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Performance studies of aerobic FBBR for the treatment of dairy wastewater

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As the dairy wastewater produces lot of pollution problems, treatment of wastes before disposal becomes important. The endeavor to have a continuously operating, non clogging biofilm reactor with no need for backwashing, and high specific biofilm surface area culminated in the most advanced technology of Aerobic Fluidized Bed treatment where the biomass grows on small elements that move along with the water in the reactor. By the study, the FBB has been proved as highly efficient for strong dairy wastewater treatment. For an organic loading in the range 2.2 to 10.2 kg COD/m3d the efficiency variation was from 94.58 to 82.11%. The reactor combines all the advantages and best features of conventional treatment systems while eliminating the drawbacks of those.

Introduction

The Dairy industry in India is a complex as well as organized industry of a large magnitude. Its magnitude can be understood from the fact that India is the largest milk producing country in the world. But hygienic requirements in the industry result in a huge amount of wastewater generation, mostly from milk and milk products. The wastes are organic, but strength is higher than that of community waste. In addition to the above, treatment of dairy waste is complicated due to marked variations in hourly, daily and seasonal flow rates. Hence dairy industry is noted as a significant contributor to pollution.

A dissolved oxygen level of 7 mg/l is present in rivers or lakes. If this level reaches below 4 to 5 mg/l the aquatic life is in danger because the micro-organisms present in the waste or in the water of the river use the dissolved oxygen to convert the organic matter constituting of protein, lactose, fat, etc into end products. Hence it has become necessary for the dairy industry to treat its waste before it is discharged into rivers or lakes.

All conventional treatment methods used for the treatment of dairy waste are associated with its own inherent drawbacks. Aerated Lagoons and Stabilization ponds can be provided only where land cost is low, where the system can be installed some distance away from residential areas and climatic conditions are low. Activated Sludge Process has problems like sludge bulking, need of sludge recycling, regular monitoring of M.L.S.S etc. Trickling Filters are susceptible to environmental stresses and clogging problems. The Fluidized Bed Bioreactor (FBB) is an attempt to give a solution to avoid all those problems as it combines all advantages provided by Activated Sludge Process as well as Trickling Filter, at the same time avoiding the worst effects from all conventional methods.

Experimental Design

A laboratory scale treatment system with fluidized bed was fabricated. The reactor column was made up of perplex glass. The column was of 1.8m height and the effluent was filled to 0.50m. The diameter was 0.10m. The empty bed height used for filling biomass carrier media was 0.20m, which was approximately 40%. The reactor was designed as operating in three phases i.e., in gas-liquid-solid phases. The influent feed of dairy wastewater was supplied by a peristaltic pump of 30-lit/hr capacity and the flow was controlled for each run. As the process was aerobic, continuous aeration was given with the help of an air compressor. The oxygen flow rate was calculated and adjusted throughout. The aerator was a spiral copper tube with holes all around which provided diffused air for keeping the media in fluidized state. For better contact of the moving biofilm and the waste, counter current mode was accepted. The influent was flowing downwards and air was given from bottom to top. The elevation view of the experimental set up is given in Figure 1.

Start up stage

The reactor was filled with media to the required volume. To develop the biomass the start up was done with acclimatization using dilute cow dung slurry. Daily fresh cow dung was sluried, filtered and fed to the reactor. This was continued till there was development of a good biofilm. This was achieved after 10 days continuous feeding in phase 1 and after 2 weeks in the phase 2. After obtaining a visible biofilm inside the carrier media, feeding of dairy waste was started.

Experimental stages

The experiment was divided into two phases for studying the performance of the two different media. In each phase after the acclimatization dairy waste resembling that from an integrated dairy unit was fed. The experimental stages were

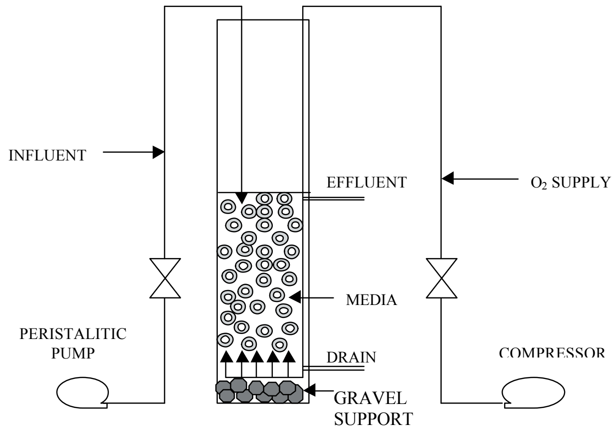

Figure 1. Sketch of the experimental set up

Table 1. Properties of media used in Phase 1

Material	Polypropylene
Density	0.94g/cm^3
Shape	Corrugated cylinder
Dimensions	Length 20 mm
	Diameter 15 mm
Specific surfac	160m^2/ m^3
Filling rate	40%

Table 1. Properties of media used in Phase 2

Material	Polypropylene
Density	0.94g/cm^3
Shape	Cylinder with a cross inside and longitudinal fins outside
Dimensions	Length 20 mm
	Diameter 15-10 mm (tapered)
Specific surfac	300m^2/ m^3
Filling rate	40%

varied with different organic loading rates. In each organic loading rate the effect of different hydraulic loading rates were found out by varying the hydraulic retention time.

In first run an influent COD of 550mg/l (approx.) was maintained. By giving an influent COD of 1000mg/l (approx.) and 2500 mg/l (approx.) the organic loading rates were changed. In all these stages the hydraulic retention time tried was 4hrs and 6hrs. For each run the air required was calculated and provided continuously.

Calculation of air required was as follows:-
Air Required = BOD load (kg/d) / [(Specific gravity (kg/m3) x %O2 in air x Blow in Depth x Specific OTE)]
Where,

Specific gravity of air = 1.165 (kg/ m3)
O2 in air = 23%
Blow in Depth = 0.50 m
Specific Oxygen Transfer Efficiency = 30%

As per the Central Pollution Control Board Studies (1982) the COD of the effluent from an integrated dairy unit varies from 502-2290 mg/L. Hence in the laboratory experiment Average COD values tested were 500, 1000 and 2500 mg/L. With each organic loading two hydraulic retention times, 4hrs and 6hrs were tested. But as the highest organic loading rate didn't give high removal efficiency with maximum retention time (6 hrs), the second analysis with 4hrs retention time was not conducted in both phases.

Table 3. Details of loading rates on fluidized bed, bioreactor in Phase 1

Parameters	Case 1	Case 2	Case 3	Case 4	Case 5
Average COD, mg/L	529	545	1035	1068	2549
Retention Time, hrs	4	6	4	6	6
Flow rate, L/hr	0.982	0.66	0.982	0.66	0.66
COD loading, Kg/m3d	3.164	2.17	6.194	4.3	10.19
BOD loading, Kg/m3d	2.26	1.552	4.42	3.05	7.28
Air required, Lpm	1.534	1.05	3	2.07	4.95

Table 4. Details of loading rates on fluidized bed, bioreactor in Phase 2

Parameters	Case 1	Case 2	Case 3	Case 4	Case 5
Average COD, mg/L	555	548	1026	1049	2549
Retention Time, hrs	4	6	4	6	6
Flow rate, L/hr	0.982	0.66	0.982	0.66	0.66
COD loading, Kg/m3d	3.32	2.19	6.14	4.17	10.19
BOD loading, Kg/m3d	2.30	1.56	3.07	2.99	5.46
Air required, Lpm	1.611	1.06	2.085	2.03	4.94

Analysis

At the start of each run BOD was calculated and Total Nitrogen was measured. In each run the parameters analyzed daily were, COD, Nitrate, Suspended Solids, Alkalinity, Dissolved Oxygen and pH. The pH and Dissolved Oxygen level in the reactor were checked continuously to note any change in the reactor due to the microbial activities. Sufficient number of days were allowed in between the runs when the experimental parameters were changed, for attaining the flow equalization.

At the end of each phase the media was taken out for biomass measurement and microbial analysis. Details of loading in each phase are shown in tables 3 and 4.

Results and discussion

The study was conducted for nearly six months. Analysis of effluent started after getting a visible biofilm around the carrier media used in each phase.

Formation of biofilm

The development of a thin biofilm was observed after one week of acclimatization with filtered cow dung slurry. The growth was more in the inside of the media in both cases and on outside minor slime adhesion only was seen. Passing of dairy wastewater had been started after a stable growth of microbial film in the inside surface of the polypropylene media.

The treated effluent was analyzed for COD, Nitrate, Suspended Solids and Alkalinity. Daily monitoring was done for Dissolved Oxygen and pH in the reactor.

Comparative study of the results obtained

In phase 1 with corrugated cylindrical media, the biofilm started developing after one week of acclimatization. The feeding of dairy waste was started after the development of biofilm which was visible in the inside part of the media. On the outside part and in the corrugated portions less biofilm was seen. In phase 2 with the cylindrical media with four chambers inside, the biofilm growth needed nearly 2 weeks time to stabilize. The treatment of dairy waste started after that period.

Effect of organic loading rate on treatment efficiency

Depending upon the organic loading rate and media used, the reactor showed varying performance.

In case 1 with first corrugated cylindrical media, for an organic loading rate of 3.32 kg/m3d the COD removal efficiency was 79.25%. When reactor was operated with second chambered cylindrical media the COD removal efficiency was by 90.43%.

When the loading rate was 2.19 kg/m3d the COD removal efficiency was 85.01%. With chambered media at this loading rate the COD removal efficiency was 94.58%.When the organic loading rate was 6.2 kg/m3d, reactor with first corrugated cylindrical media gave removal efficiency of 72.81 %. When second media was used, there was 85.88% COD removal efficiency at steady state.

For an organic loading of 4.3 kg/m3d, the FBB with first media gave steady state COD removal efficiency of 78.55%. When reactor was tested with the second media at this loading rate, there was an efficiency of 90.06%.The maximum

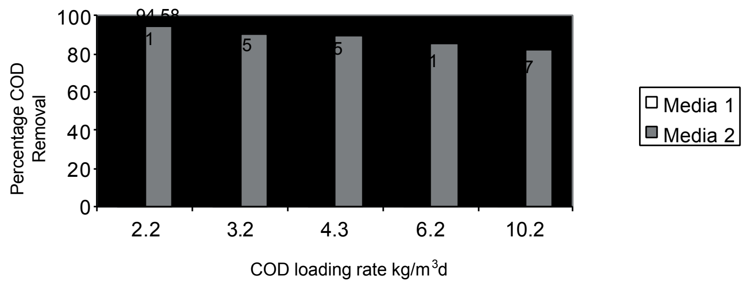

Figure 2. Comparison of both media in COD removal efficiency

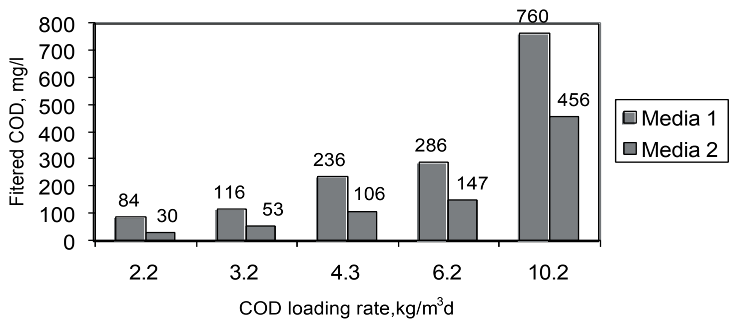

Figure 3. Filtered COD of effluent under various loading

loading rate tried was 10.19 mg/l. In reactor with corrugated cylindrical media there had been an efficiency of 70.17% l while the efficiency was 82.11% when chambered cylindrical media was used.

The performance of the reactor in COD removal is shown in Figure 2. The value of filtered COD in each run is expressed in the Figure 3. It was coming within permissible limits for COD loading rate less than 4.3 kg/m3d

Effect of hydraulic retention time on efficiency

The hydraulic retention time of the liquid in the reactor was varied twice for each organic loading. First retention time of 4 hrs was given and then it was changed to 6hrs. These values of retention time were tested in comparison with the retention time given in conventional activated sludge plants. There had been variation in performance efficiency while different retention times were tested. An increase in the hydraulic loading rate decreased the organic removal efficiency of the reactor.

When lesser loading was given to reactor i.e., for a COD of 500mg/l, efficiency of the reactor increased to 85.01% from 79.25% when HRT was increased to 6hrs from the earlier applied 4hrs. With second chambered cylindrical media also there was an increase in efficiency of reactor from 90.43 to 94.58% by the increase in retention time.In case 3 where the reactor was subjected to influent feed with COD of 1000mg/l the removal efficiency was around 72.81% at HRT 4hrs and it changed to 78.55% at an HRT of 6hrs. The performance of the reactor was similar with second media also as the efficiency got increased to 90.06% from 85.88%.

The effect of hydraulic retention time on better performance efficiency of the FBB is represented in Figure 4 and in 5.

Removal of suspended solids

In Suspended Solids removal the performance of the reactor with second chambered cylindrical media was better compared to the treatment with the first corrugated cylindrical media. The amount of suspended solids in the influent showed fluctuation with the organic loading adopted. This may be due to the un-dissolved milk powder particles. The variation was generally from 109 to 170 mg/l under different loading conditions. The effluent obtained had suspended solids of only 32 mg/l in case 2 of reactor with second media. The low level of suspended solids expresses the reduced amount of sloughed biomass, which is advantageous. As a result the sludge generated inside the reactor was not high. The performance of FBB in Suspended Solids removal is represented in Figure 6 and 7

Biomass estimations

Biomass measurement was done to find attached and non-attached biomass on media. (Edwards et al, 1992). Sample medias were transferred to 125ml flask and rinsed three times with distilled water; rinsate was filtered through 1µm

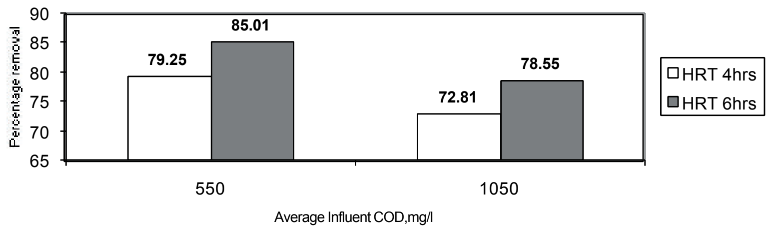

Figure 4. Effect of hydraulic retention time on percentage COD removal in Phase 1

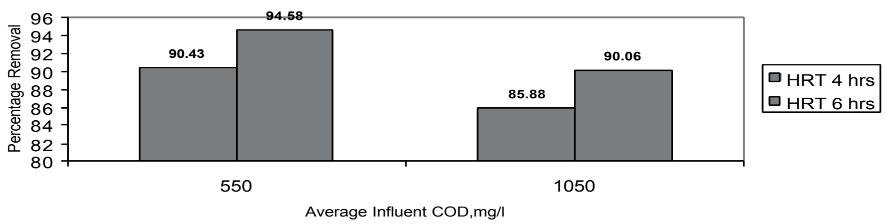

Figure 5. Effect of hydraulic retention time on percentage COD removal in Phase 2

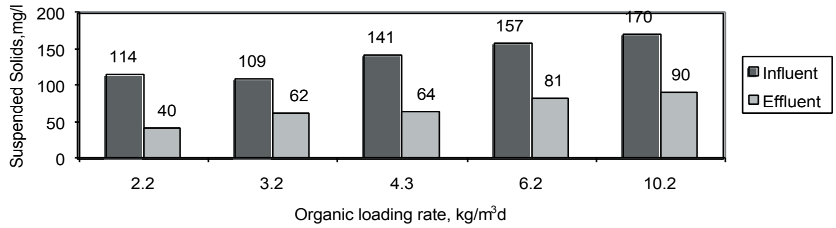

Figure 6. Suspended Solids Removal in Phase 1

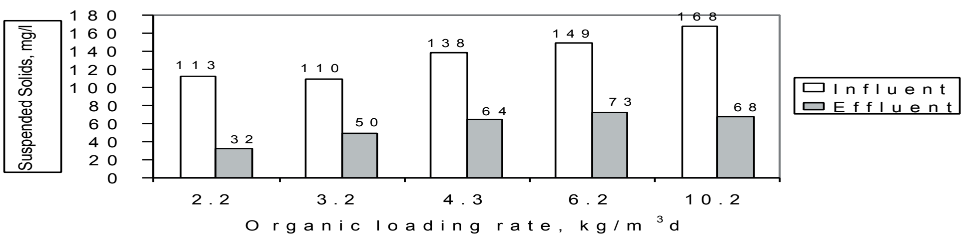

Figure 7. Suspended Solids Removal in Phase 2

glass fiber filter for determination of Total Suspended Solids. This TSS value was used as a measurement of non-attached solids and expressed in mg/L of fluidized bed. The rinsed bed material was dried at 105oC, weighed and digested in concentrated nitric acid for 24 hours. The digested sample was rinsed and dried again at 105oC. The change in dry weight following the acid digestion was used to calculate the attached biomass of the Fluidized bed (mg/L).

The biofilm growth was plenty in the inside of the media. When media with cylindrical shape and four chambers inside was used the growth was more and the film thickness on the outside surface was less in both media. The attached biomass was near 20,000mg/l in corrugated cylindrical media and in second media it was nearly 33,000mg/l. The measurement of non-attached biomass showed lesser amount compared to this value. The non-attached biomass was 2500mg/l in phase 1 and it was 4000mg/l in phase 2 with second media. This shows that the unit was operating in the extended aeration range, indicating that the final sludge production would be minimal. Also it avoids the need of monitoring of MLSS.

The dissolved oxygen level was maintained around 4 mg/l in all stages at steady state except when very high loading of 10 kg/m3d decreased D.O level to 0.45mg/l with corrugated cylindrical media usage.

The dissolved oxygen level and pH in the reactor was found to be suitable for the normal aerobic microbial activities. The slightly alkaline condition in the reactor indicated a complete aerobic degradation of the organic matter.

Microbial analysis

In spread plate and streak plate techniques there was plenty of colony formations when a loop full of sample was put on the petridishes. The sample was serially diluted to get a widely spread apart colony form which was countable. Colony Forming Unit value obtained from spread plate method was 148 in 1ml of 100 times diluted drop.

The differential staining of microbial film showed spore forming and non-spore forming bacterial growth. The long to very short rods, often in chains showed resemblance with lactobacillus. The gram-positive forms were seen in plenty and there was presence of some gram-negative cocci and diplococcal bacteria also. Results showed the presence of protozoan, which were not taking stains and were seen as transparent, except in some rare cases. The biofilm scraped from the media showed big clusters of bacterial growth.

Conclusions

1. The highly organic wastewater from dairy industry can be effectively treated using aerobic fluidized bed bioreactor. As the BOD of the waste generated from chilling unit is very high an anaerobic pretreatment can be given before aerobic process for removing organic load by 50%.
2. The carrier media used in the reactor have high influence on the treatment efficiency. The major factors, which affect the performance, are shape and surface area of the media. Other factors include roughness, porosity and specific density of the media. The chambered cylindrical media used in second phase was found to be highly efficient than the corrugated cylindrical media.
3. Organic removal efficiency increases with hydraulic retention time and decreases with loading rate and hydraulic flow rate.
4. The reactor is compact and can be subjected to intermittent and shock loading. There is no need for sludge recycling, as attached biomass is very high in the media. There will not be clogging or channeling in the reactor as the media is in motion always.
5. Fluidized bed bioreactor is efficient in nitrification. Formation of nitrate increases with nitrogen loading rate.
6. The sloughed biomass in suspended form was not high and as a result the reactor can meet the effluent standards.
7. Fluidized bed reactor with freely moving media inside is cost effective requiring less running and maintenance cost. The polypropylene media is durable and do not need replacement for a large period. The reactor is maintenance free for a large flow variation.
8. Uninterrupted power supply is needed for the efficient and steady functioning of the reactor as microorganisms need oxygen for survival.
9. More researches can be done in the field so that widespread application of fluidized bed bioreactors with freely moving carrier media can be made in treating strong industrial effluents from food processing units, paper and pulp, pharmaceuticals etc.

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