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Factors affecting the performance of membrane bioreactor for piggery wastewater treatment

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A B S T R A C T

This study was conducted to identify the factors affecting the performance of membrane bioreactor (MBR) for piggery wastewater treatment. The change of organic and nitrogen concentrations in piggery wastewater was studied to investigate the treatment efficiency. The increase of COD, BOD and NH_3–N from 1150 to 2050 mg/L, 683 to 1198 mg/L and 154 to 248 mg/L has led to the decrease of treatment efficiency. Removal efficiencies of COD, BOD and NH_3–N have decreased from 96.0% to 92.0%, 97.0% to 92.7% and 93.2% to 69.5%, respectively. The effects of biomass characteristics on membrane fouling were determined based on Pearson's correlation coefficient (r_p). It was found that MLSS had a negative correlation with permeate flux ($r_p = -0.745$, at significant level of 0.05) while sludge floc size a positive correlation ($r_p = 0.731$, at significant level of 0.05). MLSS and sludge floc size were found to be the dominant factors that controlled the membrane filterability while sludge viscosity, EPS, SMP and SV_{30} have taken as the sub-factors affecting membrane fouling.

1. Introduction

Piggery wastewater contains high amount of suspended solids, organic matter, nitrogen and phosphorus. The lack of appropriate management for piggery wastewater created an important environmental impact. Suitable design for the treatment of piggery wastewater was required to meet the discharge criteria of livestock wastewater in Korea (Park et al., 2003). Chemical precipitation (CP) process can be one of the pre-treatment alternatives for the removal of suspended solids and phosphorus while application of biological process for organic and nitrogen removal (Iamchaturapatr, 2002; Obaja et al., 2003; Kornboonraksa et al., 2009). Among the biological processes, membrane bioreactor (MBR) has been regarded as the advanced treatment technology due to the high effluent quality, high biomass concentration operations resulting compact bioreactors, wide range of operating conditions such as sludge age and organic loading rate (Xing et al., 2000). However, the main obstacle for MBR process is membrane fouling that caused the deterioration of membrane permeability. Recently, most of the research works have focused on the MBR process treating synthetic or municipal wastewater. A few have addressed on wastewater with high-strength and low-biodegradable such as piggery wastewater. Besides, factors affecting membrane fouling was not explored (Kim et al., 2008). As the membrane modules are immersed in activated sludge tank, the influence of sludge properties on membrane fouling is very complex (Wang et al., 2006). Several researchers have reported that the biological constituents (mixed liquor suspended solids (MLSS), extracellular polymeric substance (EPS), soluble microbial products (SMP)), rheological properties (sludge viscosity) and morphological characteristics (sludge floc size, filament index (FI)) of mixed liquors played an important role on membrane fouling potential (Lee et al., 2001; Bai and Leow, 2002; Lim and Bai, 2003). Among various parameters, MLSS, sludge floc size and EPS are suspected as the key factors influencing the membrane fouling. In this research study, application of CP–MBR hybrid process is expected to contribute more alternation on piggery wastewater treatment. The change of organic and nitrogen concentrations in piggery wastewater was studied to investigate the treatment performance of MBR process. MLSS concentration, concentrations of proteins, carbohydrates and COD fractions of EPS and SMP, sludge viscosity, sludge floc size and SV_{30} were analyzed to identify the main factors affecting the membrane fouling based on statistical analysis.

2. Methods

2.1. Supernatant characterization

Piggery wastewater contains high amounts of suspended solids, colloids and turbidity that are impossible to feed directly to MBR

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Nomenclature

CP	chemical precipitation
CP–MBR	chemical precipitation and membrane bioreactor
DO	dissolved oxygen (mg/L)
EPS	extracellular polymeric substance
EPSc	carbohydrates fractions in EPS solution (mg/g VSS)
EPSp	proteins fractions in EPS solution (mg/g VSS)
EPS-COD	COD fractions in EPS solution (mg/g VSS)
$FeCl_3$	ferric chloride
FSI	floc size index
F/M	food to microorganism ratio (mg COD/mg MLVSS d)
HRT	hydraulic retention time
J	permeate flux (L/m^2 d or m^3/m^2 s)
MBR	membrane bioreactor
MLSS	mixed liquor suspended solids (mg/L)
MLVSS	mixed liquor volatile suspended solids (mg/L)
OLR	organic loading rate (kg COD/m^3 d or kg BOD/m^3 d)
PDA	photometric dispersion analyzer
R_f	fouling resistance due to pore blocking and cake formation (m^{-1})
R_m	intrinsic membrane resistance (m^{-1})
R_t	total membrane fouling resistance (m^{-1})
SMP	soluble microbial products
SMPp	proteins fractions in SMP solution (mg/g VSS)
SMPc	carbohydrates fractions in SMP solution (mg/g VSS)
SMP-COD	COD fractions in SMP solution (mg/g VSS)
SPSS	Statistical Package for the Social Science
SS	suspended solids (mg/L)
SV_{30}	sludge volume after 30 min of sedimentation (mL/L)
TMP	transmembrane pressure (kg/m s^2)
VSS	volatile suspended solids (mg/L)

Greek symbol

μ	permeate viscosity (kg/m s)

process. Pre-treatment as chemical precipitation (CP) was required to reduce the high concentration of solid particles. In order to investigate the effects of organic and nitrogen concentrations on MBR performance, piggery wastewater diluted with tap water was prepared in two different proportions. At run I application (from day 1 to day 300), an average COD concentration of 5000 mg/L was supplied to CP process while run II application (from day 301 to day 391) was operated at a higher average COD concentration of 10,000 mg/L. The increase of an average COD concentration from 5000 to 10,000 mg/L has led to the increase of BOD, NH_3–N, SS and turbidity concentrations as shown in Table 1. From the previous study, it was found that $FeCl_3$ was the most effective coagulant to remove suspended solids in CP process (Kornboonraksa et al., 2009). Optimum $FeCl_3$ dosage of 1500 and 3000 mg/L corresponded to COD concentration of 5000 and 10,000 mg/L, respectively, and lime was added to neutralize the treated solution. Characteristics of treated piggery wastewater by CP process are shown in Table 1.

Table 1
Composition of piggery wastewater and treated piggery wastewater by CP process.

Parameters	Unit	Piggery wastewater	Treated piggery wastewater by CP process
Run I application (day 0–300)			
COD	mg/L	4685–5390	907–1541
BOD	mg/L	1710–1895	510–870
NH_3–N	mg/L	245–261	128–190
SS	mg/L	1890–2600	5–135
Turbidity	NTU	331–703	5–74
Conductivity	ms/cm	2.0–3.3	1.9–4.1
Alkalinity	mg $CaCO_3$/L	880–1220	280–1050
pH	–	6.9–7.2	5.7–7.6
Run II application (day 301–391)			
COD	mg/L	9437–10,369	1606–3051
BOD	mg/L	2400–2650	930–1590
NH_3–N	mg/L	427–504	198–342
SS	mg/L	4148–4600	30–283
Turbidity	NTU	1790–2373	40–104
Conductivity	ms/cm	3.7–4.0	3.3–4.8
Alkalinity	mg $CaCO_3$/L	1640–1880	510–1000
pH	–	7.2–7.3	6.2–7.6

Note: CP: chemical precipitation.

2.2. Experimental set-up

Treated piggery wastewater by CP process (hereafter refers as supernatant) was separately collected in a supernatant tank before feeding to the MBR process. MBR process was operated at constant permeate flux mode under no sludge withdrawal condition except sampling the activated sludge for analysis. Intermittent permeate suction was performed to reduce membrane fouling. It was produced by a 10 min-suction followed by a 10 min-rest. Nitrification and denitrification occurred alternately in MBR process through an intermittent 60 min on and off aeration. Detailed operational condition of the MBR process is summarized in Table 2. Microfiltration membrane set-up was procured from Korea Membrane Separation Co., Ltd. Detailed specification of membrane used in this experiment is summarized in Table 3.

2.3. Analytical methods

COD, BOD, NH_3–N, SS, turbidity, conductivity, pH and alkalinity were periodically monitored in this experiment. Analytical procedure was taken according to the standard methods (APHA et al., 1998). MLSS, MLVSS, SV_{30}, EPS and SMP were measured to identify the sludge characteristics in bioreactor. EPS was extracted by thermal treatment method (Kornboonraksa et al., 2009). Viscosity was measured by rotational viscometer (Brookfield LVDV-II) to identify the rheological properties of the sludge. Floc size index of the sludge was monitored by photometric dispersion analyzer

Table 2
Operational condition of the MBR process.

Parameters	Unit	Value
Duration	d	391
Reactor volume	L	12
HRT	d	1.5–2.8
Flux	L/m^2 d	48–200
OLR	kg COD/m^3 d	0.31–0.77
DO concentration		
(1) Aeration cycle mode	mg/L	2–4
(2) Non-aeration cycle mode	mg/L	0.1–0.3
Temperature	°C	23–25
pH	–	7.2–7.6