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EFFECT OF TEMPERATURE ON ANAEROBIC FILTER TREATMENT OF DAIRY WASTEWATER

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ABSTRACT

An 11-month study was conducted to compare the performances of three laboratory plastic medium upflow anaerobic filters operating at 12.5°C, 21°C, and 30°C, treating dairy wastewater. Two of the reactors were started at 21°C and the third at 30°C. Steady-state operation of the three reactors was carried out at different hydraulic retention times (HRTs) of 1 to 6 days. It was found that the start-up of anaerobic filters was possible at 21°C without any adverse effect on its future performance. Temperature effects on organic removal efficiency were not found to be pronounced at high HRTs. The anaerobic filter at 30°C consistently achieved higher levels of performance compared to the other reactors at 12.5°C and 21°C. The anaerobic filter operating at 12.5°C was the most affected by changes in HRT. At an HRT of 4 days, average COD removals in the three anaerobic filters were approximately 92%, 85%, and 78% at 30°C, 21°C, and 12.5°C respectively. The volume of methane generation (m^3/kg COD removed) was lower at lower temperatures; the amount of methane in biogas was found to be higher at lower temperatures.

KEYWORDS

Dairy wastewater; anaerobic filter; temperature; wastewater treatment; industrial wastewater, methane; plastic media.

INTRODUCTION

Only limited information is available on the performance of anaerobic filters in treating dairy wastewater at low temperatures. The usual temperature of the dairy wastewater is approximately 25-30°C; in cold climates, the temperature may decrease if the treatment plant is located at some distance from the dairy. It was proposed to examine the performance of anaerobic filters operating at 10-20°C without the benefit of heating the wastewater or the filter housing and compare this performance with anaerobic filters operating at 30-35°C. The objective of the study was therefore to evaluate the performance of anaerobic filters operating at 12.5°C, 21°C, and 30°C, treating dairy wastewater, especially to determine the effect of low temperature under different hydraulic retention times (HRTs) as well as the effect of temperature (21°C vs 30°C) on the start-up of anaerobic filters. The efficiency of removal of various parameters such as biochemical oxygen demand 5d at 20°C, (BOD), chemical oxygen demand (COD), and suspended solids (SS) were to be determined to assess performance; volatile acids (CA) production and methane (CH_4) generation were also to be investigated.

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ANAEROBIC WASTEWATER TREATMENT AT LOW TEMPERATURES

Rudolfs (1927) carried out studies on temperature effects while digesting sewage sludge; the experiments were conducted at four different temperatures of 10, 18, 29.5 and 35°C. It was observed that digestion was extremely slow at temperatures below 10°C and that raising the temperature a few degrees above 10°C had comparatively little effect. The total amount of gas produced per unit of organic material removed was found to be not dependent upon the temperature. Maximum digestion was observed at 27-28°C; even at 35°C, the digestion was found to be less than that at 27-28°C. Cullimore and Maule (1982) observed that hog waste lagoons continued to produce biogas down to 4-5°C. The peak production of the gas at 300 $L/m^2 \cdot week$ was observed in July and August of the year when the temperature ranged from 19.5 to 28°C. In the month of November, the gas production was 20-60 $L/m^2 \cdot week$ when the temperature dropped from 19°C to 8°C. The laboratory studies carried out by the same investigators indicated that the minimal temperature for biogas production ranged from a low of 2.73°C to 13.3°C. These results led the investigators to believe that psychrophilic methanogens existed at these temperatures. This aspect was supported by Zehnder et al. (1981) who reported that methane fermentation would occur over a wide temperature range of 0 to 97°C. Cullimore and Maule (1982) also noticed that the methane concentration in the biogas at 4°C varied from 17.5 to 95% (the normal range was 60-72%) and was 43-49% at 40°C. Oldham and Nemath (1973) found that only 50% of the BOD removal was achieved at 10°C while treating hog manure for an HRT of 25 days or less. Switzenbaum and Jewell (1980) carried out studies related to the treatment of low strength wastes using anaerobic attached-film expanded bed process. They observed that this was an efficient process capable of achieving high organic removal percentages at low temperatures (10-20°C) with an influent COD less than or equal to 600 mg/L with short HRTs (several hours) and at high organic loading rates (OLRs) (up to 8 $kg/m^3 \cdot d$). Loehr and Ruf (1968) reported that an anaerobic lagoon treating the waste from a milking parlor showed a BOD removal of 85% during summer when the temperature was 29°C. During winter, when the temperature was 2°C the removal was only 20%. Lin et al. (1982) studied the performance of an anaerobic lagoon-filter model treating a potato processing effluent at temperatures below 20°C. The system was run at different temperatures dropping the temperature from 20° to 2°C in steps of 2°C. At each temperature, the system was operated until steady state was reached; but at 2°C the run was halted due to a pronounced increase of COD and total volatile acids in the lagoon and filter effluents, indicating that the system was approaching failure. Again the temperature was increased to 6°C, then to 8°C, when the system recovered. It was found that between 20 and 10°C, the overall removals of COD and SS averaged 94 and 95% respectively, but when the temperature was dropped from 10 to 4°C, the overall COD and SS removals decreased from 94 to 85% and 95 to 93% respectively. The system performance was not analyzed at 2°C as the steady state at this temperature was never attained.

Speece and Kem (1970) studied the effect of short-term temperature variations on methane production using raw sludge as the substrate. They did not find any gas production below 20°C, but as soon as the temperature was raised above 20°C, gas production resumed at a rate proportional to the temperature within a range of 20-45°C.

van den Berg and Kennedy (1982) reported that performance of fixed film reactors increased linearly with temperature in the range of 10 to 35°C. At 55°C, they observed that the reactor performance was the same as at 35°. They indicated that the reactor could be used at ambient temperatures, with relatively small penalty in performance. Oleszkiewicz and Koriarski (1982) conducted a study to evaluate the applicability of anaerobic filters at temperatures lower than the mesophilic range (20-26°C) while treating the dilute piggery wastes which had a COD of 9400 mg/L and they found that the system was able to remove COD to the extent of 70-90% with the methane generation of approximately 0.16 m^3/kg COD removed/day. They also observed that after attaining stability, the system was resistant to short-term temperature changes within 16 to 30°C. Viraraghavan and Dickenson (1989) evaluated the performance of anaerobic filters at 5, 10 and 20°C treating septic tank effluent. Plastic ballast rings were used in the reactors as the media. It was observed that COD removal efficienty depended both on temperature and HRT. The reactor with the highest temperature (20°C) consistently achieved higher levels of performance at all HRTs than the other reactors at 5 and 10°C. Reactor at 10°C gave better results than that at 5°C. The efficiencies of all the reactors decreased with a decrease in HRT. However, it was observed that the reactor at 5°C was the most affected by changes in HRTs. Cordoba et al. (1988) studied the performance of anaerobic filters at low temperatures while treating dairy wastewater. Studies were conducted at four different temperatures, 30, 26, 20, and 16°C. COD removal efficiency was maximum at 30°C at all OLRs and decreased with the decrease in temperature. At 30°C, the removal efficiency of the filter was over 95% when subjected to an OLR of approximately 3 kg COD/m^3•d and at this loading rate, the efficiency of the filter at 16°C was about 80%. The COD removal efficiency decreased with an increase in OLR at all temperatures studied.

MATERIALS AND METHODS

Dairy Wastewater

The wastewater was collected every week from a local dairy which produced milk and cream during the study. Before each sample was transferred to the feed barrels, it was analyzed for COD and pH; these were adjusted to approximately 4000 mg/L and 7.0 respectively.

Reactors

The reactors used for this study were constructed of clear acrylic material with an internal diameter of 100 mm. Each reactor contained two equal sections 600 mm long for a total height of 1.2 m. Gas which escaped from the top of the reactor was collected by a water displacement method. The empty volume of each reactor was 9.48 L. The volume occupied by the media in each reactor was 0.33 L; thus the effective volume of the reactor with media was 9.15 L.

Media

Plastic ballast rings of 50 mm diameter (specific surface area - 114 m^2/m^3) obtained from Glistch Canada, Ltd. were used as the media in the reactors. Each reactor was randomly packed with 29 rings.

Experimental Set-up

The feed was pumped from the feed barrels into all the reactors by a multi-head peristalitic pump connected to a timer, allowing the operation of the system at the desired HRT.

Start-up

The start-up of the system was initiated at two different temperatures. Two of the reactors were started-up at room temperature (21°C) and the other at 30°C. During the start-up phase, the HRT was maintained at 6 days. The feeding procedure was started with a very dilute strength dairy wastewater (10%) together with the seed sludge (anaerobically digested sludge) which had a solids concentration of approximately 6%. The concentration of the influent wastewater was increased in steps to almost its full feed concentration at the end of 68 days. The system was subjected to shock loads on 69th and 141st days; the system recovered and the start-up was completed on 160th day.

Steady-state Operation

After the start-up operation was completed, temperature of one of the reactors

(R_1) was lowered to 12.5°C in two steps. The temperature was first lowered to 15°C in the one step and after three days, it was further lowered to 12.5°C in one step. The performance of the reactors at three different temperatures was studied at different HRTs of 6, 4, 3, 2 and 1 d respectively, corresponding to average organic loading rates (OLRs) of 0.63, 1.04, 1.48, 2.01 and 4.03 kg COD/m^3·d respectively.

Analytical Procedures

Influent and effluent samples were analyzed in accordance with the "Standard Methods" (1980) for BOD, COD, SS, nitrogen, phosphorus and pH. Volatile acids and alkalinity was determined by the method developed by Ripley et al. (1986). The biogas was analyzed for carbon dioxide by Orsat gas analyzer. Total biogas minus carbon dioxide content was accounted for by the methane content.

RESULTS AND DISCUSSION

Characteristics of Dairy Wastewater

The characteristics of dairy wastewater are shown in Table 1.

TABLE 1 Characteristics of Dairy Wastewater

Characteristics	Number of samples	Range	Mean	Standard deviation
pH	43	3.4-7.2	-	-
SS	43	265-2300	1258	569
VSS	43	210-2100	921	498
COD	43	1840-5240	3978	579
SCOD	22	720-2170	1569	435
BOD	43	1110-3840	2430	777
TKN	11	110-215	174	56
NH_3-N	11	31-71	46	12
PO_4-P	11	25-143	76	34
Alkalinity (as $CaCO_3$)	11	380-1470	822	364

Note: All values are in mg/L except pH.

Start-up Phase

Figure 1 shows the COD removal in all the three reactors during start-up.

The reactor operated at 30°C performed better than those at 21°C during the entire start-up period; the difference in performance (5 to 6% in COD removal) was however not substantial. Higher temperature (30° vs 21°C) did not help the reactor to recover faster from the effects of shock load. The results showed that the anaerobic filter can be started-up at 21°C without any marked disadvantage.

Steady-state Phase

Chemical oxygen demand. Figure 2 shows COD removal in all the three reactors during the steady-state phase.

Figure 3 shows the effect of temperature on COD removal.

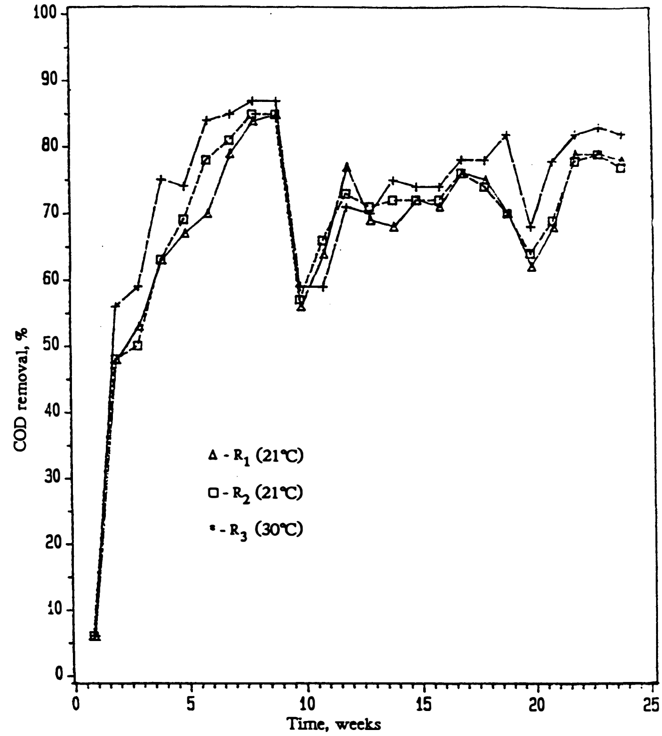

Figure 1.

COD removal during start-up

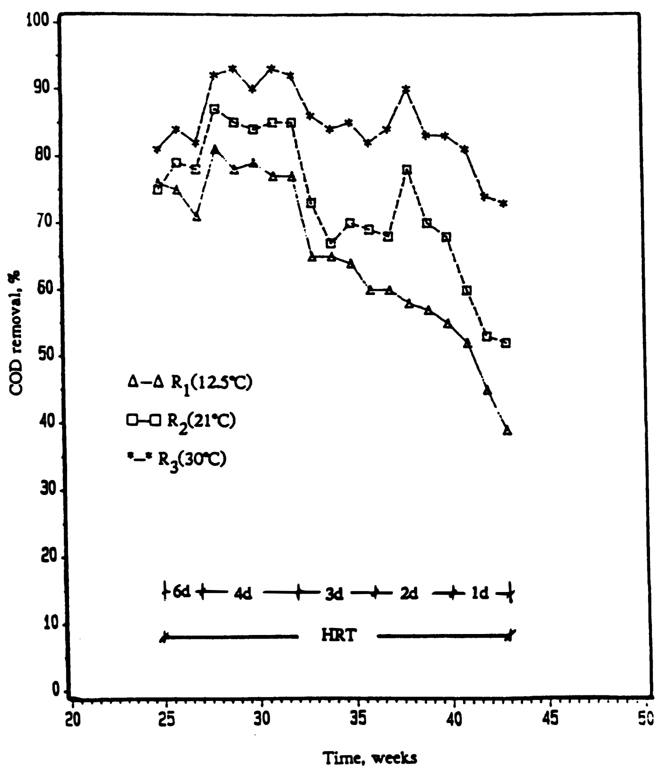

Figure 2.

COD removal during steady-state

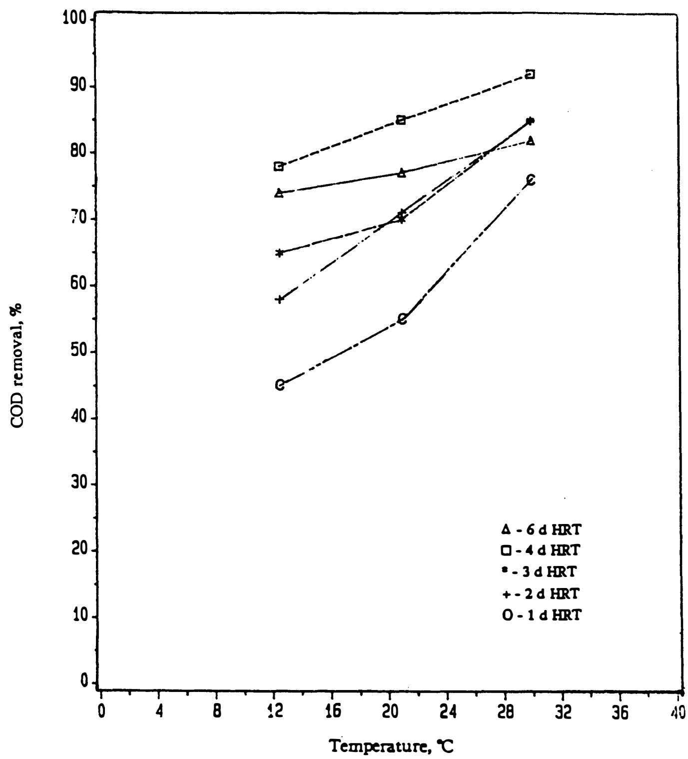

Figure 3. Effect of temperature on COD removal

Table 2 shows the summary of performance of the anaerobic filters during steady-state operation.

TABLE 2 Summary of Performance of the Anaerobic Filters

HRT d	Temp. C°	Organic loading rate kg COD/m^3·d	Mean influent COD mg/L	COD removal %	Methane production m^3/kg COD removed
6	12.5	0.63	3560	74	0.08
	21			77	0.25
	30			82	0.29
4	12.5	1.04	4120	78	0.18
	21			85	0.24
	30			92	0.27
3	12.5	1.48	4250	65	0.14
	21			70	0.23
	30			85	0.27
2	12.5	2.005	4010	58	0.09
	21			71	0.18
	30			85	0.23
1	12.5	4.03	3920	45	0.02
	21			55	0.18
	30			76	0.21

Note: R_1 - Reactor at 12.5°C
R_2 - Reactor at 21°C
R_3 - Reactor at 30°C

Reactors R_2 and R_3 demonstrated excellent removals of COD (55 to 85% in the case of R_2 and 76 to 92% in the case of R_3) while reactor R_1 provided a low removal of COD (45 to 78%) at all hydraulic loadings. Even though the reduction of COD in all the reactors was minimum at an HRT of 1 day, R_3 functioned well with a removal of 76%, while R_2 and R_1 removed only 55 and 45% respectively. Rittman et al. (1981) observed only 49% COD removal at 23°C at an HRT of 1 day; however they reported a removal of 90% at an HRT of 3 days. Their studies showed higher removals of COD than reported in this study (70%) in respect of R_2 at an HRT of 3 days. Cordoba et al. (1988) reported the following averaged removal efficiencies at an OLR of 4 kg COD/m³·d: 1) 87% at 30°C; 2) 83% at 20°C; and 3) 78% at 16°C. Their study showed that the removal efficiency decreased with a decrease in temperature. Although the same trend was observed in this study, the removals were not as high as reported by Cordoba et al. (1988); the average COD removals at various temperatures at an approximate OLR of 4 kg COD/m³·d were as follows: 1) 76% at 30°C; 2) 55% at 21°C; and 3) 45% at 12.5°C. The better removal efficiencies claimed by Cordoba et al. (1988) could be due to the type of wastewater and media used in their study.

Suspended solids. All the reactors showed an excellent removal of SS. Reactor R_3 demonstrated the best performance at all HRTs followed by R_2 and R_1. Maximum removal of SS occurred in all the reactors at an HRT of 6 days. SS removals ranged from 70 to 85% in R_1, 77 to 92% in R_2 and 83 to 96% in R_3. SS removal generally decreased with a decrease in HRT.

Methane production. Table 2 shows the methane production rate at various HRTs in the three reactors. The rate of methane production significantly varied between the reactors. Reactor R_1 reported the least methane production and R_3 reported the maximum. It was observed that the methane production rate decreased with a decrease in temperature. The same findings were reported by Cordoba et al. (1988), while treating dairy wastewater at different temperatures (from 16°C to 40°C). Considering all the HRTs, the average daily methane production in R_1, R_2, and R_3 was 0.104, 0.218, 0.254 m³ of methane/kg COD removed (at STP). These values are less than the theoretical value of 0.3 m³ of methane/kg COD removed (Choi and Burkhead, 1984). The methane production rate in R_1, R_2, and R_3 ranged from 0.03 to 0.18, 0.18 to 0.26 and 0.21 to 0.27 m³/kg COD removed (at STP). The reasons for this low production may be mainly due to two reasons, first being the effect of temperature on the reactors and second being the fluctuations in the strength of dairy wastewater samples. Cordoba et al. (1988) also reported a poor gas production rate ranging from 10 to 51% of the theoretical yield, while treating dairy wastewater at the temperatures mentioned earlier. Methane concentration increased with the decrease in temperature. Average concentrations of methane in R_1, R_2, and R_3 were 80, 70.4 and 68.4% respectively. Lin et al. (1982) who treated potato processing wastewater in anaerobic filters at low temperatures reported that the methane content in the biogas at 21°C was 78% and was more than 80% at 4°C; these findings agree with results of this study. Cullimore and Maule (1982) observed that the normal range of methane content of the biogas (while treating hog waste) at 4°C was 60 to 72%, in contrast to 43 to 49% at 40°C. This higher methane content at lower temperatures is due to the fact that the solubility of carbon dioxide in water at lower temperatures is higher than that of methane.

CONCLUSIONS

The following conclusions are drawn based on the results obtained in this study:

1. COD removal during the start-up was 5-6% more at 30°C than that at 21°C. The temperature variation (21°C and 30°C) during start-up did not affect the subsequent steady-state performance.

2. During steady-state operation, removal of COD in all the reactors decreased with a decrease in temperature and HRT.

3. Maximum gas production occurred at 30°C and 6 days HRT. Minimum gas production occurred at 12.5°C and 1 d HRT. The maximum methane content in the biogas was observed at the lowest temperature (80% methane at 12.5°C) and the minimum methane content at the highest temperature (68.4% at 30°C).

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