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Efficiency Assessment of the Anaerobic Filter Reactor for Rural domestic sewage treatment at a low temperature

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Abstract: In this research paper, the efficiency of anaerobic filter (AF) reactor was examined for rural domestic sewage treatment at different operational temperature of 30°C, 22°C, 18°C and 15°C and different loading rates r respectively. At each temperature experimented, a stable CODt removal was observed with upflow velocity lower than 0.34 m/h. At these upflow velocities the removal rates of COD were 83 and 71% at temperature 30°C and 22°C respectively. Moreover at temperature 18°C and 15°C, the COD removal rates were 68 and 44% respectively. The removal of COD was the result of biological degradation and solids accumulation in the reactor. At temperature 30°C, constant 220 g sludge mass and a constant sludge volume index (SVI) value of 12 ml/g was observed in the reactor and COD removal was attributed to biological degradation only. Solids accumulation was observed in addition to biological degradation with an increase in reactor sludge as the temperature decreased. The study found out that, the decrease in biological degradation at lower temperatures was offset by solids accumulation and this explains the similar overall COD removal efficiency observed at 30°C, 22°C and 18°C. As the temperature decreases, there was an increase in the effluent TSS concentration in reactor. A lower effluent TSS concentration was observed at temperature 18°C and 15°C revealing the suitability of the anaerobic filter reactor in rural domestic sewage treatment.

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1. Introduction

Anaerobic treatment nowadays is becoming popular for rural domesticis sewage because of its low construction, operation and maintenance costs, small land requirement, low excess sludge production and production of biogas. Even though the anaerobic treatment of rural domestic sewage has been used at large scale in several hot countries, the process to date has not been applied at full scale in temperate countries. This is chiefly because of lower removal efficiencies. Also, in temperate regions, a longer hydraulic retention time (HRT) is needed due to the lower rate of hydrolysis (de Man AWA et al, 1986) and the higher amount of accumulating suspended solids (SS) in the reactor (Zeeman G, Lettinga G, 1999). However, when treating domestic sewage in granular sludge anaerobic filter (AF) reactors at low temperatures, accumulation of SS occurs in the granular sludge bed, which leads to deterioration of the overall methanogenic activity and the reactor performance (de Man AWA et al, 1986, Uemura S,et al, 2000).

Domestic wastewater has typically low concentrations of COD, resulting in relatively small methane production that is insufficient to heat the reactor to more favorable mesophilic temperatures. Moreover, the relatively high concentration of particulate matter present in domestic wastewater requires an initial hydrolysis step, which is significantly affected by temperature and is usually the rate-limiting step in sub-tropical climate regions.

In tropical countries AF reactors for rural domestic sewage have found wide acceptance. There are several full-scale plants already in operation in China, Colombia, Brazil, Indonesia, India and Egypt and COD removals above 80% have been observed by several authors (Souza and Foresti, 1996; Chernicharo and Cardoso, 1999; Kalogo and Verstraete, 2000). The effluent quality at these installations is reported to be 140 mg COD/l, 75 mg BOD/l and 30 mg TSS/l. At low temperatures, the low hydrolysis rate and a decrease in the degradable organic matter fraction were found to cause the deterioration of the overall anaerobic reactor performance (Elmitwalli et al., 2001). AF COD removals of ~65% at 20°C and of 55–65% at 13–17°C were observed by several authors (Lettinga et al., 1981; Grin et al., 1983; Vieira and Souza, 1986; Elmitwalli et al., 1999; Seghezzo et al., 2000). A decrease in the effluent quality was also observed, together with a decline in the gas production rate. Agrawal et al. (1997) observed a 78% decrease in the gas production rate when the temperature was reduced from 27°C to 10°C. The low gas production coincided with a 25% lower COD removal at 10°C than at 27°C, indicating suspended solids accumulation in the reactor.

One possible way to improve the performance of AF reactor at low temperatures is to provide surface area for biomass attachment and growth in the reactor volume above the sludge blanket.

This case study focuses on the effect of temperature on the efficiency of AF reactor for rural domestic sewage treatment at different upflow velocities, hydraulic retention times (HRT) and organic loading rates.

2. Material and methods

In Fig. 1 a schematic diagram of the experimental set-up, consisting of an AF reactor constructed of plexiglass with a working volume of 5.2 litres (6.0 cm diameter, 106.5 cm high), with five sampling ports placed at different heights and an inflow manifold at the bottom of the reactors to ensure equal influent distribution. The AF reactor was filled with 2.5 litres of granular sludge taken from Wuxi municapl wastewater Treatment Corporation. The concentration of TSS in the reactor after the filling was 120 g TSS/l. The reactor was fed with rural domestic sewage after primary sedimentation from southeast university campus, Wuxi. Effluent samples and methane production readings were taken at HRT 1 from the reactor after influent sampling. All samples were tested on a regular basis for pH, TSS, VSS, CODt, CODs and VFA. After every two days, sludge samples were taken from top, mid and lower sample ports and were tested for SVI, TSS and VSS. All analyses were performed according to Standard Methods for the Examination of Water and Wastewater (APHA, 1995). Well mixed effluent samples were used for CODt and samples allowed to settle for 15 minutes were used for CODs. The calculation of COD removal was base on influent CODt. The volatile fatty acids concentration was measured using the five-point titration method (Moosbrugger et al., 1993). The methane gas produced was collected and measured as described by Haandel and Lettinga (1994). The reactor was operated at 26 -30oC with HRT of 1 day to allow sludge acclimatization to domestic sewage. Later, the HRT was steadily reduced with the increase in organic loading rate. The HRT was further shortened after the efficiency reached stable state for a period of times. . When the experimental regime was completed at 30°C, the same method was conducted out for reactor temperatures of 15°C, 18°C and 22°C. The reactor was operated at a temperature of 30°C for 4 months and 2 months for each of the other temperatures.

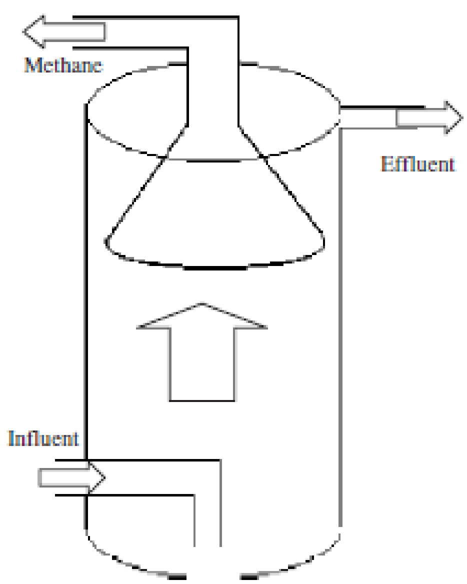

Figure 1: schematic diagram of AF reactor equipped with a gas/solid separator

3. Results and discussion

The AF reactor run very well during the start-up period and the removal efficiency of TSS was 78.2%. As time goes, the CODt removal efficiency increases from 67.8 to 83.5% at the end of the period. A VFA result indicates no accumulation occurred in the reactor as can be noticed from the similarity in the result of effluent with that of influent. At the end of the start-up period, the reactor was operated at 30oC for four Months and the HRT was slowly reduced from 1 day to 1 hour only, with increase in organic load ing roate (OLR) from 0.3 to 32.6 g COD/l/day. A stable effluent COD concentration was observed in the reactor when the HRT was reduced from 1 day to 2 hours. The average CODt and CODs were 98.6 (□32) and 73.7(□23) mg/l respectively. For HRTs shorter than 3 hours owing to upflow velocities and influent organic load higher than 0.35 m/h and 5.0 g COD/l/day, respectively), the effluent quality significantly deteriorated. While at longer HRTs (from 3hours to 1 day) the removal of COD was often constant (around 78%), it decreased to 52.4% for CODt and 69.5% for CODs at 2 hour HRT and 33.6% for CODt and 51.4% for CODs at 1 hour HRT. The reduction in CODs removal rate can be explained by too short HRT to complete COD degradation. When the HRT was longer, the effluent VFA concentration was almost zero, while on the other hand, when the HRT was shorter, the effluent VFA concentration increased when VFA was present in the influent. A maximum COD removal of between 6.0 and 8.8 g COD/l/day was observed at influent loadings between 16.4 and 23.8 g COD/l/day. At the highest organic load of 31.8 g COD/l/day, a decrease to 5.4 g COD removed per litre per day was observed in the reactor. The decrease in CODt removal can be explained by the sharp increase in effluent TSS from about 20 mg/l, at HRT longer than 3 hours, to about 100 mg/l and 220 mg/l, at 2 and 1 hour HRT respectively (Figure 2). It appears that the higher upflow velocity caused influent suspended solids washout, as opposed to a gradual increase that would be expected if the retention time was limiting. When the reactor was submitted to two different influent TSS concentrations (150 mg TSS/l and 300 mg TSS/l) at different HRT, the same upflow velocity limitation (0.35 m/h) was observed. At shorter HRT, the TSS removal began to decrease, leading to the conclusion that the high upflow velocity was the limiting rate for both CODt and TSS removal and not the retention time. The critical upflow velocity where CODt removal decreased is similar to the range reported by other authors, 0.33 to 0.67 m/h (Collivignarelli et al., 1991; Lettinga and Hulshoff Pol, 1991; Maaskant et al., 1991; Vieira and Garcia, 1992; Chernicharo and Cardoso, 1999; Kalogo and Verstraete, 2000). The same upflow velocity limitation was observed at all temperatures studied (30, 22, 18 and 15°C), with an almost constant CODt removal for lower upflow velocities in both reactors. For each temperature studied the CODt removal at HRT longer than 3 hours decreased with the decrease in the temperature (Table 1). These results suggest a much lower biodegradability at lower temperatures of a range of compounds comprising the heterogeneous composition of domestic wastewater. In addition, it is possible that lower temperatures induced shifts in the bacterial population with predominantly slower kinetics.

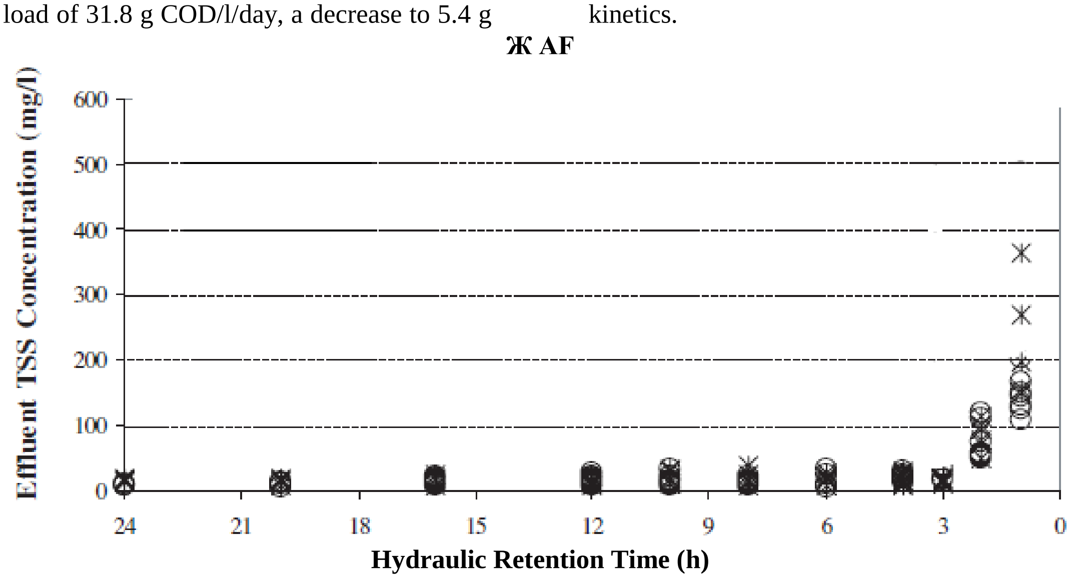

Figure 2: Effluent TSS concentration as a function of HRT

Table 1: Maximum COD removal (%) at different temperatures

Temperature	15°C, and	18°C	22°C.	30°C
AF	44	68	71	83

At temperature of 15°C, 18°C and 22°C, the methane production showed similarities. The methane production rate at these temperatures increased with increasing influent COD organic load, up to 10.0 g COD/l/day for 30°C and 5.0 g COD/l/day for 22°C and 18°C. At higher loads a constant methane production of,100, 225 and 85 ml CH4/l/day was observed for 30°C, 222°C and 18°C, respectively. At 15°C a very low methane production was experimented for all the inflow organic loads, 25 ml CH4/l/day. The calculated temperature activity coefficient based on the maximum methane production was 1.21 (R2 □□0.94). Furthermore, the experimental temperature activity coefficient is higher than the one observed for methanogenic bacteria in batch experiments with granular sludge, 1.146 (R2 □□0.91). According to these results, one can conclude that the hydrolytic bacteria were more affected by temperature alteration than the methanogenic bacteria. As observed, the maximum methane production rate demonstrates a decrease with temperature, as with the CODt removal. Nevertheless, the decrease in the maximum methane production was much more marked than the decrease in the CODt removal. This incident can be explained by suspended solids accumulation in the reactor, which resulted in better COD removal, but methane production has not improved. The phenomenon of suspended solids accumulation in the reactor was not obvious at temperature of 30°C. The sludge mass in the reactor during summer conditions (30°C) had a constant value of 220 g and a constant SVI value of 12 ml/g. At lower temperature, solids of different characteristics were built up on top of the floc. The increase in the accumulation of particulate matter in the reactor approximately equaled the decrease in the biological degradation rate with temperature and explains the same overall COD removal efficiencies attained at 30°C, 22°C and 18°C for the reactor, as seen in Table 1. Owing to the higher SVI value, the flocculent type sludge had a greater sensitivity to upflow velocities than the granular sludge, explaining the accumulation of the particulate matterl on top of the typical bacterial granules and the increase in the effluent TSS concentration at (Figure 2). Furthermore, the sensitivity to upflow velocities together with the increase in the TSS accumulation in the reactor with the decrease in the temperature led to an increase in the effluent TSS concentration at longer HRTs with the decrease in temperature (Table2).

Table 2: Effluent TSS concentration (mg/l) at upflow velocities lower than 0.35 m/h, at different Temperatures

Temperature	15°C, and	18°C	22°C.	30°C
AF	130	70	26	18

The methane production during the transition period from winter to summer conditions initially increased and then gradually declined over time, reaching values similar to the previous one of summer (30°C). In comparison, the removal of CODt at the beginning of the new warmer season was very low (58%) in comparison to the previous summer. The low CODt removal suggests that the high gas production observed was due to the degradation of the accumulated suspended matter and not the influent organic matter. Improvement in CODt removal was observed with time. The improvement in CODt removal together with the reduction in the gas production reveals that the accumulated matter was worn out and influent degradation reached the values observed in the first summer season.

4. Conclusions

Removal rates of COD in summer were quite well. Whereas in winter (lower temperature), when the bacterial activity is lower, solids accumulation in the reactor is more pronounced with better solids retention. In the reactor, the accumulated sludge from the winter is subsequently digested in the following summer, which is evidenced by a large gas production at the beginning of the new warm season. Based on the results obtained in this case study, one can conclude that the AF reactor is suitable for rural domestic sewage treatment even in cold climates.

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