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Pretreatment of Swine Wastewater Using Anaerobic Filter

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Abstract

Efforts were made to assess the efficiency of an anaerobic filter packed with porous floating ceramic media and to identify the optimum operational condition of anaerobic filter as a pretreatment of swine wastewater for the subsequent biological removal of nitrogen and phosphorus. A stepwise decrease in hydraulic retention time (HRT) and an increase in organic loading rate (OLR) were utilized in an anaerobic filter reactor at mesophilic temperature (35°C). The optimum operating condition of the anaerobic filter was found to be at an HRT of 1 d. A soluble chemical oxygen demand (COD) removal efficiency of 62% and a total suspended solids removal efficiency of 39% at an HRT of 1 d were achieved with an OLR of 16.0 kg total COD/(m^3·d), respectively. The maximum methane production rate approached 1.70 vol of biogas produced per volume of reactor per day at an HRT of 1 d. It was likely that the effluent COD/total Kjeldahl nitrogen ratio of 22, the COD/total phosphorous ratio of 47, and the high effluent alkalinity >2500 mg/L as $CaCO_3$ of the anaerobic filter operated at an HRT of 1 d was adequate for the subsequent biological removal of nitrogen and phosphorus.

Index Entries: Pretreatment; anaerobic filter; swine wastewater; nitrogen; phosphorus; anaerobic digestion.

Introduction

The consumption of meat has currently increased in Korea since the dietary pattern has changed during the past decade. Consequently, the number of livestock heads bred on the farms shows an increasing trend

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every year, and the scale of livestock farms becomes larger. Accordingly, the generation of livestock wastewater has been drastically increased during the past 10 yr—from 140,000 t in 1991 to 200,000 t in 2000 *(1)*.

Swine wastewater is generally characterized by a high concentration of dissolved organic matters. In 1999, in Korea, a new effluent regulation for the treatment of swine wastewater became effective. The discharge guideline should meet biochemical oxygen demand (BOD) and suspended solids (SS) concentration <30 mg/L, chemical oxygen demand (COD) concentration <50 mg/L, total nitrogen concentration <60 mg/L, and total phosphorous concentration <8 mg/L. This regulation is much more strict than that of the European communities, which allow the direct discharge of effluent from the anaerobically pretreated swine wastewater to the cropland. Physicochemical and biologic characteristics of high-strength swine wastewater vary according to the quantity of flushing water used in the swine barns.

Such a wide range of total solids (TS) content makes it difficult to select the proper reactor configuration for anaerobic pretreatment *(2,3)*. Scraped swine wastewater frequently encounters high concentrations of ammonia of >5000–6000 mg/L with a relatively low TS content of <2%, which makes it hard to degrade under the normal anaerobic treatment process. To maintain the water quality of the drinking water reservoir, a nationwide effort to remove nitrogen and phosphorus from the swine wastewater has been made. In general, the treatment scheme for such a highly concentrated wastewater consists of anaerobic pretreatment followed by advanced biologic nutrient removal systems. It was often found that the degree of pretreatment greatly influenced the subsequent biologic nutrient removal process because of the resulting unbalanced carbon/nitrogen/phosphorous ratio. The higher COD removal in the anaerobic pretreatment may cause an adverse effect on the following advanced treatment *(4,5)*. Therefore, the objective of this research was to assess the efficiency of an anaerobic filter packed with porous floating ceramic media and to identify the optimum operation conditions of the anaerobic filter as a pretreatment of swine wastewater for the subsequent removal of nitrogen and phosphorus.

Materials and Methods

Anaerobic Filter Process

Figure 1 shows the experimental apparatus of the anaerobic filter process used in our study. The anaerobic filter was made of acryl consisting of a cylindrical pipe tank, and its effective volume was 30 L. The anaerobic filter was packed with porous floating ceramic media at a packing volume of about 10 L. The average size of the media was 7 to 8 mm, average pore size was 14–19 μm, and porosity was 73–78%. All experiments were conducted in a temperature-controlled room maintained at 35 ± 1°C. Substrate was fed continuously from the bottom using a peristaltic pump. A substrate feed tank and an effluent storage tank were installed in the refrigerator (4°C) to prevent deterioration.

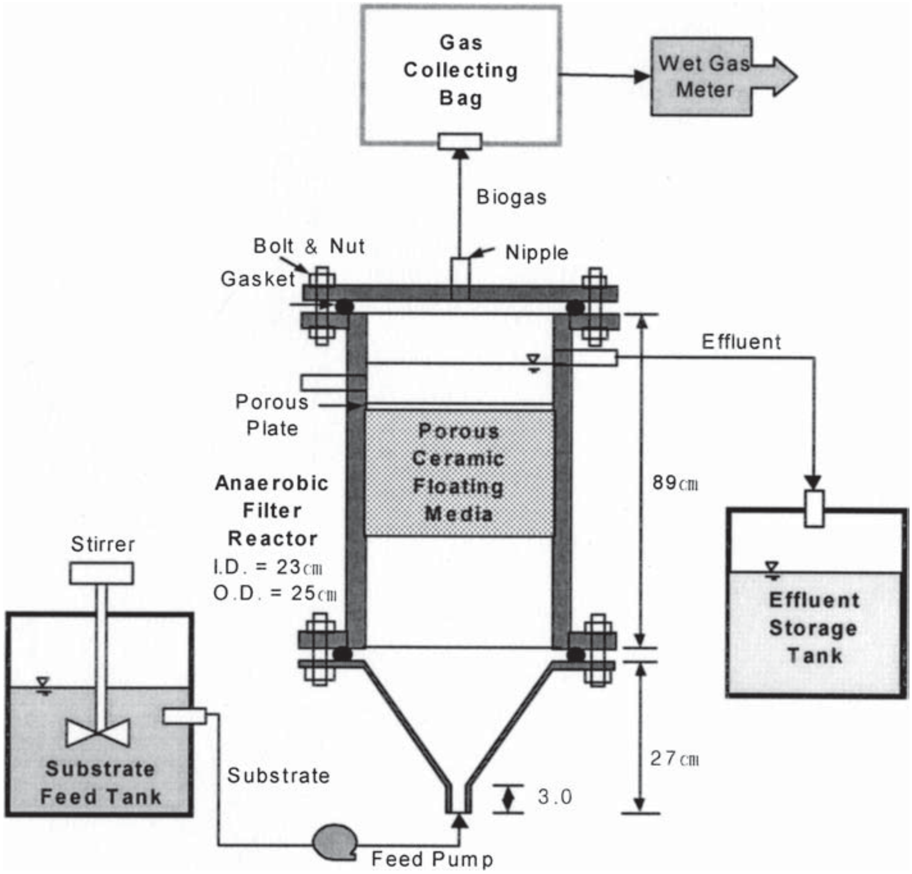

Fig. 1. Schematic diagram of anaerobic filter process.

Substrate

The substrate was obtained from the swine farm of Chungnam National University. The raw swine waste was pretreated by screening and diluting to maintain the uniform total COD (COD_{tot}) concentration of 16,000 mg/L. The chemical composition of the substrate is given in Table 1.

Operation

The seed was obtained from the mesophilic digester in a municipal sewage treatment plant at Daejeon, Korea. The supplemental alkali agents and trace elements were added to the reactor at the beginning of the operation. The addition of supplemental trace elements was based on milligrams of trace element added per kilogram of COD removed during the operation: 100–2000 mg of Fe, 5–300 mg of Ni, 5–200 mg of Co, 1–4 mg of Mo, 2–4 mg of Se, and 2–8 mg of Wo added per kilogram of COD removed.

Table 1
Chemical Composition of Feed Substrate

Parameter	Mean value
COD_{tot} (mg/L)	15,929
COD_{sol} (mg/L)	3209
TSS (mg/L)	10,530
VSS (mg/L)	7535
TKN (mg/L)	407
NH_3-N (mg/L)	357
TP (mg/L)	247
pH	7.23
Total alkalinity (mg/L as $CaCO_3$)	2399
VFA (mg/L as C_2)	2195

A stepwise decrease in hydraulic retention times (HRTs) and an increase in organic loading rates (OLRs) were utilized in the anaerobic filter, reducing the HRTs from 3 d to 2, 1, and 0.5 d, respectively. Their concomitant increases in OLRs were from 5.3 kg of $COD_{tot}/(m^3 \cdot d)$ to 8.0, 16.0, and 32.0 kg of $COD_{tot}/(m^3 \cdot d)$. The operation took more than 1 mo at each HRT to obtain reliable results at a steady-state condition.

Analytical Methods

Biogas volume was measured by a wet-gas test meter and calibrated at conditions of standard temperature and pressure (1 atm, 0°C). Gas composition was analyzed using a Shimadzu Model GC-14A with a thermal conductivity detector. COD, SS, pH, alkalinity, total Kjeldahl nitrogen (TKN), NH_3-N, and total phosphorus (TP) of the effluent and influent were analyzed according to APHA standard methods *(6)*. Volatile fatty acids (VFAs) were analyzed using a Shimadzu Model GC-14A with a flame ionization detector.

Results and Discussion

The results of the operating anaerobic filter to treat a slurry type of swine wastewater are summarized in Table 2. It was often observed that the methane content became lower as the reactor OLRs increased as a result of a large quantity of anaerobic hydrolytic products. However, the methane content of anaerobic filter operated at different HRTs remained above the range of 71–84% for the entire experiment, as shown in Fig. 2A. This was probably owing to the anaerobic active biomass developed on the porous floating ceramic media in the anaerobic filter, as illustrated in Fig. 3. Scanning electron microscopic examination revealed that there were a great number of sites on the porous surface of the floating ceramic media. It was also observed that numbers of *Methanococcus* sp. were attached and grew on the surface of the media, as illustrated in Fig. 4.

Table 2
Results of Anaerobic Filter Operated at Different HRTs with Swine Wastewater

	HRT (d)			
Parameter	3	2	1	0.5
OLR (g COD_{tot}/[L·d])	5.3	8.0	16.0	32.0
CH_4 productivity (v/v-d)	1.07	1.19	1.69	1.68
Gas composition (CH_4, %)	71	75	77	84
Specific methane productivity (m^3 CH_4/kg COD destroyed)	0.3	0.29	0.24	0.13
COD_{tot} removal (%)	68	52	44	39
COD_{sol} removal (%)	71	77	62	60
TSS removal (%)	59	52	39	30
VSS removal (%)	59	58	27	23
COD/TKN ratio	12	18	22	24
COD/TP ratio	31	44	47	54
pH	7.74	7.61	7.53	7.65
Alkalinity (mg/L as $CaCO_3$)	2514	2651	2555	2675
VFA (mg/L as C_2)	57	166	176	238
V/A ratio	0.02	0.06	0.07	0.09
P/A ratio	0.03	0.1	0.22	0.31

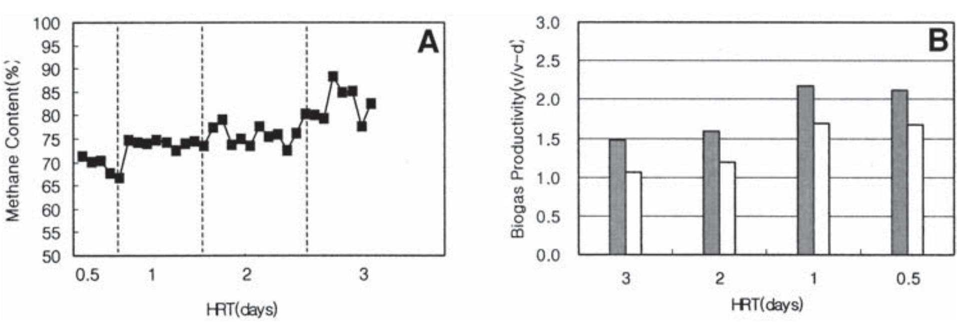

Fig. 2. **(A)** Methane contents of anaerobic filter at different HRTs; **(B)** biogas productivity of anaerobic filter at different HRTs: ■, biogas; □, methane.

The volume of biogas produced from anaerobic filter at different HRTs was expressed as the biogas productivity, volume of biogas produced per volume of reactor per day (v/[v·d]). As shown in Fig. 2B, the methane production rates were directly related to the OLR and thus reflect the COD removal efficiency.

The maximum methane production rate was 1.69 v/(v·d) at an OLR of 16.0 kg of COD/(m^3·d) in the reactor operated at an HRT of 1 d. No great difference in methane production rate was found between the reactors operated at an HRT of 1 and 0.5 d. The specific methane productivity stayed above 0.24 m^3/kg of COD destroyed when the anaerobic filter was operated at an HRT of 1 d or longer.

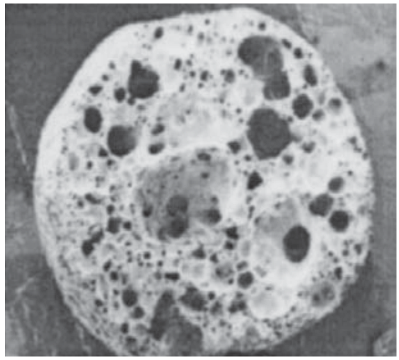

Fig. 3. Scanning electron microscopic examination of surface of floating ceramic media.

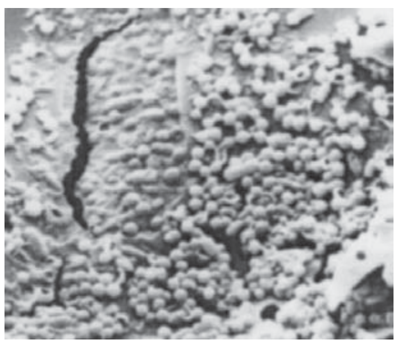

Fig. 4. Scanning electron microscopic examination of anaerobic microorganisms attached to surface of media.

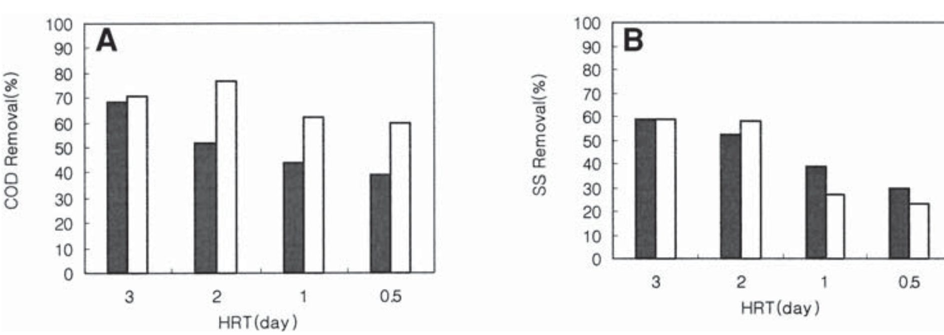

Fig. 5. Removal efficiency of anaerobic filter at different HRTs: **(A)** (■) COD_{tot}, (□) COD_{sol}; **(B)** (■) TSS; (□) volatile SS (VSS).

The soluble COD (COD_{sol}) removal efficiencies as a function of HRT were compared with the anaerobic filter operated at different HRTs, as shown in Fig. 5A. It became clear that the COD_{sol} removal efficiencies of the anaerobic filter gradually decreased as the HRT became shorter or the OLRs

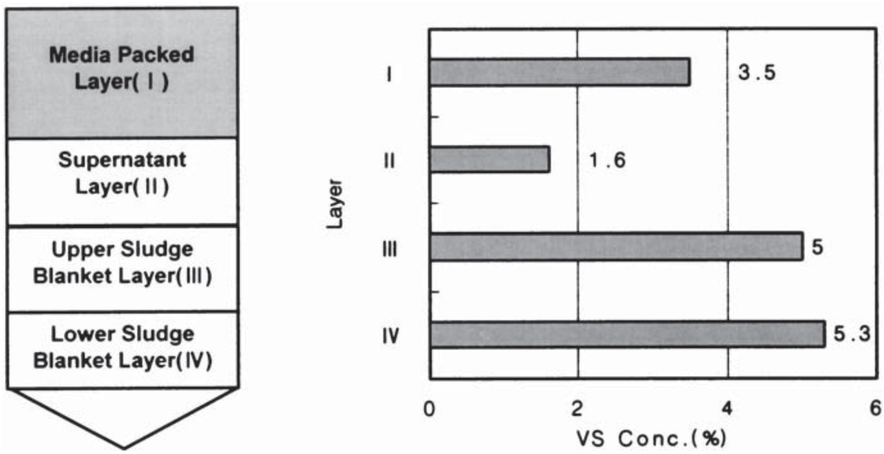

Fig. 6. Biomass concentration of each layer in anaerobic filter.

increased. However, the magnitude in COD_{sol} removal efficiencies among operating HRTs was not great.

The maximum COD_{sol} removal of 77% was achieved when the anaerobic filter was operated at an HRT of 2 d with an OLR of 8.0 kg/(m^3·d), while that of 62% was obtained at an HRT of 1 d with an OLR of 16.0 kg/(m^3·d). Even at a shorter HRT of 0.5 d with an OLR of 32.0 kg/m^3, COD_{sol} removal of 60% was reached. These results are better than those obtained by Bolt et al. *(7)*, who reported that COD_{tot} removal was 40% using the suspended particle attached growth system at 35°C with an OLR of 5.67 g of COD_{tot}/(L·d). One of the very important parameters for the pretreatment of swine wastewater followed by the biologic nutrient removal system is the characteristics of effluent from the pretreatment system such as COD_{tot} concentration, C/N ratio, and carbon sources. It is likely that the average effluent COD_{tot} concentration of 8738 mg/L from the anaerobic filter when operated at an HRT of 1 d would be a good substrate for the subsequent biologic nutrient removal system.

The total SS (TSS) removal efficiencies at different HRTs are illustrated in Fig. 5B, and the trend was similar to that of COD_{tot} removal. It was found that the TSS removal efficiencies of the anaerobic filter gradually decreased as the HRT became shorter. The TSS removal efficiency was 39% at an HRT of 1 d. Considering an influent TSS concentration of 10,530 mg/L, about 4100 mg/L of SS was retained inside the anaerobic filter. It was observed that a TSS removal efficiency of 30% at an HRT of 0.5 d was insufficient because attempts to decrease shorter HRT caused continual bacterial washout.

After all the experiments were terminated, the anaerobic filter was opened to investigate the quantity and distribution of active biomass developed inside it. As shown in Fig. 6, four distinctive biomass layers were observed: media-packed layer, supernatant layer, upper sludge blanket layer, and lower sludge blanket layer.

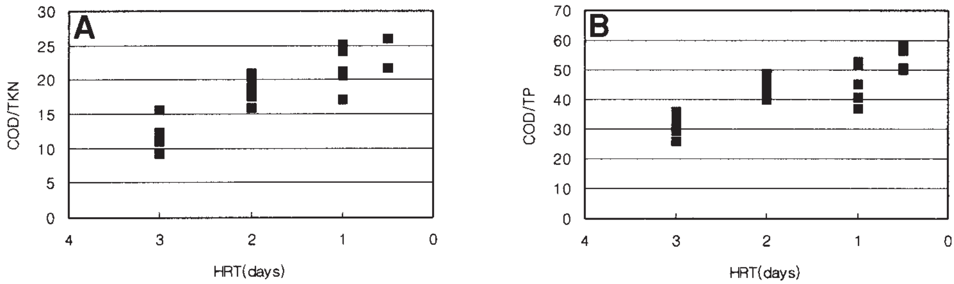

Fig. 7. Effluent **(A)** COD/TKN ratio and **(B)** COD/TP ratio of anaerobic filter.

The layers' respective volatile solids (VS) concentrations were 3.5, 1.5, 5, and 5.3%. The portion of VS at the upper sludge blanket layer was approx 60% of TS concentration (8.5%), while that of the lower sludge blanket layer showed 20% of TS concentration (13.6%). The uppermost media-packed layer showed 3.5% VS concentration, which was much higher than that of the supernatant layer (1.5%).

As summarized in Table 2, during the entire operation of the anaerobic filter, the effluent pH was maintained at 7.53–7.74 owing to the high alkaline concentration of the substrate. The reactor's alkalinity was stable even with the higher OLR of 32 kg/(m^3·d). This was probably owing to the fact that high VFA content produced from anaerobic fermentation of swine wastewater was well buffered by the reactor's alkalinity.

The VFA concentration ranged from 57 to 238 mg/L as C_2, and accumulation of VFA, often caused by the high organic load was not found. Anaerobic filters were also stable with respect to the parameters explaining anaerobic reactor stability, the propionate-to-acetate (P/A) ratio of <1.4, and the VFA-to-alkalinity (V/A) ratio of <0.3 during the entire operation. As illustrated in Table 2, the ratios of P/A and V/A of the operating anaerobic filter were much less than those values of the rapid tools to measure reactor stability *(8–10)*.

It was often found that the degree of pretreatment greatly influenced the subsequent nutrient removal process because of the resulting unbalanced carbon/nitrogen/phosphorous ratio.

It was therefore necessary that the operation variables of the anaerobic pretreatment process to treat swine wastewater be optimized for the subsequent biologic nutrient removal system, because the performance of a biologic nutrient removal system is strongly affected by the characteristics of the effluent of the anaerobic pretreatment process *(11,12)*. The parameters affecting the subsequent biologic nutrient removal process were (1) pH and temperature; (2) high buffering capacity to compensate drop in pH caused by the nitrification; and (3) e.g., C, N, P balance.

The pH of the anaerobic filter was very high owing to the high alkaline concentration of swine wastewater. VFA concentration was <238 mg/L at all operating conditions. Such a low VFA concentration could not play a roll as a carbon source for denitrification. However, a high alkalinity concentration of >2500 mg/L as $CaCO_3$, high pH, and high effluent temperature are obviously beneficial to subsequent biologic nitrification.

As shown in Fig. 7, COD/TKN ratio ranged from 12 to 24, and COD/TP ratio ranged from 31 to 54, showing sufficient ranges for the subsequent biologic nitrification/denitrification and phosphorous removal. It has been reported that COD/TKN ratio and COD/TP ratio should be above 8 and 33, respectively, in order to achieve effective nitrogen and phosphorous removal *(13)*.

Conclusion

The present study was conducted to assess the effect of HRT on the efficiency of the anaerobic filter packed with porous floating ceramic media to treat swine wastewater. Efforts were made to identify the optimal operation condition of the anaerobic filter as a pretreatment for the subsequent biological removal of nitrogen and phosphorus because the higher COD removal in the anaerobic pretreatment may cause an adverse effect on the following biologic processes. A stepwise decrease in HRT and an increase in OLR were utilized in the anaerobic filter at mesophilic temperature (35°C).

The optimum operating condition of the anaerobic filter packed with porous floating ceramic media for the pretreatment of swine wastewater appeared to be at an HRT of 1 d. The maximum methane productivity in this process approached 1.69 v/(v·d) and achieved 62% COD_{tot} and 39% TSS removal efficiencies with an OLR of 16.0 kg/(m^3·d) at an HRT of 1 d.

One of the most important parameters to evaluate the feasibility of substrate to be used in biologic nutrient removal has been documented as the COD/TKN and COD/TP ratios of substrate. In our study, the COD/TKN ratio of 12:24 and the COD/TP ratio of 31:54 of the anaerobic filter effluent at an HRT of 1 d were sufficient. In addition, high effluent alkalinity concentration >2500 mg/L as $CaCO_3$, high effluent pH above 7.5, and high effluent temperature of 35°C are obviously beneficial to subsequent biologic nitrification. Therefore, the effluent from the anaerobic filter packed with porous floating ceramic media operated at an HRT of 1 d to treat swine wastewater was found to be an adequate substrate for the following biologic nutrient removal.

Acknowledgment

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