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Biodegradation study of oily wastewater in a suspended growth anaerobic reactor

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The present study focussed on the increase in the quantity of acclimated microorganisms and biodegradability of synthetic oily wastewater in anaerobic environment. Acclimatization was carried out for a period of around seven months under batch mode. During the period of acclimatization, synthetic dextrose feed and synthetic oil feed were added to the anaerobic reactor at certain interval for proper growth of microorganisms. At the commencement of the process, there was addition of 100 mL dextrose feed to the reactor followed by decrease in the quantity of dextrose feed and increase in the amount of oil feed in different consecutive runs. Variations in different parameters including pH, Mixed Liquor Suspended Solid (MLSS), oil and grease as well as COD were observed in different batches. Out of ten ratios of synthetic feed for acclimatization, 40:60 and 0:100 were found to give the highest percentage removal of oil and COD respectively. There was inhibition from oil noticed after the ratio of 10:90.

Keywords: Oily wastewater, anaerobic biodegradation, suspended growth, synthetic feed, oil removal.

Introduction

Environmental pollution is a serious problem due to increase in population, rapid urbanization and rise of economic growth, which directly or indirectly affect the human beings as well as other species. Garages or workshops, gas stations, petroleum refineries, kitchens, canteens, restaurants, slaughter house and tannery, food processing, vegetable oil producing, metal processing and many other industries are the probable sources responsible for generation of a large amount of wastewater containing oil and grease[1,2]. Production of a large amount of oil containing wastewater has become a key environmental problem, which needs to be focussed. A variety of techniques are available for the treatment of oil carrying wastewater, which include biological treatment, physicochemical treatment and hybrid processes[3–5]. The biological processes are considered to be efficient as well as economical which can be used for the treatment of oily wastewater[6,7].

Biodegradation by anaerobic process can be a good solution for the treatment of oil containing wastewater because of its numerous advantages i.e. less production of sludge, requirement of low energy and methane gas production[8,9]. This process is environmental-friendly too as it allows the stabilization of organic matter with reduction of the emission of green house gas. Good results have been obtained during treatment of oily wastewater by utilizing anaerobic technology[10]. The reactors such as upflow anaerobic sludge blanket (UASB), anaerobic filter, upflow anaerobic sludge fixed film reactor (UASFF), expanded bed, fluidized bed, stationary packed beds have been widely used reactors for anaerobic treatment of wastewater[8,10].

Anaerobic contact process could successfully remove oily substances as well as suspended solids from bakery waste[10]. Again, palm oil mill effluent (POME) was treated successfully by using fluidised bed reactor (FBR) as well as anaerobic filter (AF)[12]. COD and FOG (fat, oil and grease) removal efficiency was more than 80% from oily wastewater coming out of food industry in three UASB reactors[13]. Again, treatment of heavy oil produced water using anaerobic baffled reactor was found to be effective for the removal of oil and COD[14]. The COD removal from POME was found to be very high by using UASFF reactor[15]. Furthermore, Gasim *et al.* (2012)[4] reported COD removal efficiency of 77–83% from petroleum refinery wastewater by using two UASB reactors working in parallel.

It was revealed from the literature studies that anaerobic treatment of oily wastewater is a favourable technique as it is environmental-friendly, economical and gives satisfactory results. Hence, in the present work, anaerobic treatment technique was used for the treatment of oily wastewater. The objective of the present work is to study biodegradation of synthetic oily wastewater under suspended growth condition in anaerobic environment using anaerobic seed previously collected and stored from another anaerobic reactor of Environmental Engineering Laboratory of Civil Engineering Department, IIEST, Shibpur.

Materials and methods

(A) Reactor details:

The biomass was acclimatized in a laboratory scale 4L anaerobic reactor (as shown in Fig. 1) made of Plexiglas sheet and Plexiglas base plate with 3L of working volume. The reactor was provided with one feed pipe, one gas collection pipe, one gas collection chamber, one water displacement chamber, four sampling ports and one sludge withdrawal port made of brass with 20 mm diameter. The reactor was maintained at a temperature of 35°C in order to avoid seasonal temperature variation and operated under batch mode for a period of seven months in Environmental Engineering Laboratory of Civil Engineering Department, IIEST, Shibpur. The reactor content was also mixed (manual mixing) at certain interval of time.

(B) Feed composition:

Synthetic dextrose containing wastewater of concentration 10000 mg/L with C:N:P as 100:5:1 and oily wastewater of concentration 1000 mg/L with COD:N:P as 100:5:1 were prepared as mentioned in Table 1 and added to the anaerobic reactor at varying proportion during acclimation. Ten acclimation batches include synthetic dextrose feed (S1) and synthetic oil feed (S2) with combination of S1 (90 mL) + S2 (10 mL), S1 (80 mL) + S2 (20 mL), S1 (70 mL) + S2 (30 mL), S1 (60 mL) + S2 (40 mL), S1 (50 mL) + S2 (50 mL), S1 (40 mL) + S2 (60 mL), S1 (30 mL) + S2 (70 mL), S1 (20 mL) + S2 (80 mL), S1 (10 mL) + S2 (90 mL), S1 (0 mL) + S2 (100 mL).

(C) Analytical method:

Acclimation process was followed by change in MLSS, pH, removal of COD and oil and grease and the parameters were measured as per Standard Methods (2000)[16]. pH was measured prior to filtration by using pH meter and MLSS was obtained by filtering and drying the commercial filter paper at a temperature of 105°C. Oil and grease and COD were measured by Soxhlet extraction method and closed reflux dichromate method respectively.

(D) Anaerobic treatability:

Depending on the rate of biodegradation, the batch durations varied between 120 to 310 h. The pH was adjusted in a range of 7–7.8 by adding 1 *N* Na_2CO_3. Nutrients of phosphate buffer, magnesium sulphate, ferric chloride and calcium chloride were added at the rate of 1 mL per litre of the reactor content. The specific oil degradation rate (SODR) for different batches were calculated by following formula and represented in Fig. 5.

$$SODR = (S_{o0} - S_o)/(T \times X)$$

where, S_{o0} = initial concentration of oil and grease in mg/L, S_o = final concentration of oil and grease in mg/L, T = batch period in h and X = MLSS in mg/L.

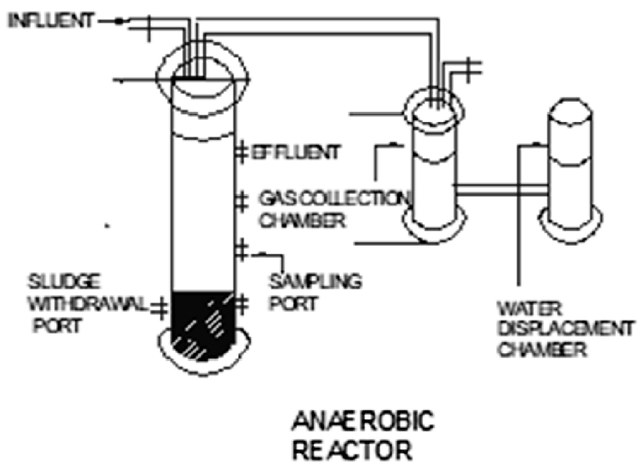

Fig. 1. Schematic diagram of laboratory scale anaerobic reactor.

Table 1. Composition of synthetic dextrose and oil bearing feed

Constituents	Amount per litre in dextrose bearing feed	Amount per litre in oil bearing feed
Dextrose	10 g	–
Oil (Castrol CRB prima diesel engine oil)	–	1.11 mL
NH_4Cl	0.7642 g	0.1364 g
KH_2PO_4	0.1754 g	0.0313 g

Results and discussion

(A) Batch study:

The results of ten batches during acclimation process in anaerobic reactor are represented through Fig. 2 to Fig. 7. pH variation throughout acclimation process was summarised in Fig. 2. pH in different batches were obtained in the range of 6.37 to 7.72. During few batches, a gradual fall in pH was observed with respect to time in anaerobic reactor which may be due to acidogenic phase[17]. It is necessary to bring pH in the range of 7–7.8. It is mentioned by Jeganathan *et al.* (2006) that pH of 7.2±0.3 is optimum value for anaerobic process[13]. In batch 6 and batch 10, pH change is not substantial which may be due to increase in MLSS with reduction in COD as well as oil content[18]. In batch 7, the value of pH was below 6.5, which was adjusted with 1 *N* Na_2CO_3 solution. Fig. 3 indicates the profile of oil and grease during ten batches in acclimation process. It was observed from Fig. 3 that there was sustained reduction in oil and grease from the starting of the batch process till the steady state which was achieved at about 168 h in most of the batches. Oil and grease removal was minimum under batch 5, with reduction in biomass growth as compared to previous batches.

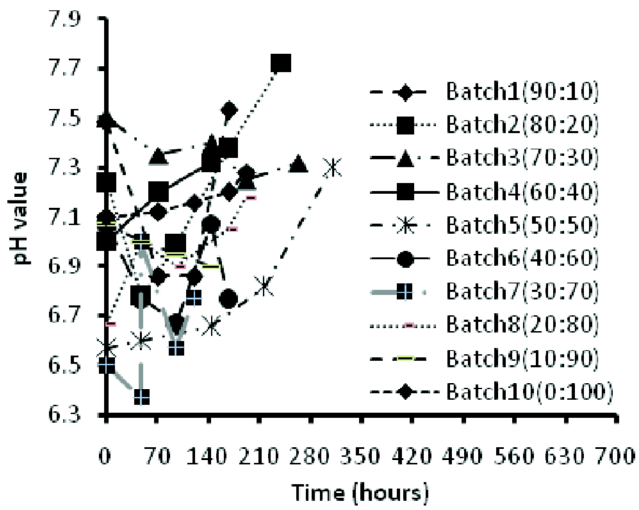

Fig. 2. pH profile for various dextrose to oil feed ratios.

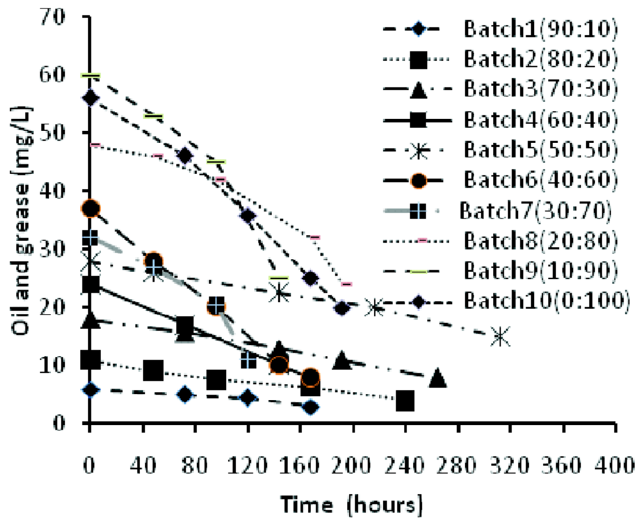

Fig. 3. Oil and grease profile for various dextrose to oil feed ratios.

The percentage removal of oil during acclimatization in different batches is represented in Fig. 4. During initial batches of acclimation, the percentage removal of oil was less which was increased after batch 5. It was further reduced in batch 8 and in the following batches it was increased again. Although this graph represents percentage removal of oil with batches, it is governed by factors like MLSS and pH along with time.

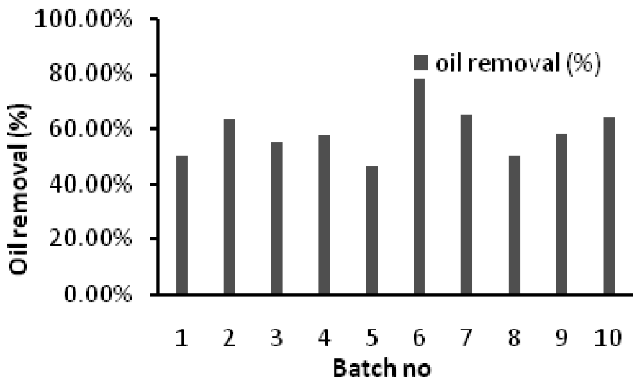

Fig. 4. Percentage oil and grease removal in various batches.

The oil removal was obtained in the range of 46.43 to 78.38%. The percentage removal of oil was found to be the highest in batch 6.

Fig. 5 depicts the profile of specific oil degradation rate (SODR) in different batches which reveals that batch 9 (10:90 ratio) was the optimum condition for removal of oil and grease after which inhibition took place. Nutrients like phosphate buffer solution, magnesium sulphate solution, ferric chloride solution and calcium chloride solution were added to the reactor and batch period was increased to outdo the inhibition.

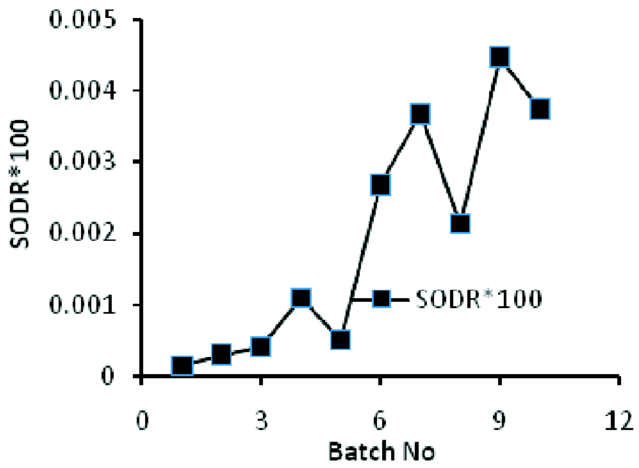

Fig. 5. Profile of specific oil degradation rate (SODR) for various batches during acclimation.

The values obtained after multiplying 100 with SODR have been used in the graph. The trend of COD profile with respect to time for each batch was observed to follow a particular trend which decreased rapidly during the initial hours as in case of general biological processes as presented in Fig. 6. In each batch decrease in COD value with respect to time indicates progressive reduction of organic matter[19].

Fig. 7 indicates percentage removal of COD in different batches during acclimation. Percentage COD removal was increasing with respect to time from batch 1-4 due to addition of higher concentration of dextrose feed which is easily biodegradable. Again, there is decreasing trend in percentage COD removal from batch 4-7 probably due to higher concentration of oil feed which is not easily biodegraded and biomass was not easily acclimatized with such higher concentration. Again, there is increase in percentage COD removal from batch 7-10 which is due to the fact that biomass

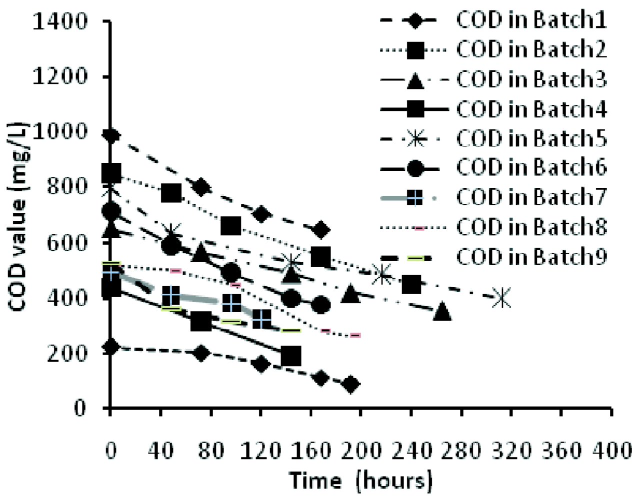

Fig. 6. COD profile for various batches with varying dextrose to oil feed ratios.

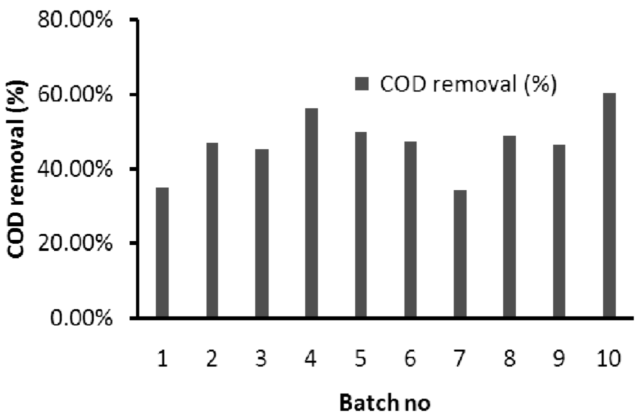

Fig. 7. Percentage COD removal in various batches.

was more acclimatized with oil with respect to time. In most of the batches, steady state was reached at about 168 h. The COD removal was obtained in the range of 34.3 to 60.5%. The percentage removal of COD was found to be the highest in batch 10.

COD concentration in the feed was decreasing from 302.4–25 mg/L with respect to time in 10 batches which is due to decrease in concentration of dextrose feed (of strength 10,000 mg/L) and increase in concentration of oil feed (of strength 1000 mg/L). Though initial concentration of COD in the reactor was increasing with respect to time for most of the batches, but in batch 5 and batch 8, there is increase in COD concentration with respect to previous batch, which is due to addition of lactose broth and cowdung slurry with anaerobic seed respectively for improving the condition of reactor.

Oil concentration in the feed was increasing from 3.33–33.33 mg/L with respect to time in 10 batches. Though initial concentration of oil and grease in the reactor was increasing with respect to time for most of the batches, but it is less in comparison to just previous batches in case of batch 7 and 10. This is because each batch was done two times and the batch with superior result was taken into consideration.

Shin *et al.* (1990) studied the performance of an anaerobic contact process for the treatment of bakery waste carrying high concentration of oily substances. The removal of COD and FOG (Fat, Oil and Grease) by anaerobic contact process was found to be 97.3% and 99.3% respectively during a period of 5 weeks[10]. Borja and Banks (1995) studied the treatment of Palm Oil Mill Effluent (POME) by using fluidised bed reactor (FBR) and anaerobic filter (AF) operated at 35°C. The removal efficiency of COD was more than 90% in both reactors at residence time of 6 h and organic loading of 10 g COD/litre/d[12].

Again, Najafpour *et al.* (2006) studied anaerobic digestion technique for the treatment of POME by using UASFF (upflow anaerobic sludge-fixed film) reactor. Treatment was done at an operating condition of 1.5 and 3 days of HRT with 38°C temperature. There was increase in organic loading from 2.63–23.15 g COD/litre.d. The removal efficiency of COD was found to be 89% and 97% at HRT of 1.5 and 3 days respectively. There was increase in COD removal efficiency from 53 to 85% during the first week with OLR 2.63 g COD/Ld.

There was a shock loading to microorganisms due to sudden increase in COD and the microbes took some time to acclimatize with new environment. The COD removal efficiency was found to be 85% after start up period of 26 days at OLR of 23.15 g COD/Ld. Hence, anaerobic treatability of POME with high concentration of suspended biomass using UASFF bioreactor was established successfully[15].

Jeganathan *et al.* (2006) studied the treatability of three UASB reactors operated under different conditions for the treatment of oily wastewater from food industry. To operate three systems safely, the overall COD loading rate was given as 3.6, 3.8 and 2.3 COD/m^{3}d for systems 1, 2 and 3 respectively. The anaerobic degradability for the three reactors was quite good at such rate of loading. The COD and FOG removal efficiency was more than 80% for three systems at OLR of 3 kg COD/m^{3}d. The removal efficiency of COD and FOG was more than 90% in case of system 1 and respectively 88% and 80% in case of system 2. On day 163, the removal efficiency of COD dropped down from 90% to 70% and that of FOG from 90% to 80% for system 1. Again on day 251, the removal efficiency of COD dropped down from 88% to 55% and that of FOG from 90% to 76% for the system 2[13].

The removal of oil and COD in anaerobic baffled reactor (ABR) was found to be 88% and 65% respectively after successful start up for heavy oil produced water (Ji *et al.*, 2009)[14]. Initially (30–44 days) oil removal rate was 31%, which increased to 88% in later stage (150–164 days) with the increasing rate of oil loading. Again, COD removal rate was initially (30–44 days) 30% and increased to 65% in later stage (164–196 days) along with the increasing rate of COD loading.

Gasim *et al.* (2012) studied removal efficiency of COD from petroleum refinery wastewater using UASB (two numbers) working in parallel with four rates of organic volumetric loading i.e. 0.58, 0.89, 1.21 and 2.34 kg/m^{3}d. The COD removal efficiency was found to be 77–83% for all the organic volumetric loadings in two UASB reactors. The highest removal efficiency was observed to be 83% during application of 1.21 kg/m^{3}d organic loading. The removal efficiency of COD was increased with increase in organic loading and after reaching maximum value, there was decrease in COD removal efficiency with the increase in organic loading[6].

Conclusion

The present study shows that anaerobic biomass is capable of degrading oil containing wastewater. The biomass can be acclimatised in batch mode by gradually increasing synthetic oil feed with dextrose feed as co-substrate. During acclimation process, steady state was reached at about 168 h for most of the batches. Inhibition was noticed after dextrose to oil feed ratio of 10:90 which was overcome by increasing batch period and adding requisite nutrients. The maximum percentage removal of COD and oil and grease were found at the ratio of 0:100 and 40:60 respectively.

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