Desalination and Water Treatment
www.deswater.com

32 (2011) 397–403
August

1944-3994 / 1944-3986
doi: 10.5004/dwt.2011.2758

Performance evaluation of chemical precipitation and upflow anaerobic floating filter hybrid processes for piggery wastewater treatment

Seunghwan Lee

School of Civil and Environmental Engineering, Kumoh National Institute of Technology, Gumi 730-701, Korea
Tel. +82 (54) 478-7632; Fax +82 (54) 478-7859; email: dlee@kumoh.ac.kr

Received 27 August 2010 ; Accepted in revised form 1 March 2011

ABSTRACT

The study was conducted to study the performance evaluation of chemical precipitation (CP) combined with upflow anaerobic floating filter (UAFF) hybrid processes for the treatment of raw piggery wastewater. Several series of experiments have been carried out in the laboratory-scale unit using ten times diluted raw piggery wastewater, involving CP and UAFF processes operating separately and combined. The best operating conditions for the combined process were determined by optimizing the sub-processes (CP and UAFF separately). In the CP sub-unit various types and dosages of coagulants were examined including: aluminium sulfate ($Al_2(SO_4)_3$), poly aluminium chloride (PAC), ferric chloride ($FeCl_3$), ferric sulfate ($Fe_2(SO_4)_3$), ferrous sulfate ($FeSO_4$) and ferrous chloride ($FeCl_2$). Aluminium and ferric coagulants have shown the higher removal efficiency and aluminium sulfate ($Al_2(SO_4)_3$) was chosen for further experiments. Organic loading rate (OLR) and chemical constitutes caused by acid coagulants in CP have shown a significant effect on biogas production rate. Combined process of CP followed by UAFF has shown 90–95% of COD, 95–98% of SS, 75–80% of Color and 91–95% of TP removal efficiencies. There was 10–25% of increase in the removals of COD, SS and Color in comparison to the results obtained after treating the wastewater with only one of the methods — CP or UAFF. Further 3–10% of increase in the removal was observed in the process of UAFF followed by CP in comparison to results achieved from the CP followed by UAFF process, while nutrients removal was insignificant. Sludge blanket (70% of total biomass) also played an important role for the increase of removal efficiency.

Keywords: Piggery wastewater; Chemical precipitation; Anaerobic reactor; Biogas generation

1. Introduction

In most of the Asian countries animal production is growing rapidly due to the increase of population and related rise in demand for animal protein. In Thailand the change from a traditional small-scale farming to large-scale industries has caused an increase in emission of pollutants and resulted in environmental degradation and deterioration of public health [1,2]. Pork production is a major agricultural enterprise in Thailand where approximately seven million pigs are farmed [3]. For many Asian countries a major concern arising from the expansion of pig farming is the problem of disposing the pig manure to the waterways without a proper treatment. Several innovative technologies of piggery wastewater treatment that can be potentially appropriate for urban environments have been continually explored and developed [3]. Upflow anaerobic sludge blanket (UASB) has been extensively applied in the past few decades. One of its main advantages is reduced clogging, especially when

Presented at the Third International Conference on Challenges in Environmental Science & Engineering, CESE-2010
26 September – 1 October 2010, The Sebel, Cairns, Queensland, Australia

applied to wastewater containing high amount of solids. The formation of a good granular sludge bed is however highly dependent on the characteristics of treated wastewater and is sometimes difficult to achieve. Upflow anaerobic floating filter (UAFF) is a combined process of fixed bed filter and UASB. The packing media in UAFF is placed at the top of the reactor in order to provide better solids capture and prevent the loss of large amounts of solids due to process upsets or change in the sludge blanket characteristics and density.

In current practice, chemical precipitation can be used as a means of improving the performance of primary settling facilities or in secondary and advanced wastewater treatment. Chemical precipitation (CP) has the advantage of requiring a smaller land area for unit operations compared to biological treatment processes. The unit operations are completely enclosed and often required low maintenance [4]. This process is effective and can be used to treat high-strength and toxic wastewaters. Duration of the treatment is also shorter than other techniques. Disadvantages include high capital cost and heavy metal leakage. Chemicals can be expensive and cause corrosion [5,6]. Several sources state that anaerobic treatment was found to be an effective option for the treatment of piggery wastewater due to its low investment and maintenance costs [7–9]. Only few studies have been carried out to investigate the effectiveness of treating the piggery wastewater by combined system of anaerobic treatment and CP. This study was conducted to examine the effect of CP in UAFF system, to evaluate the performance of combined system, and to investigate the best operating conditions of this combined process for piggery wastewater treatment.

2. Materials and experimental methods

2.1. Wastewater characteristics

Piggery wastewater was collected at the effluent point of disposal lagoon from one of the pig farms in the province of Chachengsao, Thailand, and diluted ten times using the distilled water. Dilution of raw piggery wastewater was required to identify the detailed performance of chemicals involved for the CP process. Ten times of dilution was confirmed by trial-and-error method. Characteristics of diluted raw piggery wastewater are summarized in Table 1.

Table 1
Characteristics of diluted raw piggery wastewater

Parameters	Raw piggery wastewater
COD, mg/L	3,500–4,700
SS, mg/L	1,000–1,500
Color, ADMI	600–700
TKN, mg/L	700–800
NH3-N, mg/L	500–550
TP, mg/L	50–60
pH	7.8–8.2

2.2. Experimental set-up

A laboratory-scale experimental set-up was designed to investigate the performance of CP and UAFF units operating separately and combined. Initially samples of raw piggery wastewater were treated by CP and UAFF independently. The best operational conditions for both methods were determined by analyzing the removal efficiencies of major wastewater quality parameters such as pH, COD, SS, Color, TKN, TP and NH_3-N [10]. Secondly two kinds of a combined system were examined: (1) UAFF followed by CP, and (2) CP followed by UAFF.

In the CP unit a continuous reactor was examined. The set-up consisted of a rapid mixing reactor and a sedimentation tank interconnected. Rapid mixing reactor was made of an acrylic tube with internal dimensions of ∅150 mm × 200 mm × 4 mm (diameter × height × thickness), accommodating a volume of between 0.3–1.5 L. For sludge sedimentation, a long shaped rectangular tank of total volume of 18 L was assembled out of acrylic plate. In order to obtain the best operating conditions, the actual experiment was preceded by a series of measurements taken in a batch reactor. Different types and dosages of acid coagulants were examined in the batch experiments. In each experiment 400 mL of piggery wastewater was manually fed into the batch reactor. The wastewater pH was altered by the addition of sulfuric acid (12 N H_2SO_4) prior to the addition of acid coagulant. Initially the mixing speed was fixed to 1,500 rpm for 15 s. After the optimal dosages and pH for each of the acid coagulants were determined, further experiments were carried out in order to find the appropriate mixing regime. Optimum mixing speed was determined followed by the examination of mixing and settling times. After each experiment the supernatant was drawn off from the middle of the reactor and the major water quality parameters were analyzed. A list of acid coagulants and the dosages used in these experiments are shown in Table 2. Flowrate of raw water entering the continuous reactor was adjusted so that the settling time could be maintained at 30 min. Water quality parameters monitored were COD, SS, colour, TP, org-N and TKN [10,11]. Table 3 shows the final operating conditions such as acid coagulant dosage, pH, mixing speed and time determined in the CP sub-unit.

Three set of laboratory-scale UAFF reactors made of acrylic pipes (inner diameter and height of 12.5 and 100 cm respectively), having a working capacity of 11 L were used in the experiment as shown in Fig. 1. Influent was continuously fed with upflow velocity of 0.04 m/h by peristatic pumps to control the hydraulic retention time (HRT) at 24 h under ambient temperature condition

Table 2
Operational parameters of acid coagulants in batch reactor

Acid coagulants	Dosages (g/L)
Aluminium sulfate ($Al_2(SO_3)$)	1.0–7.5
Ferric chloride ($FeCl_3$)	0.5–3.0
Ferric sulfate ($Fe_2(SO_4)$)	0.5–3.0
Poly aluminium chloride (PAC)	0.25–0.44
Ferrous sulfate ($FeSO_4$)	0.5–3.0
Ferrous chloride ($FeCl_2$)	0.5–3.0

Table 3
Operating conditions of chemical precipitation (CP) experimental set-up

Parameters	Value
1. Rapid mixing tank	
Detention time (*DT*), s	60
Rotational speed (*n*), rpm	1,000
2. Sedimentation tank	
Detention time (*DT*), min	60
Average overflow rate, $m^3/m^2.d$	4.8
3. Chemical feeding tank	
Aluminium sulfate, $Al_2(SO_4)_3$. g/L	1.25

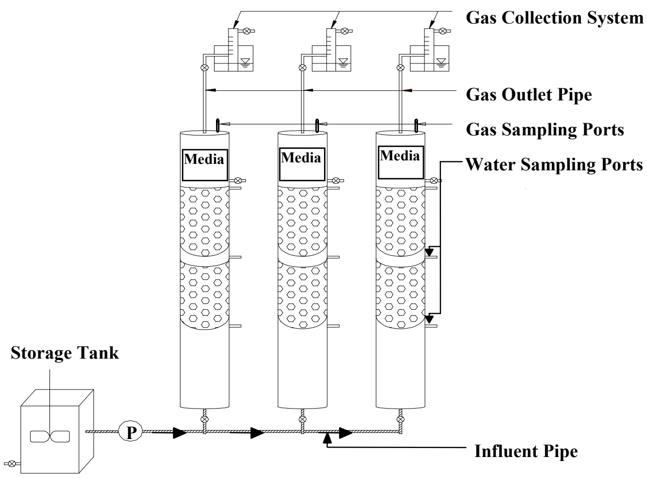

Fig. 1. Experimental set-up of upflow anaerobic floating filter (UAFF).

(22–28°C). Approximately 20% of each UAFF reactor was occupied by packing media which functioned as a filter and allowed the anaerobic bacteria to grow in the attached form. Sponge cubes were used as the packing media and their physical properties are presented in Table 4. UAFF system performance was investigated by the determination of influent and effluent water quality characteristics.

Table 4
Physical characteristics of floating media

Media type	Sponge cube
Width (W), cm	1.5
Length (L)/Height (H), cm	1.5/1.5
Specific surface area, m^2 m^3	2,417
Packing density, kg/m^3	104
Porosity, %	96.2
Packing weight, g	21.8

Seeding was required for the development of anaerobic bacteria cultures in the UAFF reactors. This was obtained by placing an amount of pig sludge, drawn from the anaerobic pond in each reactor for a period of one week. Afterwards fresh piggery wastewater with an average daily COD loading rate of 1.6–1.8 kg COD/m^3 of wastewater was continuously fed into three set of UAFF reactors. During the operation time, percentage removal of COD was periodically monitored until the system reached the stabilizing stage (up to 52 days). In the combined CP and UAFF system, treated piggery wastewater from CP was continuously fed into the UAFF reactors with an average daily COD loading rate of 1.1–1.2 kg COD/m^3 of wastewater (53–81 days). Effluent from UAFF was collected and analyzed periodically and the biogas generated at each reactor was kept in the gas collector.

3. Results and discussion

In this section the overall performance of all analyzed units and set-ups is presented and in-depth description of the results obtained from the combination of CP followed by UAFF was discussed. Although it was found that this system was slightly less effective than the combination of UAFF followed by CP, we have focused on it for the practical application of the system in industries. CP unit takes less time than UAFF one, occupies less space and quickly eliminates such nuisances as odour. Due to the above mentioned strengths, people in the pig farm prefer to the combination of CP followed by UAFF system.

3.1. Chemical precipitation (CP)

In the CP sub-unit various types and dosages of coagulants were examined such as aluminium sulfate ($Al_2(SO_4)_3$), poly aluminium chloride (PAC), ferric chloride ($FeCl_3$), ferric sulfate ($Fe_2(SO_4)_3$), ferrous sulfate ($FeSO_4$) and ferrous chloride ($FeCl_2$) to identify the most effective acid coagulants. Among the acid coagulants examined in the batch reactor measurements the ferric and aluminum compounds were found to be the most effective. Generally acid coagulants containing the ferrous ion (Fe^{2+}) has shown the worst removal efficiencies for

COD, SS and color. Fe^{2+} react with hydroxide ions (OH^-) in the wastewater to form ferrous hydroxide ($Fe(OH)_2$) in the soluble form. $Fe(OH)_2$ is next oxidized to ferric hydroxide [$Fe(OH)_3$] in the precipitated form by the dissolved oxygen present in the wastewater [5]. Reaction was inhibited at the low pH due to the insufficient hydroxide ions present in the wastewater causing the reduction of $Fe(OH)_2$ to $Fe(OH)_3$ reaction. This results in the decrease of COD, SS and color removal efficiencies in piggery wastewater [4]. Ferric ions (Fe^{3+}) were found to be more effective than aluminium salts as coagulants. One of the main reasons for this is that floc particles obtained from aluminium salts have much lower settleability than iron salts. Comparing PAC with $Al_2(SO_4)_3$, the required amount of PAC to reach the similar COD and SS removal efficiencies was less than $Al_2(SO_4)_3$. It is suspected that PAC is formed in polymerized hydrolysis of aluminium already while aluminium sulfate still needs to hydrolyze [4]. Despite of all the advantages of PAC and ferric coagulants, $Al_2(SO_4)_3$ was chosen for further experiments due to the economical reason [11]. With the increased dosage of aluminium sulfate, there was a corresponding increase in the removal efficiency of COD and SS. With the increase of initial aluminium sulfate concentration from 1.0 g/L to 2.5 g/L, the increase of removal efficiency was proportional. The highest removal efficiencies for COD and SS were 70% and 95% respectively, using the coagulant dosage of 2.5 g/L $Al_2(SO_4)_3$ at pH 4.0–5.0. Higher than 2.5 g/L of $Al_2(SO_4)_3$ dosage, the removal efficiencies of COD and SS decreased due to restabilization, where increased dosage made available more aluminium hydroxide species which readily absorbed suspended solids [13].

3.2. Upflow anaerobic floating filter (UAFF)

In the UAFF sub-unit, lab-scale UAFF reactors were operated for 86 days. Influent COD concentration was maintained at approximately 1,000 mg/l, equivalent to an organic loading rate (OLR) of 1.087 kg COD/m^3.d. The effluent COD fluctuated between 300–700 mg/L in the first two weeks and maintained around 600 mg/L for another 40 days. Slowly improved performance during the initial period corresponded to a latency phase where the attachment of biomass took place followed by the recovery of biological activities. Poor adhesion of biomass and low biomass content may limit the removal of organic matters in this period. It was stated that the establishment of the first bacterial layer was important and surface of the support material, i.e. pores and crevices where bacteria can first adhere played an important role in this process [14,15]. After about 60 days of operation, COD removal efficiencies in the reactors gradually improved to 70–90%. As a result, effluent COD concentrations of 100–300 mg/L were obtained. It was mentioned that the majority of effluent COD from anaerobic treatment system originated from soluble microbial products (SMP) produced by system itself and required further post-treatment [16–19]. Biogas composition was occasionally analyzed during the experimental period. Major composition was found to be methane at a content of about 60%.

3.3. Comparison of methods

Characteristics of the effluent obtained from each of the methods (CP, UAFF, CP + UAFF and UAFF + CP) were compared as shown in Table 5. Combination of UAFF with CP has shown the best performance of COD, SS, Color and TP removals out of four options mentioned above. In every mode of operation, ammonia (NH_3-N) and TKN removals were very low (maximum 30%) compared to other water quality parameters.

3.4. Organics and nutrients removal

Organics and nutrient removals were periodically monitored to identify the performance of the combined system. Fig. 2 shows the removal efficiencies of COD, SS, color, TKN, NH_3-N and TP at the CP followed by UAFF system. Here the raw wastewater was collected from CP treated water and the operational time was counted from the CP process. Average removal efficiencies of COD started from 30% at the initial stage of operation and increased to 65%. More than 55% of removal efficiency was maintained after 65 days of operation. Removal efficiency of SS was in the range of 40% to 55% for the UAFF unit. Effluent SS concentration was kept below 60 mg/L throughout the experiment. Generally anaerobic filter achieves more than 80% of SS removal in wastewater

Table 5
Comparison of removal efficiency at various modes of operation

Parameters	CP [%]	UAFF [%]	CP + UAFF [%]	UAFF + CP [%]
COD	70–72	82–87	90–95	96–98
SS	90–95	84–92	95–98	96–99
Color	65–73	60–68	75–80	88–91
TKN	5–17	20–27	25–32	27–33
NH3-N	1–5	15–24	20–30	15–30
TP	91–95	64–73	91–95	>98

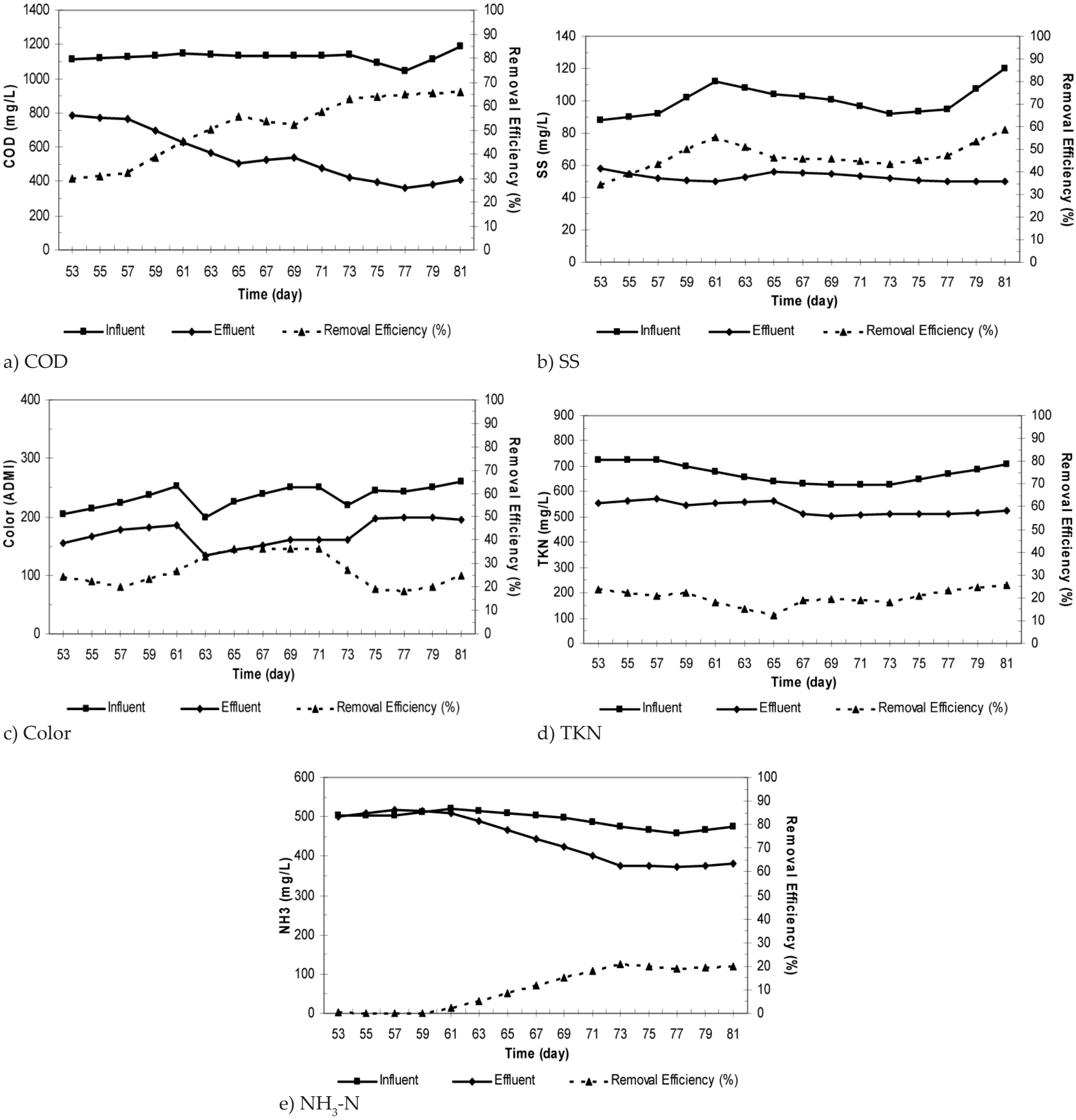

Fig. 2. Performance of CP followed by UAFF process at various water quality parameters.

[5]. In this UAFF process, SS removal was relatively low (up to 65%), as more than 90% of removal was already achieved by CP process. Color removal was in the range of 25% to 40%. Nutrients (TKN and NH3-N) removal was limited to the range of 15–25%. Approximately 70–80% of TKN in piggery wastewater was in the form of NH3-N, which can not be eliminated by CP. In addition, as the UAFF operated in anaerobic condition, TKN removal was only possible due to the conversion into biomass [20]. Little reduction of ammonia nitrogen may occur from air bubble of rapid mixing from acid coagulant process that stirs ammonia to release out to atmosphere [13]. Effluent TP concentration has slightly increased in comparison to the influent one. Phosphorus can leak from the sludge under anaerobic condition due to the conversion of ATP to ADP resulting the increase of phosphorus concentration in effluent from UAFF [4,5].

3.5. Variations of pH and volatile fatty acid (VFA)

Variations of pH and volatile fatty acid (VFA) are the critical elements to identify the changes of wastewater properties after the biological and chemical process have taken place. The pH and VFA were periodically monitored to identify the performance of the combined system. Fig. 3 shows the variation of pH and volatile fatty acid (VFA) in UAFF reactor using CP treated wastewater. With the increase of VFA, pH of the influent gradually decreased. The pH of the third reactor, however, has kept constant (pH = 8.0). Although the initial pH of influent was adjusted by acetic acid between 6.0 and 7.5, gradual increase of pH was observed with the increase of anaerobic reactor. Reaction activities of anaerobe bacteria give rise to alkalinity in wastewater, which results in the pH incremental phenomena [4].

3.6. Biogas generation

Fig. 4 shows the variation of biogas generation and organic loading rate at two different modes of operation: UAFF alone, and combination of CP followed by UAFF. Application of CP followed by UAFF process resulted in the remarkable decrease of biogas production rate in all reactors. Decrease of organic loading rate (OLR) from 1.4–1.8 to 1.1–1.2 kg COD/m³.d after 53 days of operation has brought the decrease of biogas production rate. Chemical constitutes in CP treated water such as SO_4^{2-} generated from $Al_2(SO_4)_3$ disturbs the methane producing bacteria resulting in lower biogas generation rate [4,21,22]. Increase of anaerobic reactor in UAFF has brought the increase of biogas production. Biogas generation rate in the third reactor, however, was negligible after employing CP and UAFF process as the remaining biodegradable materials are minimum.

4. Conclusions

Performance evaluation of chemical precipitation (CP) combined with upflow anaerobic floating filter (UAFF) for piggery wastewater treatment was successfully investigated. Operating conditions for the combined system

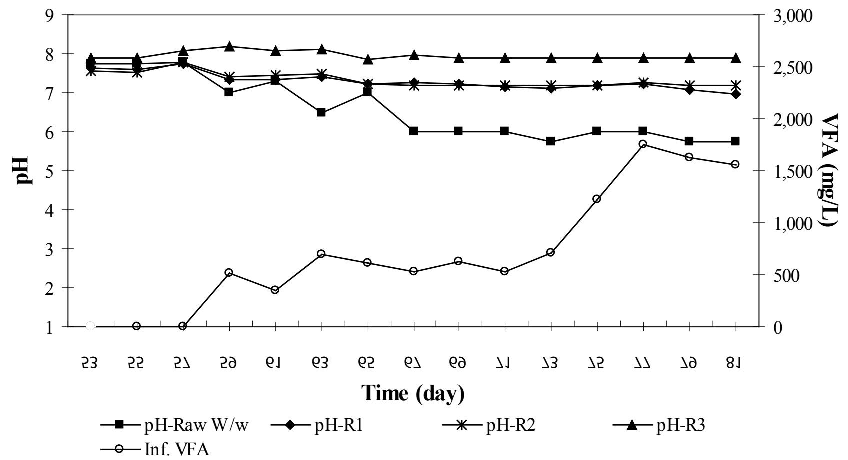

Fig. 3. Variation of pH and VFA concentration in each UAFF reactor (R1: the first reactor, R2: the second reactor, R3: the third reactor).

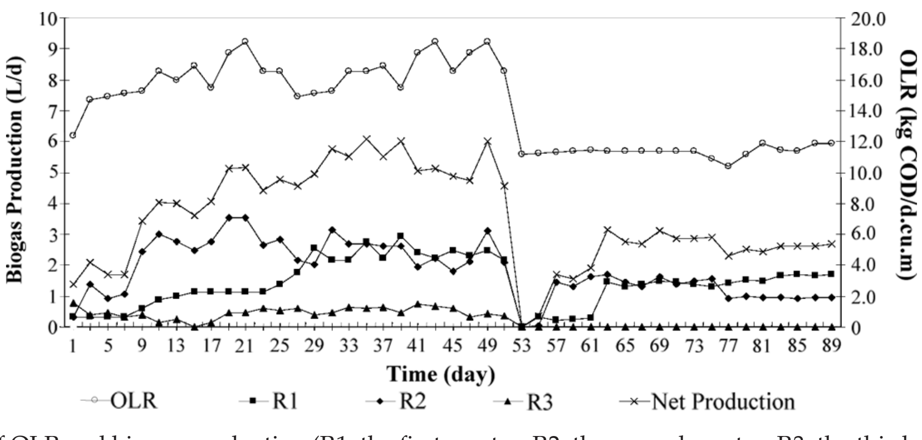

Fig. 4. Variations of OLR and biogas production (R1: the first reactor, R2: the second reactor, R3: the third reactor).

were found through the optimization of CP and UAFF units working separately. It was found that the most suitable coagulant out of examined ones was aluminium sulfate ($Al_2(SO_4)_3$), which fulfilled both removal efficiency and economical requirements. CP unit operating separately resulted in 70–72% and 90–95% of COD and SS removal efficiency respectively. Decrease of organic loading rate obtained in the CP unit and chemical constitutes present in the water due to $Al_2(SO_4)_3$ usage have affected to the methane producing bacteria resulting in lower biogas generation. Combination of CP followed by UAFF system was found to be preferable applicable option for industries. This combined process has shown 90–95% of COD, 95–98% of SS, 75–80% of Color and 91–95% of TP removal efficiencies. Reaction activities of anaerobe bacteria give rise to alkalinity in wastewater, which results in the pH incremental phenomena. Increase of anaerobic reactor in UAFF has brought the increase of biogas production.

Acknowledgements

The authors are grateful for the financial support from KIST (Korea Institute of Science and Technology), Korea (2009-7AL-003) to conduct this study. This is also to acknowledge that this work has been conducted during the corresponding author's sabbatical year (2009.3–2010.2).

References

[1] EPA, Environmental Impacts of Animal Feeding Operations, Office of Water, Standards and Applied Sciences Division, Washington DC, December 1998.
[2] EPA, Development Document for the Proposed Revisions to the National Pollutant Discharge Elimination System Regulation and the Effluent Guidelines for Concentrated Animal Feeding Operations, Washington DC, January 2001.
[3] Thailand Department of Agriculture (TDA), Strategies and working plans for livestock development during the eighth national development plan, Bangkok, Thailand, 1997.
[4] J. Bratby, Coagulation and Flocculation with an Emphasis on Water and Wastewater Treatment, Uplands Press Ltd., Croydon CR91LB, 1980.
[5] Metcalf & Eddy, Wastewater Engineering: Treatment Disposal and Reuse, International Edition, McGraw Hill Inc., New York, 2003.
[6] W.J. Eilbeck and G. Mattock, Chemical Processes in Wastewater Treatment, Ellis Harwood Ltd., 1987.
[7] T. Kornboonraksa and S.H. Lee, Factors affecting the performance of membrane bioreactor for piggery wastewater treatment, Biores. Techbol., 100 (2009) 2926–2932.
[8] T. Kornboonraksa, H.S. Lee, S.H. Lee and C. Chiemchaisri, Application of chemical precipitation and membrane bioreactor hybrid process for piggery wastewater treatment, Bioresource Technol., 100(6) (2009) 1963–1968.
[9] T.D. Reynolds and P.A. Richards, Unit Operations and Processes in Environmental Engineering, 2nd ed., PWS, Boston, MA, 1996.
[10] APHA/AWWA/WEF, Standard Methods for the Examination of Water and Wastewater, 20th ed., Amer. Water Works Assoc. and Water Envir. Fed., USA, 1998,
[11] S.H. Lee, J. Iamchaturapatr, C. Polprasert and K.H. Ahn, Application of chemical precipitation for piggery wastewater treatment, Wat. Sci. Technol., 49(5–6) (2005) 381–388.
[12] R. Bade, S.H. Lee, H.S. Lee and S.E. Lee, Hexavalent chromate removal from wastewater using micellar enhanced ultrafiltration and activated carbon fibre processes; validation of experiment with mathematical equations, Desalination, 229 (2008) 272–278.
[13] A. Adin, Y. Soffer and R. Ben Aim, Effluent pretreatment by iron coagulation applying various dose combinations for particle separation, Wat. Sci. Technol., 38(6) (1998) 27–34.
[14] E. Choi, Z. Yun and T.H Chung, Strong nitrogenous and agro-wastewater: current technological overview and future direction. Wat. Sci. Technol., 49 (2004) 1–5.
[15] D.J. Kim, T.K. Kim, E.J. Choi, W.C. Park, T.H. Kim, D.H.Z. Yuan, L. Blackall and J. Keller, Fluorescence in situ hybridization analysis of nitrifiers in piggery wastewater treatment reactors. Wat. Sci. Technol., 49 (2004) 73–79.
[16] C. Chiemchaisri, W. Wiwattanakom and S.H. Lee, Enhancement of organic and nitrogen removal in up-flow floating filter media reactor for piggery wastewater treatment, Intern. J. Environ. Pollut., 37 (2009) 34–44.
[17] H.Y. Ng and S.W. Hermanowicz, Membrane bioreactor operation at short solids retention times: performance and biomass characteristics. Wat. Res., 39(6) (2005) 981–992.
[18] U. Abeling and C.F. Seyfried, Anaerobic-aerobic treatment of high strength ammonium wastewater — nitrogen removal via nitrite, Wat. Sci. Technol., 26 (1992) 1007–1015.
[19] O.V. Shipin, S.H. Lee, C. Chiemchaisri, W. Wiwattanakom, G.C. Ghosh, A.J. Anceno and W.F. Stevens, Piggery wastewater treatment in a tropical climate: biological and chemical treatment options. Environ. Technol., 28 (2006) 329–337.
[20] S.H. Lee, J.C. Park and D. Brissonneau, Biogas generation and recovery potential within selected agro-industries and the solid waste management sector in Thailand, Environ. Eng. Res., 8(3) (2003) 107–115.
[21] N. Clair, L. Sawyer, P. McCarty and G. Parkin, Chemistry for Environmental Engineering, 4th ed., McGraw-Hill Inc., New York, 1994.
[22] T. Kornboonraksa, S.H. Lee, S.E. Lee and H.S. Lee, Online monitoring of floc formation in various flocculants for piggery wastewater treatment, Desal. Wat. Treat., 1 (2009) 248–252.