg/L and the BOD/COD ratio higher than 0.3. Hoilijoki investigated nitrification of anaerobically pre-treated municipal landfill leachate in lab-scale activated sludge reactor (Sahrigi et al. 2002). Aerobic post-treatment produced effluent with COD 150–500 mg/L, BOD less than 7 mg/L and on an average, NH4-N less than 13 mg/L.

Agdag et al. studied treatment of the leachate is produced from the organic fraction of municipal solid waste (food) in a sequential two-staged up-flow anaerobic sludge blanket (UASB)/aerobic continuous stirred tank reactor (CSTR) at a different organic load rate (Agdag and Sponza 2004). COD removal efficiencies of the first and the second anaerobic and aerobic total system were 79, 42, 89 and 98%, respectively, at a COD loading rate of 4.3, 5.76, 7.2, 10.4, 12.8 and 16 g/L per day. The methane content of the first UASB was approximately 60%. The NH4-N removal efficiency of the total system was 99.6% after the aerobic stage. Complete removal of COD and NH(3)-N was reported for combined reverse osmosis (RO) and UASB with an initial COD concentration of 35,000 mg/L and NH(3)-N concentration of 1,600 mg/ L (Kurniawan et al. 2010).

Anaerobic biological treatment of landfill leachate has been studied by many investigators. Up to 92% chemical oxygen demand (COD) removals have been obtained using upflow anaerobic sludge blanket reactors (Kennedy and Lentz 2000). Anaerobic and sequential anaerobic–aerobic reactors have been used for landfill leachate treatment at different temperatures such as 11 and 24°C (Marttinen et al. 2002). Nearly 75% COD removals have been achieved by anaerobic treatment at 24°C with a 10-h hydraulic retention time (HRT). The overall COD removal in the sequential process was 80–90% with nearly 80% ammonium removal. Maehlum (1995) used on-site anaerobic–aerobic lagoons and formed wetlands for biological treatment of landfill leachate. Overall N, P and Fe removals obtained in this system were above 70% for diluted leachate. A combination of anaerobic–aerobic and rotating biological contact (RBC) processes has been used for leachate treatment by Park et al. (2001). The effluent of the RBC process was subjected to flocculation–sedimentation; adsorption and finally reverse osmosis and nearly 98% of the organic materials of low MW have been removed. The average for ferric chloride and neutraolor have been removed in color (97 and 84%), COD (47 and 44%), biochemical oxygen demand (BOD) (75 and 96%), detergents (56 and 85%), arsenic (86 and 86%) and cyanide (97 and 74%) with physico-chemical treatment (Madera and Viviana 2009).

Location of this study was the landfill of Shiraz at Iran and the year was 2008. Some problem Shiraz's Landfill is that, it is not applied by a leachate collection system and produces leachate with high organic matter above 50,000 mg COD/L. The objective of this research has been done to determine treatability of landfill leachate of Shiraz city from Iran in upflow anaerobic sludge blanket (UASB)/aerated lagoon COD, BOD_5 removal, alkalinity, NH_4-N variation in anaerobic/aerobic reactors were evaluated.

Experimental laboratory-scale reactors and seed

One continuously fed PVC anaerobic UASB and an aerobic CSTR reactor were used in sequence for the experimentation. The UASB reactor had 10 L of effective volume with an internal diameter of 7.4 cm and a height of 160 cm. Nine sampling ports (20 and 30 cm apart at bottom and top, respectively) were provided to quantify the sludge characteristics at different elevations along the reactor. It was operated at 25–40°C using a warm water tube located around the reactor. The CSTR reactor consisted of an aeration tank by effective volume of 20 L. First to forth port regulates 20, 30, 40 and 60 L of lagoon volume for fixing of organic loading rate. A schematic of the laboratory-scale sequential UASB and CSTR reactors used in this study is presented in Fig. 1. Dissolved oxygen concentration was kept higher than 2 mg/L in the CSTR reactor. Anaerobic sludge was used as seed in UASB reactor and was taken from invert of anaerobic ponds of RAMAK industry in Shiraz's city. It has 45 g VSS/L.

Analytical procedures

The COD in the influent and effluent samples were determined by the closed reflux colorimetric method. Gas production was measured by a liquid displacement method. Total gas was measured by passing the gas through distilled water containing 2% H_2SO_4 (w/v) and 10% NaCl (w/v) (Gulsen and Turan 1999, 2002). Methane gas was detected using 3% NaOH (w/v) containing distilled water (Boiler and Gujer 1986). Temperature, pH and dissolved oxygen were measured using a pH meter (WWT pH 330), an electronic digital heater and an oxygen meter (WWT Oxi 330), respectively. Ammonia nitrogen and nitrate were measured using spectroquant kits numbered 14752 and 14542 in a photometer Merck SQ 300. Heavy metal measured by atomic adsorption as describe in standard method. Alkalinity was measured by titration with acid to $pH = 4.5$. Other routine analyses, including alkalinity, nitrogen, and phosphorus were performed using procedures outlined in standard methods.

Wastewater composition

The leachate was brought from Shiraz sanitary landfill once every month. Shiraz Landfill leachate was characterized by high COD and ammonia concentrations. The composition of leachate as feed used is provided in Table 1.

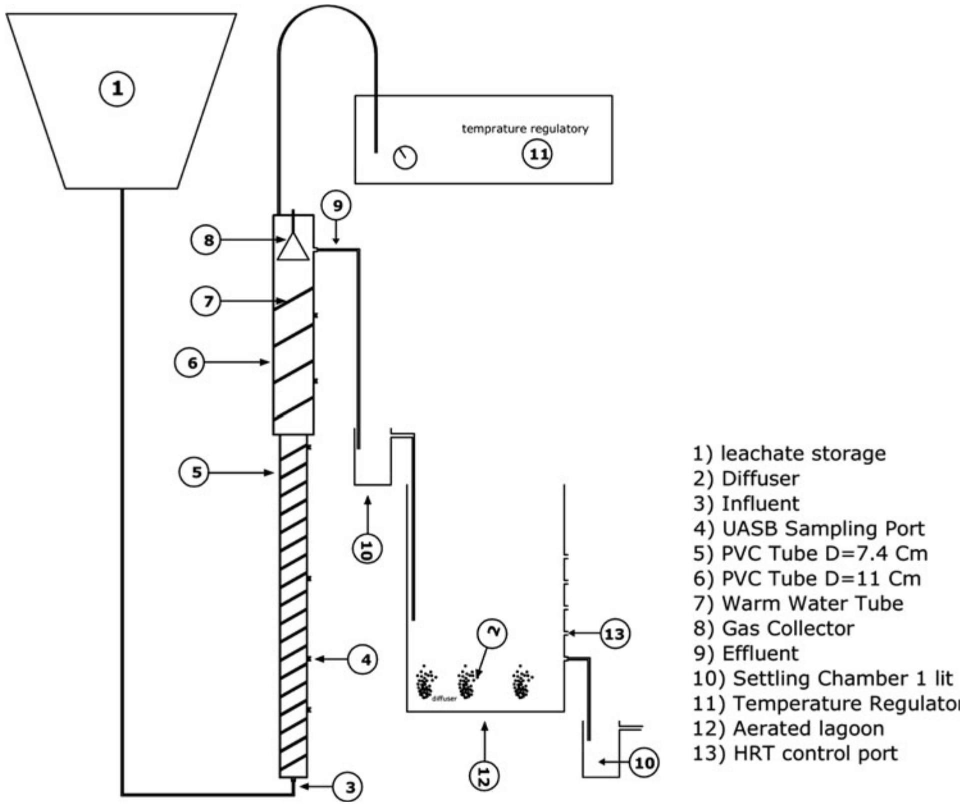

Fig. 1 Schematic of laboratory-scale of UASB and aerated lagoon used for treatment of Shiraz's landfill leachate

Table 1 Composition of leachate as feed used

Lagoon HRT (day)	UASB HRT (day)	Feed NH_4-N (mg/L)	Feed COD (mg/L)	OLR (g/L/day)	Operation period
4	2	115.6	1,000	0.5	0–15
4	2	200	2,000	1	15–45
4	2	425	10,000	5	45–60
4	2	500	14,000	7	60–85
6	2	550	20,000	10	85–110
6	2	650	30,000	15	110–125
6	2	802	35,000	17.5	125–150
6	2	810	40,000	20	150–165

Operating conditions

This study was carried out 160 days. During the start-up period, the reactors were fed with diluted landfill leachate containing, $NaHCO_3$ having a COD concentration of 1,000 mg/L and an organic loading rate of 1 kg/m^3/day. The start-up phase took about 1 month with no leachate addition. After the start-up period, the COD concentration of leachate was steadily increased from 1,000 to 60,000 mg/L by an increase in the dilution factor. The sequential reactor was operated at constant flow rate 5 L/day. Hydraulic retention times were 2 and 4 days in anaerobic and aerobic step, respectively. A constant temperature room was used to maintain the temperature of the reactors at 25 ± 5°C in the summer and warm water tube in winter. To monitor the performances of the reactors, influent and effluent pH were measured daily, while COD and NH_3-N were monitored in steady state condition. The attainment of the steady state was verified by checking whether the mean of the effluent characteristics for the last two measurements was remaining relatively constant. No dilution or recycling of feed was made in the beginning or at any of the phases of the study. TSS was monitored once a week. All analyses were carried out in accordance with the standard methods. Biomass concentration at bottom of reactor measured once a month. To compare the final biomass concentration and distribution in the reactors, sludge samples were taken from all the sampling ports at day 130 and SS, VSS, pH and COD were measured.

The effluent of the anaerobic UASB reactor was used as the influent of the aerobic reactor. The operation conditions of the sequential reactor system are shown in Table 2 and Fig. 2.

Results and discussion

Characterization of the landfill leachate

Typical composition of the landfill leachate obtained from the Shiraz Landfill area in Iran is presented in Table 1.

Table 2 Operation features of the system

Feature Date	Sample 1 08/10/2008	Sample 2 09/21/2008	Sample 3 09/24/2008	Sample 4 10/27/2008	Sample 5 11/25/2008
COD (total)	54,100[a]	41,000	75,000	89,000	76,000
COD (s)	54,096	37,584	74,500	85,000	74,500
BOD_5 (t)	50,000	37,000	42,500	62,300	53,000
BOD_5 (s)	50,000	34,000	42,100	61,400	51,000
TSS	1,500	2,000	500	1,367	1,550
PO_4	30	24	27	38	21
NH_3	1,368	1,420	2,805	2,231.3	1,750
ALK	15,000	12,000	25,000	11,000	9,000
Zn	15	8	17	7.56	9
Mn	0	4	0	1.64	5.34
Cu	0	0	0	0.29	0.36
Ni	0	0	0	0.77	1
pH	5.5	5.7	6.5	5.8	5.6

[a] Unit of all parameter is as mg/L and alkalinity as $CaCO_3$, NH_3-N as N, PO_4 as P

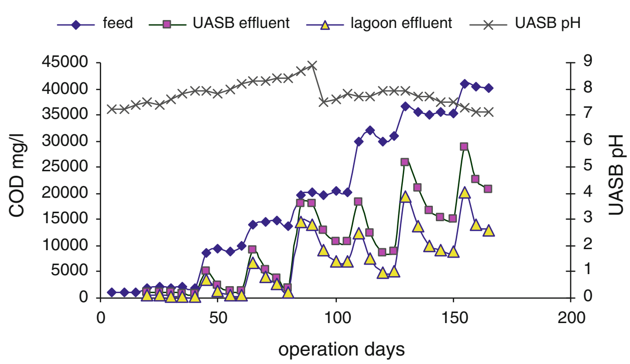

Fig. 2 Operation days for anaerobic and aerobic system

BOD_5/COD ratio in the leachate was nearly 0.9 at summer and 0.6–0.7 at fall. High and low temperature in summer and fall and variation of food materials and type of consumption and solid waste management cause a decrease of biodegradable organic component of solid waste at fall in Shiraz's city. COD/NH_4-N/PO_4-P ratio in the raw leachate was about 300/7.5/0.3 indicating high NH_4-N and low PO_4-P content. Since COD/N/P ratio should be around 300/5/1 for the anaerobic treatment of wastewater, extra PO_4-P was added to the leachate by $K_2H_2PO_4$ for nutrient balancing in the experimental studies.

COD removal in the sequential UASB and CSTR reactors

COD concentrations in effluent of reactors 1 and 2 increased as the OLRs were increased from 1 to 7 g/L/day. In the other words, COD removal efficiencies increased as the OLRs increased. COD and pH values of feed are shown in Fig. 2. As seen in Figs. 3 and 4, the COD removal efficiency increased to 87 from 59% as the OLR was increased to 7 from 1 kg/m^3/day. The COD removal

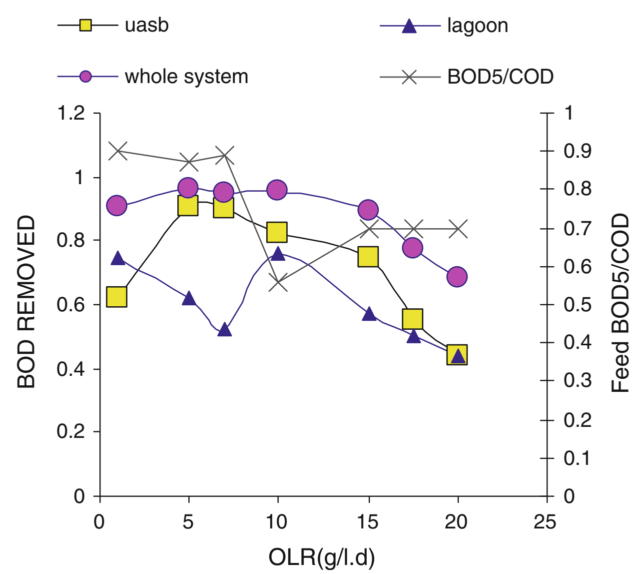

Fig. 3 BOD removal in anaerobic and aerobic steps

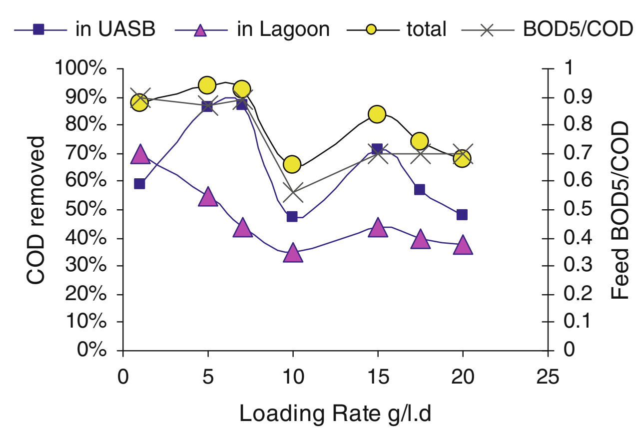

Fig. 4 COD removal in anaerobic and aerobic steps

efficiencies decreased to about 47% at OLR of 10 kg/m^3 as temperature decreased. Most anaerobic wastewater treatments have been conducted within mesophilic (30–40°C) or thermophilic (45–60°C) temperature ranges (Dhaked et al. 2010; Fang et al. 2006). To achieve COD removal efficiencies above 70%, temperature was adjusted with warm tube. Since the COD removal efficiency increased to 71 from 47% as the OLR was increased to 15 from 10 kg/m^3/day. As the COD in the influent was increased from 2,000 to 14,000 mg/L, the COD removal efficiencies increased in the UASB reactor, indicating the anaerobic UASB reactor is resistant to high COD concentrations. As seen in Figs. 3 and 4, the BOD5/COD ratio measured in the leachate samples support biodegradability. The COD removals varied between 35 and 70% in the effluent of second (CSTR) reactor. The total COD removal efficiencies varied between 66 and 94% in the whole system. In a study carried out by Kettunen et al. (1996), the COD removal was as high as 85–90% for the whole sequential anaerobic–aerobic treatment while the COD removal efficiency in the anaerobic stage was only 60%.

NH_4-N removal in the combined UASB reactor and aerated lagoon system

In this study, the NH_4-N concentration of the feed increased by decreasing the leachate dilution rates (increasing of COD and OLRs). NH_4-N concentrations of influent and effluent of UASB reactor and effluent of the aerated lagoon are shown in Fig. 5. The influent NH_4-N concentrations were recorded as 115.6, 310, 345, 420, 650, 802 and 810 as the OLRs increased to 20 from 1 g/L/day. However, the NH_4-N concentrations were 238, 450, 470, 620, 790, 1,010 and 1,012 in the effluent of UASB reactor as OLRs increase. In other words, N-NH_3 release in UASB reactor because most of the nitrogen in the solid waste

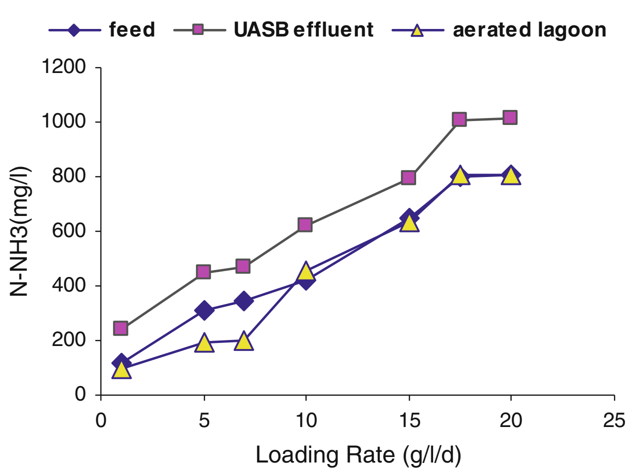

Fig. 5 N-NH3 variation in UASB and aerated lagoon

bioreactors is in ammonia form following the degradation of proteins and amino acids (Inanc et al. 2000). Ammonia nitrogen may be incorporated to cell mass. However, only small amounts would be sequestered in this manner as reported by Lin et al. (Gulsen and Turan 2002). Anaerobic ammonium oxidation using NH_4-N as the electron acceptors could not eliminate the possibility of some NH_4-N converted to N_2 gas (Gulsen and Turan 1999, 2002; Boiler and Gujer 1986; Hollopeter and Dague 1995). In stable anoxic and anaerobic UASB–SBR when the influent ammonia nitrogen (NH_4-N) was changed from 155.8 to 1298.0 mg/L, the effluent NH_4-N was varied from 0.12 to 4.1 mg/L (Sun et al. 2009). The TN and ammonia nitrogen removal efficiencies of the system consisting of a two-stage UASB, an anoxic and aerobic (A/O) reactor and a sequencing batch reactor (SBR) were 98 and 97%, respectively (Wu et al. 2009). In this study, NH_4-N was not removed in anaerobic step. NH_4-N removal efficiency was about 61, 57, 57, 23, 20, 20 and 20% in the effluent of aerobic reactor as OLRs at feed to combined system increase from 1 to 20 g/L/day. This could be explained by nitrification, which occurred in the aerobic reactor at this HRT. In a study carried out by Kettunen et al. (1996). Restraint ammonia nitrogen while feed OLR increases to 7 g/L/day was caused that no significant NH_4-N removal was obtained in the aerobic reactor. Aerobic reactor influent N-NH3 was 620 mg/L at OLR of 10 larger than 500 mg/L that has been reported as the nitrification restraint concentration (Gasten and Rozich 1986; Gee et al. 1990). So at OLR of 10 g/L/day NH_4-N removal was decreased strongly in an aerobic system. Its reason may be low detention time so is elevated to 6 from 4 days. At this case N-NH3 removal was not improved in aerobic step. The NH_4-N concentration decreased from 178 to 35 mg/L at a HRT of 10 h in the aerobic stage of the same study. Im et al. (2001), Hies and Mavinic (2001), and Jokela et al. (2002) reported that NH_4-N removal efficiency was about higher than 90% in the aerobic stage of the total system.

Gas production in UASB reactors

During 125 days of operation period, methane productions continuously increased. Figure 6 shows the volumetric methane production rate increases with the OLR addition. As can be seen in this figure, methane gas production increase to 22.5 L/day as the OLR increased to 15 g/L/day in UASB reactor. Up to the loading rates of 15 g COD/L/day, methane productions were reduced to about 17.33 L/day. The highest volumetric methane production rate (2.25 L CH_4/L/day) was observed at the volumetric COD loading rate of 15 g COD/L/day. The carbonaceous matters in the leachate are converted to methane and carbon dioxide during the anaerobic treatment. Carbon dioxide

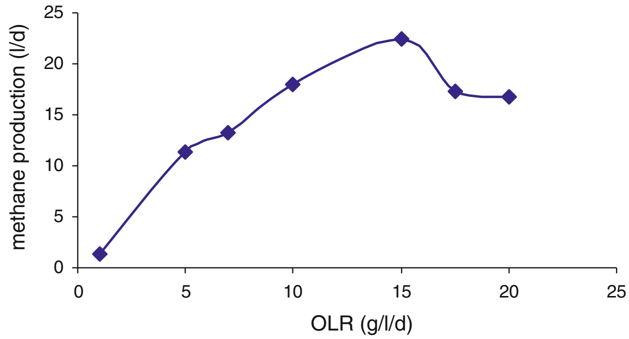

Fig. 6 Effect of OLRs on the methane gas production in UASB system

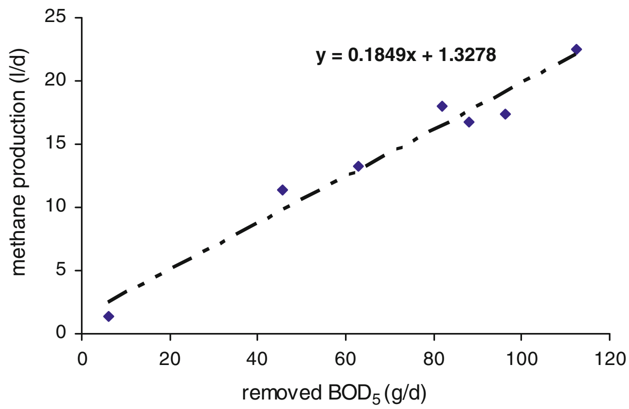

Fig. 7 Correlation of BOD removal and methane production rate for UASB

production does not cause any COD drop. Methane emitted into the gas phase causes BOD drop in leachate. Figure 7 explains that methane production rate increases with the BOD removal rate. The correlation factor was 0.18 L gas/g BOD ($R_2 = 0.96$). In the other words 5.56 g of BOD destruction produced 1 L of methane gas.

Effect of HRT on UASB efficiency

During this study, HRT was shortened from 5 to 2 days with a subsequent decrease in COD values from 75,000 to 30,000 mg/L with constant OLR of 15 g/L/day. Figure 8 shows the COD removal efficiencies as a role of hydraulic retention time in the anaerobic reactor. The COD removal efficiencies were recorded as 61, 63, 72 and 71% as the HRTs decrease to 2 from 5 days. As can be seen in this figure the maximum removal efficiency was 72% at the loading rate of 15 g/L/day which was at 3 days HRT. Control of OLRs and upflow velocity is important in efficiency of UASB reactor. In a study reported by Torkian, in upflow velocity of 0.9–1 m/h and organic loading rates of 14–25 g COD/L/day, the COD removal efficiency was achieved up to 85% (Torkian et al. 2004). But because of

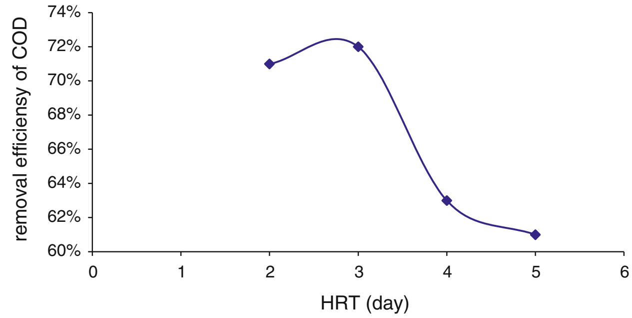

Fig. 8 Removal efficiency of COD with HRT addition

the low upflow velocity (0.03 m/h) in this study, the COD removal efficiency was not greater than 72%. Peak HRT has reported by Ramakrishnan is 30 h at COD of 2,200 mg/L with phenolic removal efficiency of 94% (Ramakrishnan and Gupta 2008).

Conclusion

In this study, the maximum removal efficiency was achieved 71% at OLR of 5 g/L/day for UASB reactor, 75% for aerated lagoon and 94% for whole system. NH_4-N was not removed in anaerobic step but maximum NH_4-N removal efficiency was about 61% in the effluent of aerobic reactor when feed COD was 2,000 mg/L. Methane gas production increase to 22.5 L/day as the OLR increased to 15 g/L/day and ideal detention time achieved 3 days in UASB reactor. The result of this study showed that effluent of UASB and CSTR reactors had not been suitable for the environment and alternative treatment such as coagulation–flocculation or chemical precipitation is necessary.

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