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Original Article

Investigation of Anaerobic Fluidized Bed Reactor/ Aerobic Moving Bed Bio Reactor (AFBR/MMBR) System for Treatment of Currant Wastewater

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Abstract

Background: Anaerobic treatment methods are more suitable for the treatment of concentrated wastewater streams, offer lower operating costs, the production of usable biogas product. The aim of this study was to investigate the performance of an Anaerobic Fluidized Bed Reactor (AFBR)-Aerobic Moving Bed Bio Reactor (MBBR) in series arrangement to treat Currant wastewater.

Methods: The bed materials of AFBR were cylindrical particles made of PVC with a diameter of 2-2.3 mm, particle density of 1250 kg/m^3.The volume of all bed materials was 1.7 liter which expanded to 2.46 liters in fluidized situation. In MBBR, support media was composed of 1.5 liters Bee-Cell 2000 having porosity of 87% and specific surface area of 650m^2/m^3.

Results: When system operated at 35 ºC, chemical oxygen demand (COD) removal efficiencies were achieved to 98% and 81.6% for organic loading rates (OLR) of 9.4 and 24.2 g COD/l.d, and hydraulic retention times (HRT) of 48 and 18 h, in average COD concentration feeding of 18.4 g/l, respectively.

Conclusion: The contribution of AFBR in total COD removal efficiency at an organic loading rate (OLR) of 9.4 g COD/l.d was 95%, and gradually decreased to 76.5% in OLR of 24.2 g COD/l.d. Also with increasing in organic loading rate the contribution of aerobic reactor in removing COD gradually decreased. In this system, the anaerobic reactor played the most important role in the removal of COD, and the aerobic MBBR was actually needed to polish the anaerobic treated wastewater.

Keywords: Anaerobic fluidized bed reactor, Moving bed bio reactor, Currant wastewater, Attached microbial

Introduction

Due to increasing population and decreasing water supplies, wastewater treatment is becoming necessary throughout the world to conserve natural water resources use for drinking water supply (1) In recent years many studies have been performed to evaluate different methods for treatment of high organic load wastewaters (2-5). Anaerobic treatment of high-strength wastewaters with high biodegradable content presents a number of advantages. For example, a high degree of purification with a high load of organic material can be achieved, requires few nutrients and usually produced small amounts of excess sludge. Also in these processes bio-gas is produced, that it is a valuable product and can be compensating some operation costs (6,7). Production and processing of Currant is different in various countries and regions based on weather conditions and technology. Processing of this agricultural product consumes a large volume of water for washing purposes; therefore a large volume of wastewater is produced through this process. This wastewater contains high concentrations of glucose and fructose and typically low concentrations of lipids, minerals and suspended solids. The wastewater also includes all compounds that found in the external surface of the grapes (8). Fluidized-Bed Reactors (FBR) have been known for more than 30 years for treating industrial and municipal wastewater (9). Also some studies have demonstrated the use of Anaerobic Fluidized-Bed Reactors (AFBR) for various industrial wastewater treatments. For example this system have been used for treatment of textile wastewater (9-11), ice-cream wastewater (12), brewery wastewater (13), winery wastewater from Grape-Red and tropical fruit (14), and sanitary landfill leachate (15). In the late of 1900s, Moving Bed Bio Reactor (MBBR) was introduced for biological treatment of different types of wastewater. Recently, it has been successfully used in treating different domestic and industrial wastewaters (16-19).

The aim of this study was to investigate the treatability of a real Currant wastewater by Anaerobic Fluidized Bed Reactor and Aerobic Moving Bed Bio-Reactor at various HRT, and different loading rates.

Materials and Methods

Anaerobic Fluidized bed reactor

The reactor was made of a plexiglass column 60 mm in diameter, 140 cm in height, with a volume of 3.95 l and the enlarged top section was used as a gas–solid separator (Fig. 1). The recycle flow was drawn from the top section using a ***Circulator Pump*** and then fed upward into the reactor. Reactor temperature was controlled by Aquarium Heater at 35±2ºC. Cylindrical particles made of PVC with a diameter of 2-2.3 mm and particle density of 1250 kg/m^3 volume of 1.7 L equivalent to 60 cm height were used as a biomass carrier.

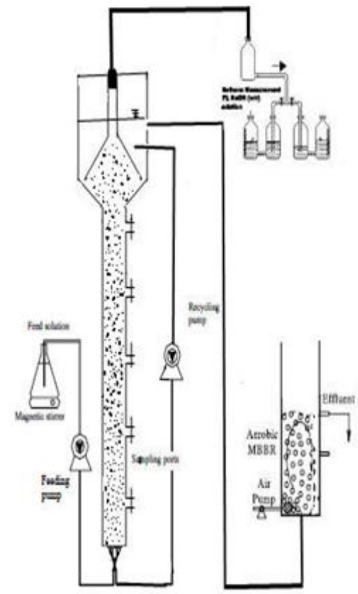

Fig. 1: Schematic configuration of Anaerobic Fluidized bed reactor / Aerobic Moving bed bio reactor system

Aerobic Moving bed bio reactor

Reactor designed for this section was a plexiglass column in inner diameter of 10 cm and 90 cm height, which 60 cm of its (4.7 liter) was considered as a useful volume and the remainder was taken as free board. Bee-Cell 2000 has been successfully used before as support media in different biofilm reactors(20); so in this study 1.5 liters of reactor was filled by Bee-Cell 2000 having porosity of 87% and a specific surface area of 650 m^2/m^3 as support media.

Start-up period

Anaerobic and aerobic reactor was seeded with 1 L of concentrated aerobic active sludge obtained from aerobic digesters of municipal wastewater treatment plant with MLSS 24.84 g/l and MLVSS 16.9 g/l. The anaerobic reactor feed contained methanol, glucose, and currant wastewater. Some macro- and micronutrients such as $CaCl_2.2H_2O$(50 mg/l), $(NH_4)_2.HPO_4$ (80 mg/l), $FeCl_2.4H_2O$ (40 mg/l), NH_4Cl (1200mg/l), $Na_2S.9H_2O$ (300mg/l),

$CuCl_2.2H_2O$ (0.5 mg/l), $MgSO_4.7H_2O$ (400 mg/l), H_3BO_3 (0.5 mg/l), $MnCl_2.4H_2O$ (0.5 mg/l), $NaWO_4.2H_2O$ (0.5mg/l), $AlCl_3.6H_2O$ (0.5 mg/l), Na_2SeO_3 (0.5 mg/l), mg/l), KCl (400 mg/l), $ZnCl_2$ (0.5 mg/l), $NaHCO_3$ (3000mg/l), $NaMoO_4.2H_2O$ (0.5 mg/l), $CoCl_2.6H_2O$ (10 mg/l), KI (10 mg/l), and $NiCl_2.6H_2O$ (0.5 mg/l), which are necessary for optimal microbial growth were used. Anaerobic reactor in colonization stage was run in the batch mode for a week and its effluent fed into the aerobic reactor. During the start-up period, the COD loading was gradually raised. Also methanol, which comprised 75% of the total influent COD, was used initially to provide an optimum environment and encouraging the growth of methanosarcina (10). Then the amount of methanol in the influent was gradually decreased to 50%, 25%, and 0% in days 11, 21, and 31, respectively by replacing with glucose and currant waste water. Moreover, NH_4Cl concentration was gradually increased to its value in nutrient (1200 mg/l) to obtain high initial C/N ratios during the start-up period (part of this N with carbon used by bacteria for building up of the new cell) to encourage extra cellular polymer production, which aids bacterial attachment on solid surface (11) (Table 2).

Operation period

In the operational period that lasted 255 days, the Anaerobic Fluidized bed reactor was fed with real currant wastewater obtained from the factory located in the Safadasht Industrial Zone, Shahriar, Iran, that in Table 1 characteristics of studied currant wastewater are given. And its effluent fed into the Aerobic Moving Bed Bio Reactor. The AFBR and MBBR were operated under five different hydraulic retention times of 48, 40, 32, 24 and 18 h, respectively. The operational conditions and the loading rate in each stage are shown in Table 2.

Table 1: Characteristics of currant wastewater used in the present study

Parameter	Value
pH Value	6
COD (mg/L)	17200-19000
BOD_5 (mg/L)	12500-13000
TSS (mg/L)	380 ± 50
COD–BOD ratio	1.45
Tot-P (mg/L)	18
Tot-N(mg/l)	60

Table 2: Organic loading and percentage of methanol, glucose, currant wastewater and ammonium chloride during the start-up

Time (day)	COD loading (kg COD/m³)	Methanol (% of total COD)	Glucose (% of total COD)	Currant Wastewater (% of total COD)	NH_4Cl
0-10	0.5 - 4	75	25	0	50
11-20	4 - 7	50	50	0	75
21-30	7 - 11	25	75	0	100
31-40	11 - 13	0	75	25	100
41-50	13 - 15	0	50	50	100
51-60	13 - 15	0	25	75	100

Analytical methods

Samples were analyzed for Chemical oxygen demand (COD), according to the Standard Methods for the Examination of Water and Wastewater (19). Temperature was measured by a thermometer and pH was measured by a- pH-meter (E520 Metrohm Herisau). Gas production was measured by a liquid displacement method. The total gas was measured by passing the gas through distilled water containing 2% H_2SO_4 (w/v) and 10% NaCl (w/v)(20). Methane gas was detected using 3% NaOH (w/v) containing distilled water(23). Methane percent was also monitored using a digital methane meter (Drager® Pac-Ex).

Results

The start-up period was completed in 60 days. So that the feed COD increased stepwise, effluent COD of the anaerobic and aerobic decreased and the COD removal efficiency of the anaerobic and whole the system gradually increased. The bed expansion in fluidized bed reactor was 35% during the start-up period and 45% in operational period. After the start-up period, the Currant wastewater was fed to the reactor. As seen in Table 2, the AFBR was operated under five different operating conditions (stage), at each stage the value of loading rate increased which lead to increase feeding of anaerobic effluent into the aerobic reactor.

COD removal in the anaerobic–aerobic system

The removal of COD and operational conditions in the anaerobic–aerobic system were evaluated at different stages as shown in Fig. 2 and Table 2. By decreasing HRT from 48 to 18h, and increasing OLR from 9.4 to 24.2 g COD/l.day, COD removal efficiency decreased from 98.1to 81.5%. This system was operated with an anaerobic–aerobic arrangement, the effluent of the anaerobic FBR was directly used as the feed of the aerobic MBBR, and so the OLR of the aerobic reactor was determined by the performance of the anaerobic FBR.

Biogas production

Fig. 3 shows by increasing loading rate, from 9.4 to 24.2 g COD/l.day, gas production increased from 20.89 to 45.9 liters gradually. Fig. 4 shows, methane and biogas yields. As shown in this figure the methane and biogas yield was 0.45 to 0.57 and 0.31 to 0.44 l/gCOD removed.

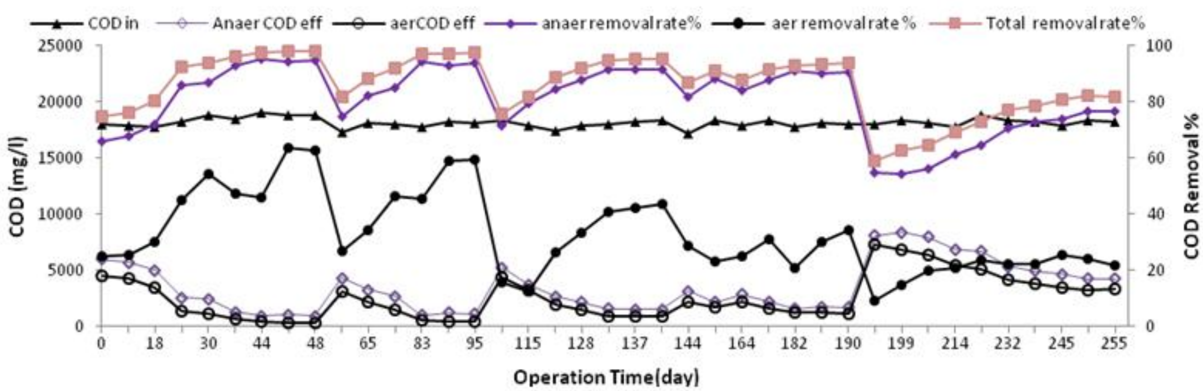

Fig. 2: Variation of COD removal related to influent COD values

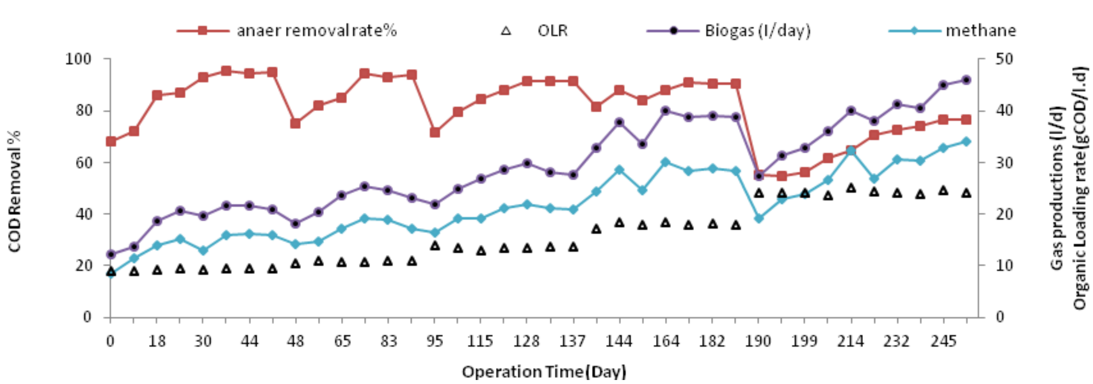

Fig. 3: Evolution of organic loading, COD removal efficiency, biogas and methane production

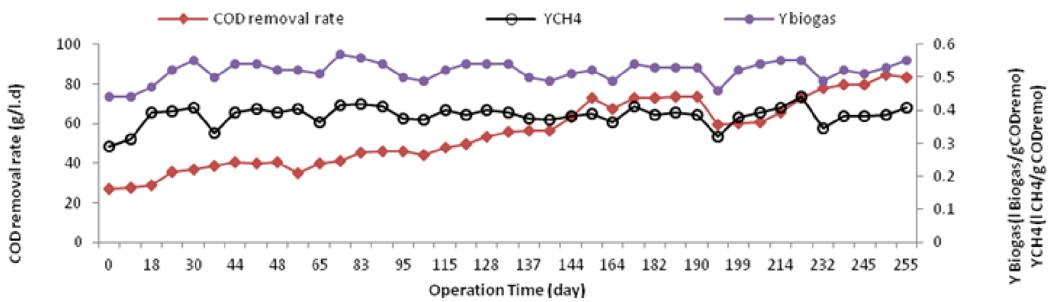

Fig. 4: Time course of biogas yield and methane yield and anaerobic COD removal

Table 3: Treatment performance and operating data of the AFBR/MBBR

Stage	day	HR	Anaerobic Fluidized bed reactor				Aerobic Moving bed bio reactor				Total COD Removal (%)
		T (h)	OLR (gCOD/l/d)	COD_{in} (mg/l)	COD_{out} (mg/l)	COD_{re} Rate (%)	OLR (gCOD/l/d)	COD_{in} (mg/l)	COD_{out} (mg/l)	COD_{re} Rate (%)	
1	1-48	48	9.4	18850	940	95	0.47	940	350	62.7	98.1
2	49 -95	40	10.87	18126	1086	94	0.65	1086	438	45.1	97.5
3	96 -140	32	13.72	18300	1544	91.6	1.16	1544	870	43.6	95.2
4	141-190	24	18	18054	1692	90.6	1.69	1692	1112	34.2	93.8
5	191 -255	18	24.2	18246	4277	76.5	5.7	4277	3350	21.6	81.5

Discussion

According to Fig. 2 and Table 3, during Stage 1, OLR in AFBR was kept at around 9.4 g COD/l.d with the feed COD concentration of 18,000±300 mg/l and HRT around 48 h. In the early days of operation in the first stage, the removal efficiency in anaerobic and aerobic reactors was 70 and 25 percent respectively. This amount gradually increased, to 95 and 62.5% at 48th day in anaerobic and aerobic reactors respectively and consequently the efficiency of whole system reached to 98%. The average effluent COD concentrations of the Anaerobic Fluidized Bed Reactor and Aerobic Moving Bed Bio Reactor were 935 and 350 mg/l respectively. This indicates that the Anaerobic Fluidized Bed Reactor –Aerobic Moving Bed Bio Reactor system had successfully operated at this OLR and operation condition.

At stage 2, the HRT of anaerobic and aerobic reactors was decreased from 48 h to 40 h and OLR in Anaerobic Fluidized Bed Reactor increased from 9.4 to 10.8 g COD/l.d and fed COD concentration was as same as the stage 1, e.g. 18,000±300 mg/l. In this stage, with increasing loading rate, the COD removal efficiency was decreased at the beginning of the stage and reached to 75% in anaerobic and 27.1 percent in aerobic reactor in 54th day. But with acclimatization of system the new loading rate, the removal efficiency was gradually increased and reached to 94% in anaerobic and 59.6% in the aerobic reactor and efficiency of whole the system reached to 97.5% and then remained constant. In this stage the average effluent COD concentration for Anaerobic Fluidized Bed Reactor and Aerobic Moving Bed Bio Reactor were 1086 mg/l and 438 mg/l.

In the stage 3, hydraulic retention time (HRT) was reduced from 40 h to 32 h and the COD concentration of influent kept constant. The loading rate increased from 10.8 to 13.7 (g/l.day). At the beginning of this stage, as in previous stages, the system efficiency decreased rapidly and reached from 94, 59.6, and 97.5 in anaerobic, aerobic and whole system respectively at 95th day to 71.5, 15.5 and 75.9at 99th day. In this stage concentration of COD in effluent decreased from 438 and 5244 mg/l to 4430 and 1086 in anaerobic ands respectively due to reduce in efficiencies.

In the stage 4, which began at 141th day, the OLR was further increased to 18 g/l.day by decreasing HRT. At the end of this stage, removal efficiency increased and reached to 90.6%, 34.2%, and 93.7% in anaerobic, aerobic, and whole of the system respectively. Also COD concentration of effluent reached to 1692 mg/l and 1112 mg/l in Anaerobic Fluidized Bed Reactor and Aerobic Moving Bed Bio Reactor respectively.

Stage 5, began when HRT reduced to 18 hours and OLR increased to 24.2 g/l.day. As can be seen in the beginning days of this period 192 day , the removal efficiency have decrease significantly from 90.6% to 55% in the anaerobic reactor, from 34.2% to 9.3% in the aerobic and from 93.7% to 59.2% in the whole of system. Also due to decreasing in removal efficiency, the COD concentration of effluent increased from 1112 to 7346 mg/l in anaerobic reactor and 1692 to 8100 mg/l in aerobic reactor. These results indicate the shock of organic load entering into the system but according to the results with continuing reactor operation at this stage the system can be resistance to overload of organics entered to reactor.

In the end of this stage, at 255th day the removal efficiency reached from 55% to 76.5% in the AFBR, from 9.3% to 21.6% in the MBBR, and from 59.2% to 81.6% in whole of the system. At this stage as in previous stages, the removed by the anaerobic and aerobic reactor. As shown in this figure the removed OLR increased linearly with increasing influent OLR in both reactors. COD removals of 80% were achieved in an anaerobic fluidized bed reactor when treating high-strength distillery the total COD removal was 75.6% and was only 5% for MBBR. Fig. 2 shows the relation between influent OLR and OLR AFBR played a major role in the COD removal compared to the MBBR, So that at the end of this stage contribution of AFBR in wastewater treating at OLR of 20 g COD/l.d. In the other study for treating distillery wastewater (wine vinasses) by anaerobic fluidized bed reactor at thermophilic condition, at organic load of 22.99 g COD/l.d, COD removal of 74.70% was achieved (24). COD removals of 80% was achieved in an anaerobic fluidized bed reactor with natural zeolite as support material when treating high-strength distillery wastewater treating at OLR of 20 g COD/l.d and HRT of 11 h (25).

In the other study with anaerobic fluidized bed reactor for treating ice-cream wastewater, in steady state was achieved with 94.4% COD reduction at an organic COD loading rate of 15.6 g/l. d and HRT 8 h(12).and in the treatability of thin stillage as a by-product of bioethanol production plants using an anaerobic fluidized bed bioreactor (AFBR) employing zeolite as the carrier media in OLR 29 g COD/l.d and HRT 3.5 ,COD removal efficiencies of 88% was achieved(26). As shown in Fig. 3, in operation stage 1 with increasing loading rate, gas production gradually increased until 48th day which OLR was 9.4 g/l.day, at this time maximum gas production was achieved and produced biogas reached to 20.89 liters. Of this amount 15.87 liters was methane gas which represents 75.6% of the total gas produced. After that the biogas production decreased and for example total gas and methane gas produced reached to 18.26 and 14.25 in 54th day when OLR increased from 9.4 to 10.8 g COD/l.day. The decreasing of biogas production with increasing of OLR was mainly due to reducing influent COD removal which can be attributed to organics load shock occurrence in the system. Fig. 4 shows, methane and biogas yields. As shown in this figure the methane and biogas yield was 0.39 and 0.52 l/gCOD removed.day, respectively.

Although the gas production decreased with increasing OLR, however the biogas and methane yields was not significantly changed. After that with gradual increasing in COD removal the amount of bio-gas and methane production increased again and in 95th day the amounts of bio gas reached to 23 liters and methane gas was 17.22 liters. In this time the biogas and methane yields were 0.5 and 0.37 l/gCOD removed.day, respectively. In Step 3, with increasing organic loading rate from 10.8 to 13.7 g COD/l. day, until 99th day the amount of biogas produced again decreased from 23 liters to 21.7 and methane gas reached from 17.22 to 16.5 liters. With starting step 4, by reducing HRT to 24 hours and increasing the OLR to 18, at the first the amount of produced gas decreased and after that increased gradually by increasing efficiency of the reactor. In the 190th day the amount of produced biogas reached to 38.8 liters and methane was 28.4 liters. In this day biogas and methane yields were 0.53 and 0.38 respectively. In step 5, with increasing the organic loading rate from 18 to 24.2 gCOD/l.day gas production was significantly reduced and reached to 27.4 liters in 192th day; the amount of methane gas was 19.8 liters in this point. In this step because the organics load shock entered to the system was higher than previous stages, so the longer time was needed to the system reach to steady state compared previous stages.

The volume of biogas produced in the end of this stage in 255th day was 45.9 liters and methane gas production reached to 34 liters. Also, biogas and methane yields were 0.55 and 0.407 l/gCOD-removed.day, respectively. The methane yield in a study was 0.375 l/gcodremoved.day for treatment of sanitary landfill leachate in a Anaerobic Fluidized Bed Reactor (15), and in another study, it was 0.345 l/gCODremoved.day for treatment of Thin Stillage Fluidized Bed Reactor (AFBR)(26) and it was 0.351 l/gCOD-removed.day in Anaerobic Fluidized Bed Reactor being fed with a synthetic wastewater containing glucose (27). These results are in accordance with the results of our study. This study showed that the anaerobic fluidized bed reactor / aerobic moving bed bio reactor arrangement was an effective and feasible process for removal of organic load from currant wastewater. In this system, when organic loading rates were 9.4 and 10.87 g COD/l.day, the removal efficiencies were 98.1% and 97.5% respectively. In these conditions the contributions of anaerobic reactor was 95% and 94% respectively. Also, with increasing in organic loading rate the contribution of aerobic reactor in removing COD gradually decreased. In this anaerobic FBR / aerobic MBBR system, the anaerobic reactor played the most important role in the removal of COD, and the aerobic MBBR was actually needed to polish the anaerobic treated wastewater and ensure the supply of high quality final effluent. The anaerobic reactor exhibited excellent performance to cut down the high COD concentrations.

Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc) have been completely observed by the authors.

Conclusion

Industrial wastewaters are usually with high organic content and cannot be treated similar to domestic wastewaters. Integrated anaerobic and aerobic treatment processes are more promising solution. The application of fluidized and moving bed as a modification of these processes have brought much better results for high strength industrial wastewaters.

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