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OPERATING FACTOR OPTIMIZATION OF MODIFIED 4-STAGE BARDENPHO PROCESS FOR PIGGERY WASTEWATER TREATMENT

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ABSTRACT

This study was conducted for finding the suitable operational factors of a modified 4-stage Bardenpho process including BJR and membrane bioreactor, a TJC and an activated carbon reactor for piggery wastewater treatment, as well as ways of treating piggery wastewater that can be discharged at the required water quality level. As a result, the TN removal efficiency of the modified 4-stage Bardenpho process was high at the influent flow rate of 4-6 m^3/day with internal recycle flow rate of 4.5-5.0 Q_{in} and then the SDNRs of the 1st anoxic reactor and the SNRs of BJR ranged 1.63-3.54 mg NO_3^--N/g MLVSS·hr and 38.3-74.2 mg NH_4^+-N/g MLVSS·hr, respectively. Also, the average removal efficiency of COD_{mn} and COD_{cr} ranged 74.0% and 63.5% at the ozone dose of 0.124 kg/hr. Therefore, the average concentrations of COD_{mn}, COD_{cr}, and TN in the final effluent were 48, 158, and 56 mg/L, respectively, which met the Korean effluent standards at the operation was conducted under suitable conditions at influent flow rate of 4-6 m^3/day with internal recycle flow rate of 4.5-5.0 Q_{in} and ozone dose of 0.124 kg/hr.

Keywords: *piggery wastewater treatment, modified 4-stage Bardenpho process, Bio Jet Reactor, Turbulent Jet Flow Contact, Korean effluent standard.*

I. INTRODUCTION

With the continuous economic growth and the rising income level due to industrialization, the consumption of stock farm products has been steadily growing, and the piggery head count is increasing in proportion. Consequently, vast amounts of animal waste and wastewater are generated. In addition, with the prohibition of marine damping since 2012 in accordance with the amendment of the enforcement regulations of the Marine Pollution Prevention Act, serious problems have occurred related to the treatment of livestock wastewater (Ministry of Maritime Affairs and Fisheries, 2006).

Piggery wastewater is usually discharged together with the excretion, cleaning wastewater, and feed residue. Hence, it contains a large amount of organics and is actually a highly nutritive substance. A survey reports the concentration of substances in the wastewater from pig farms to be SS 653-16,600 mg/L, CODmn 787-5,520 mg/L, CODcr 6,291-44,100 mg/L, TN 693-9,165 mg/L, NH4+-N 600-6,228 mg/L, and TP 27-418 mg/L (Kim and Chung, 2005). When piggery wastewater is discharged directly into rivers and streams, however, it can deplete the dissolved oxygen in the water and can cause overbreeding of algae therein, leading to the eutrophication phenomenon.

The purification treatment methods of piggery wastewater are physical, chemical, and biological in nature. Most domestic piggery excretion treatment facilities apply a biological method combining anaerobic and aerobic treatment. This particular biological method, however, requires high-level technical skills and skilled workers as well as a large piece of land (Min et al., 1998). In addition, the inconsistent concentration of the wastewater inflow and the over-the-limit quality of the wastewater discharged by public piggery wastewater treatment facilities make it difficult to operate an advanced wastewater treatment plant (Chae et al., 2008). To solve these problems, a new water treatment technology that can replace the existing livestock wastewater treatment process is required.

The purpose of this study was to determine the optimal operating conditions, satisfying the criteria for discharge water quality standards, of newly developed modified four-stage Bardenpho process and high-performance ozone dissolution process for high concentration livestock wastewater treatment. A full-scale plant of the newly proposed

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combined process was constructed for determination of optimum operation factor and was operated for five months while varying influent flow rate, internal return rate, and ozone injection amount. The changes in CODmn, CODcr, TN, and TP removal efficiencies by various operation factors were analyzed, and based on them, the conditions that meet the criteria for discharge water quality were identified.

II. METHOD & MATERIAL

Pilot-scale plant Sample analysis method

The main part of the pilot-scale plant, consisting of 1st anoxic reactor, BJR, 2nd anoxic reactor, and a membrane bioreactor, was installed at a farm in Gunsan, Korea and operated in a mode of a modified 4-stage Bardenpho process to treat piggery wastewater from 2,000 pigs. The schematic diagram of the pilot plant is shown in Fig. 1.It is noted that an air-stripping tank was installed behind the BJR to reduce the DO concentration in the internal recycle flow the BJR to the 1st anoxic reactor. Large coarse materials in the piggery waste stream from the farm were initially removed by a mechanical solids separator (not shown in Fig. 1).

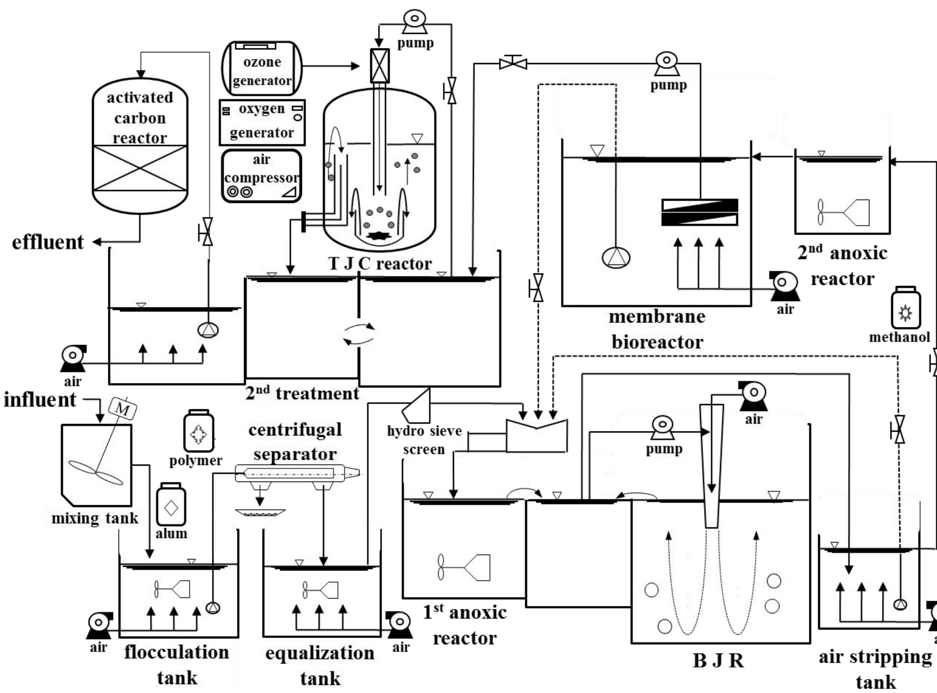

Fig. 1. Schematic diagram of the pilot-scale process of the modified 4-stage Bardenpho process including a BJR and the membrane method, a TJC reactor, and an activated carbon reactor

As a pre-treatment process, a mixture of the polymer (1.0 kg Cation Polymer per 3.0 m3 of influent wastewater) and aluminum sulfate (4.8 mL per 1.0 m3 of influent wastewater) were, then, added into the influent mixing tank, and processed through the centrifugal separator (liquid/solid) to remove the remaining coarse suspended solids. There was a small flocculation tank and a flow equalization tank before and after the separator, respectively. The piggery wastewater from the separator went, then, through a hydro sieve screen installed in front of the main process to remove a part of suspended solids from the influent piggery wastewater stream. BJR, a high-efficiency air-transferring device, was used in the first aerobic reactor, which was placed after the 1st anoxic reactor. The internal recycle flow from the air-stripping tank behind BJR to the 1st anoxic reactor was set up at the variable flow rates, which were controlled up to the nominal influent flow (Qin) to this pilot-scale plant to increase the efficiency of denitrification. The 2nd anoxic reactor was installed behind the BJR, followed by the membrane bioreactor. The return activated sludge flow from the membrane bioreactor to the 1st anoxic reactor was maintained to the nominal influent flow (i.e., 1 Qin) because the return sludge concentrations from secondary clarifiers range typically from 4,000 to 12,000 mg/L (WEF, 1998). TJC, a highly efficient ozone dissolution device, was used to treat wastewater.

BJR (Bio Jet Reactor) - The BJR process, a compact aerotropic biological process for treating the wastewater inside a reactor, provides consistent oxygen transfer coefficients by steadily producing microbubbles through a two-phase jet nozzle. The jet stream completely blends the wastewater with oxygen and steadily feeds the microorganisms, resulting in a high activity coefficient of the microorganisms.

Membrane Bioreactor - The membrane bioreactor has been gaining much attention in wastewater treatment as membrane filtration promises complete solid-liquid separation, prevents the failure of the biological systems due to biomass loss and/or bulking, and maintains a high number of mixed liquor suspended solids (MLSS) in the reactor (Ahn et al., 2003). A membrane made of polypropylene (Mitsubishi Co., Japan) was used in this study and is known to have a hydrophilic surface. The mean pore size of the membrane was 0.1 μm, and the width and height of the submerged membrane module were 400 and 1,200 mm, respectively.

TJC (Turbulent Jet Flow Contact) Reactor - This highly efficient ozone dissolution device removes solid matters and increases the ozone treatment efficiency. It converts the remaining non-biodegradable organics into biodegradable organics and oxidizes the odor and chromaticity.

Sample analysis method

The temperature, dissolved oxygen (DO), pH, and MLSS values of the modified 4-stage Bardenpho process were taken every single day during the five-month pilot-plant operation period. The temperature and concentration of MLSS were analyzed using MODEL 3100 (Insiteig), and the DO concentration and pH were analysed using YK2005WA (LUTRON). The concentrations of CODmn, CODcr, TN, NO3--N, NH4+-N, TP, and PO43--P were analyzed for the influent piggery wastewater to the 1st anoxic reactor, and for the effluents from the 1st anoxic, BJR, 2nd anoxic, membrane bioreactor, TJC and activated carbon reactor, every day in a week. The CODmn, CODcr, TN, NO3--N, NH4+-N, TP, and PO43--P concentrations were analyzed using the standard methods (Lenore et al., 1998).

Concentrations of raw piggery wastewater

The CODmn and CODcr concentrations of the raw piggery wastewater (into the influent-mixing tank) during the study period ranged from 10,710 to 13,120 mg/L and 60,600 to 82,665 mg/L, with averages of 11,985 and 70,474 mg/L, respectively. The range of the TN, NO3--N, and NH4+-N concentrations, and their averages, are also shown in Table 1.As shown in Table 1, the concentration of the raw piggery wastewater that was used in this study was 11 times higher (maximum) than the typical piggery wastewater concentration, and finding the suitable operating factors are considered important. During the operation period (April-August), the amount of influent wastewater was gradually increased from 1.0 to 8.0 m3 (wastewater from 2,000 pigs/day: 8.0 m3), and the operating factors (internal recycle flow rate from BJR to the 1st anoxic reactor and several ozone doses into the TJC reactor) were sought to satisfy the Korean effluent standards.

Table 1. Typical characteristics of the piggery wastewater in Gunsan, Jeollabukdo, South Korea

Constituent	Average Concentration	Concentration Range
CODmn (mg/L)	11,985	10,710 - 13,120
CODcr (mg/L)	70,474	60,600 - 82,665
TN (mg/L)	5,790	3,722 - 8,550
NO3--N (mg/L)	60	42 - 82
NH4+-N (mg/L)	4,356	2,808 - 5,535
TP (mg/L)	1,267	250 - 2,023
PO43--P (mg/L)	1,103	168 - 1,897
pH	8	7.3 - 8.4
Temperature (℃)	23.0	17.1 - 24.9

III. RESULT & DISCUSSION

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Fig. 2 shows the changes in the temperature, DO, pH, and MLSS concentrations via the modified 4-stage Bardenpho process (1st anoxic reactor, BJR, 2nd anoxic reactor, and membrane bioreactor) at the influent flow rate of 1-4 m3/day with an internal recycle flow rate of 0 Qin. As shown in Fig. 2a, the temperature of the BJR rapidly increased from 20.5 to 42℃ at the influent amount reached 3.0-3.5 m3/day. An aerobic reactor like BJR increases the reactor temperature to 45-50℃ due to the exothermic reaction of the microorganisms in the wastewater (Kim and Choi, 2002). Accordingly, as the influent amount of wastewater increased, the temperature of the reactor went up. The temperature of the 1st anoxic reactor was also increased by the internal recycle flow rate from the air-stripping tank behind the BJR. As excessive temperature increase inhibits the growth of microorganisms, the operation of the pilot-scale plant was stopped for 50 days, from May to the end of June, and a cooling tower was instead installed. As a result, the temperature of the air-stripping tank was kept between 30 and 34℃ during the operation period. The 1st and 2nd anoxic reactors were operated under the same conditions, but the temperature of the 2nd anoxic reactor was 2-4℃ higher than that of the 1st anoxic reactor because of the internal recycle flow rate. The growth of nitrification microorganisms is usually optimized at the DO concentration of the aerobic reactor is 4-7 mg/L (Wuhrman, 1963). To maximize the nitrification efficiency, the DO concentration of the BJR and the membrane bioreactor was operated within the range of 4-6 mg/L, as shown in Fig. 2c. In the case of the air-stripping tank, the DO concentration was kept between 0.0 and 2.2 mg/L to minimize the DO concentration of the influent to the 2nd anoxic reactor. Moreover, the pH of the BJR was operated within the range of 6.5-7.5 (Fig. 2b), according to the well-known nitrification pH range of 7.0-7.2 (U.S. EPA, 1993). The operation results showed a slight increase in the pH range from 7.5 to 7.9, caused by the alkalinity production from the denitrification reaction in the 1st anoxic reactor, which decreased from 7.9 to 6.4 in the BJR due to the alkalinity consumption during the nitrification reaction at the influent flow rate of 3.0-4.0 m3/day to the pilot-scale plant. As shown in Fig. 2d, the nitrification efficiency and MLSS concentration dropped rapidly at the pH level of the BJR dropped below 6.5. In this study, the pH level of the influent to the 1st anoxic reactor was kept over an average of 7.5. During the operation period, the average pH level of the 1st anoxic reactor was kept between 7.7 and 8.5, and the influent of the raw piggery wastewater was kept between 7.0 and 7.5. The alkalinity produced by denitrification was considered to have increased the pH level, but the pH level of the membrane bioreactor was between 7.6 and 8.2, the same as that of the 2nd anoxic reactor.

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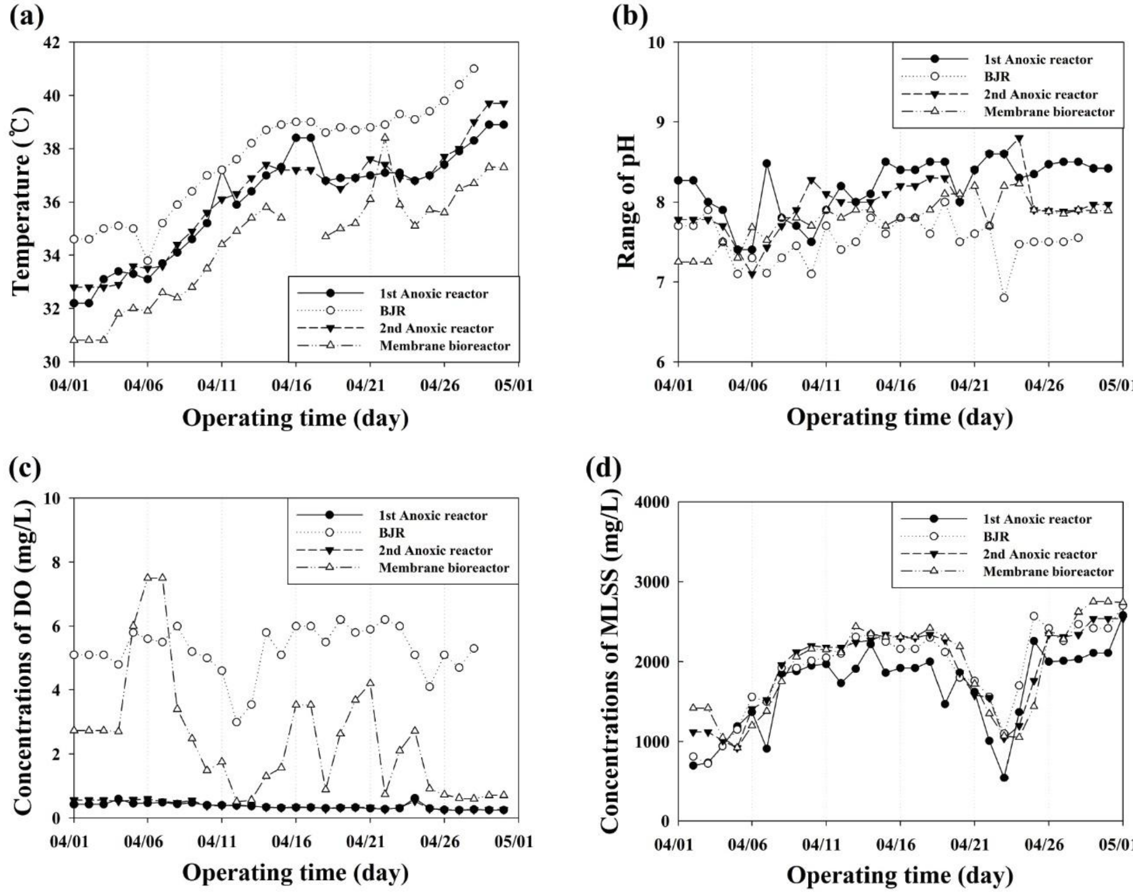

Fig. 2.Major constituents of the modified 4-stage Bardenpho process: (a) temperature; (b) pH range; (c) DO concentration profile; and (d) MLSS concentration profile with respect to the elapsed times (influent flow rate: 1-4 m3/day; internal recycle rate: 0 Qin)

As the MLSS concentration of the modified 4-stage Bardenpho process was important in determining the remaining time of the microorganisms and the capacity of the aerobicreactor, in this study, the MLSS concentration of the BJR and the membrane bioreactor was set and kept at 6,000 mg/L, considering the internal recycle flow rate, HRT, and STR. As mentioned earlier, the rapid change in the pH level and temperature in the BJR caused a significant decrease in the MLSS concentration of the modified 4-stage Bardenpho process, averaging below 1,000mg/L, but the MLSS concentration was kept by the cooling tower and by the replanting sludge(MLSS 12,000mg/L) from the nearby sewage treatment plant.Even though the MLSS concentration dropped to below 1,000mg/L due to the rapid temperature increase and pH decrease at the beginning of this study, the CODmn, CODcr, and TN removal efficiencies of the entire process were 99.8, 99.2, and 99.7%, respectively, which satisfied the Korean effluent standards (CODmn: 50 mg/L; TN: 60 mg/L). The high CODmn, CDOcr, and TN removal efficiencies were made possible by the minimal influent flow rate (1-4m3/day), which caused a low organism load into the pilot-scale plant, and by the dilution by the remaining clean water inside the reactors. As the increase in the influent amount increases the organism load and decreases the entire process's efficiency, in this study, the internal recycle flow rate of the modified 4-stage Bardenpho process and the input doses of ozone into the TJC reactor were varied to find the suitable operating coefficients that would satisfy the Korean effluent standards.

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According to the influent flow rateof 4-6m3/day(Phase 1) and 6-8m3/day (Phase 2) with internal recycle flow rate (3.5-6.5 Qin) and ozone doses (0.09-0.225 kg/hr), the changes in the CODmn, CODcr, and TN concentrations within

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two months of the continuous operation period were shown Fig. 3.Under the conditions of 4-6 m3/dayinfluent flow rate (Phase 1) with internal recycle flow rate of 3.5-5.0 Qin, the average CODmn, CODcr, and TN concentrations in the influent to the 1st anoxic reactor were 3,224, 19,699, and 2,965mg/L, respectively. The average finaleffluentconcentrations of CODmn, CODcr, and TN were 368, 743, and 111mg/L, respectively, showing exceptional average removal efficiencies of 88.6, 96.4, and 93.8%.The TN removal efficiency, however, showed a wide variation with the internal recycle flow rate of 3.5-4.5 Qin, and the CODmn and CODcr removal efficiencies were kept stable as shown in Fig. 4a. Moreover, as shown in Fig. 3c, the TN concentration rapidly increased at the end of Phase 1, even though the modified 4-stage Bardenpho process was operating properly with a less than 5 carbon/nitrogen (C/N) ration value. It was considered that the CODcr level in the influent included a large amount of biologically non-degradable materials, causing insufficient carbon elements for the denitrification reaction. Therefore, the CODcr/methanol ratio was shown to be 0.67 g MeOH/g CODcr (Lee, 2005), and the TN concentration was decreased by injecting diluted 99% methanol solution to the membrane bioreactor.

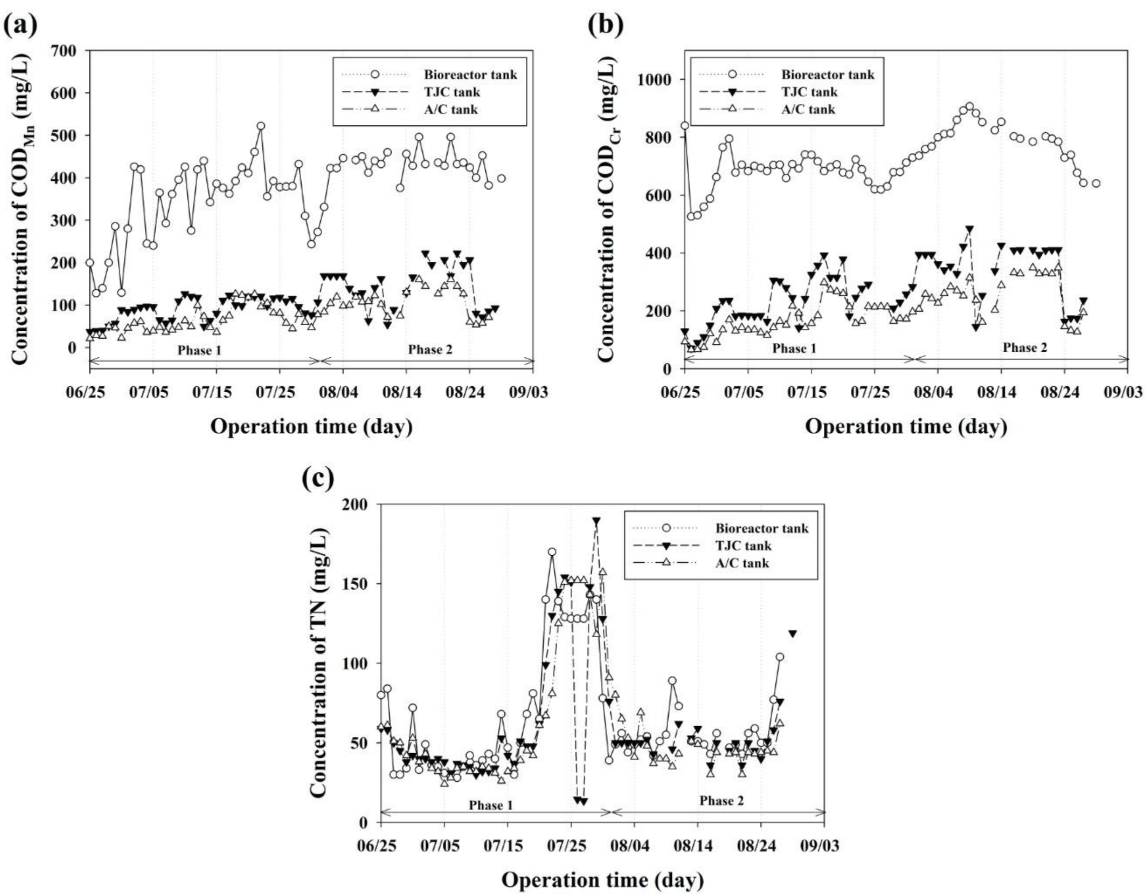

Fig. 3.Major constituents of the effluents of the modified 4-stage Bardenpho process, TJC reactor, and activated carbon reactor: (a) CODMnconcentration profile; (b) CODCr concentration profile; and (c) TN concentration profile with respect to the elapsed times for each phase (Phase 1- influent flow rate: 4-6 m3/day; internal recycle rate: 3.5-5.0 Qin; ozone dose: 0.225 kg/hr; Phase 2- influent flow rate: 6-8 m3/day; internal recycle rate: 4.5-6.5 Qin; ozone dose: 0.225 g/hr)

In this study, the variation of the ozone doses of 0.113-0.225 kg/hr were tested according to the variation of the nominal influent flow rate, to find the values that would satisfy the Korean effluent standards from the TJC reactor. The data of experiment analysed Pearson correlation between the injection of differences in ozone doses and removal efficiencies of CODmn and CODcr and also the one way ANOVA with Duncan post hoc comparison of the injection of differences in ozone doses and average removal efficiencies of CODmn and CODcr using SPSS 18.0

software. As a result, Pearson correlation coefficient (r) with p value less than 0.05 (p<.05) was negative correlation (CODmn : r = -0.592; CODcr : r = -0.613) that the removal efficiencies of CODmn and CODcr decrease as ozone doses increase. However, the F and p values of one way ANOVA with Duncan method for corporate statistics were higher than 0.05 (CODmn : F = 1.646, p = 0.118; CODcr : F = 1.438, p = 0.198) that means statistically nonsignificant between the ozone doses and the efficiencies of CODmn and CODcr. Therefore, the injection of ozone doses for removal of CODmn and CODcranalysed using the one sample t-test with 95% confidence interval was shown at Table 2. The operating conditions were 0.124 kg/hr ozone dose due to t-test was higher than other ozone doses (CODmn : t-test = 85.7; CODcr : t-test = 43.8). The CODmn and CODcr removal efficiencies of the activated carbon reactor decreased at most to 35% from 60% with the passage of the plant operating phases, but through the periodic backwash of the activated carbon reactor, the CODmn and CODcr removal efficiencieswere maintained within the range of 40-50%. Thus, the average CODmn, CODcr, and TN concentrations of the effluent from the TJC reactor were 98, 275, and 93 mg/L, and the average concentrations of the final effluent were 48, 157, and 72 mg/L. The CODmnconcentration satisfied the Korean effluent standard (50 mg/L), but the TN concentration exceeded the Korean effluent standard of 60 mg/L by 12 mg/L. Due to the lack of carbon resource, as mentioned earlier, the TN concentration rapidly increased, leading to an increase in the average value of the final effluent concentration. Therefore, under normal operating conditions, the results obtained in this study will satisfy the Korean effluent standards.

Table 2. Statistical analysis of the injection of differences in ozone doses and removal efficiencies of CODmn and CODcr

	Ozone doses (kg/hr)	Mean (%)	Standard Deviation (%)	Mean of 95% Confidence Interval (%)		t-test	F	p
				Lower	Upper			
CODmn	0.113	70.3	8.50	61.4	79.2	20.270*	1.646**	0.198**
	0.124	74.0	2.11	71.7	76.2	85.727*		
	0.135	66.0	10.3	55.2	76.8	15.712*		
	0.158	60.1	10.0	49.6	70.5	14.741*		
	0.180	53.0	7.55	45.1	60.9	17.195*		
	0.203	52.2	6.74	45.1	59.2	18.964*		
	0.225	52.7	7.97	44.3	61.0	16.177*		
CODcr	0.113	59.0	7.20	51.4	66.6	20.066*	1.438**	0.198**
	0.124	63.5	3.55	59.7	67.2	43.800*		
	0.135	58.2	9.12	48.6	67.8	15.633*		
	0.158	60.1	9.98	49.6	70.5	14.741*		
	0.180	53.0	7.55	45.1	60.9	17.195*		
	0.203	52.2	6.74	45.1	59.2	18.964*		
	0.225	52.7	7.97	44.3	61.0	16.177*		

*p<.001, **p<.05

To purify the piggery wastewater in Phase 2(6-8 m3/day), the internal recycle flow rate was increased to 5.0-6.5Qin. The average CODmn, CODcr, and TN concentrations of the influent to the 1st anoxic reactor were 3,311, 19,124, and 3,021 mg/L, respectively, and the average concentrations of the effluent from the membrane bioreactor were 452, 814, and 62 mg/L. According to the change in the internal recycle flow rate as shown in Fig. 4a, the TN removal efficiency in the previous study was 93-94%, which satisfied the Korean effluent standard, but the removal efficiency of CODcr rapidly decreased as the internal recycle flow rate increased from 5.0 Qinto 6.5 Qin. As a result, the internal recycle flow rate was considered 4.5-5.0 Qin. The average finalCODmn and CODcr concentrations of the effluent from the activecarbon reactor were 113 and 363 mg/L, respectively, which satisfied the Korean effluent standards. Therefore, the ozone dose of the TJC reactor gradually increased from 0.158 to 0.225 kg/hr, but the CODmn and CODcr removal efficiencies were 60-70%, showing no significant change from those when operating with 0.124kg/hr (Table 2). As machine breakdown was feared in this study due to overload, it was decided that the machine be operated with only 0.124 kg/hr ozone dose.

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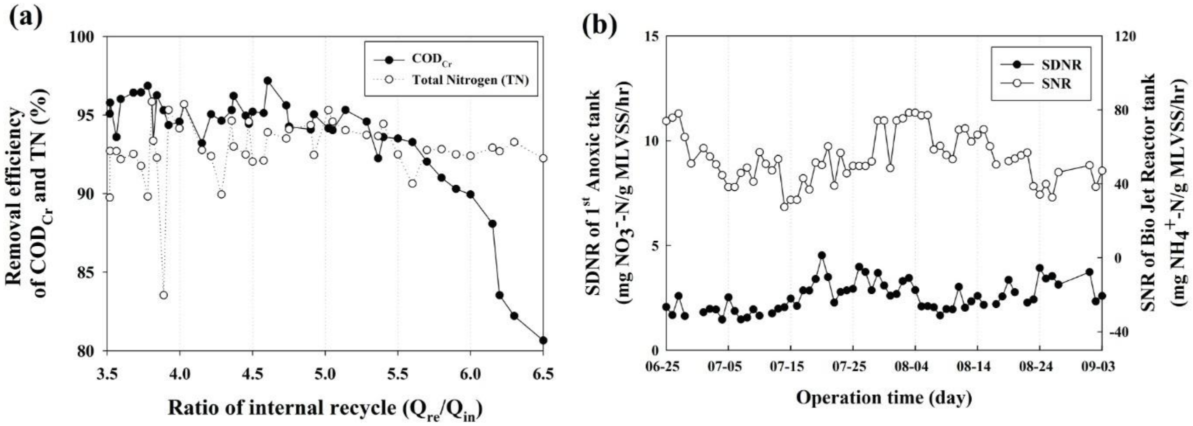

Fig. 4.Removal efficiency and SDNR and SNR with respect to the internal recycle rate: (a) removal efficiencies of CODCr and TN by the modified 4-stage Bardenpho process and (b) SDNRs in the 1st anoxic reactor and SNRs in the BJR.

In addition, the experimental results of the internal recycle flow rate were calculated through the specific denitrificaiton rates (SDNRs) of the 1stanoxic reactor and the specific nitrification rates (SNRs) of the BJR. The SDNRs ranged from 1.08 to 3.54 mg NO3--N/gMLVSS·hr of the 1stanoxicreactor in this study, as shown Fig 4 b, which had no big difference from that in the typicalpiggery wastewater treatment plant (Research papers of U.S. EPA (1993) and Whang (2004) suggested 0.625-2.5 mg NO3--N/gMLVSS·hr and 1.604 mg NO3--N/gMLVSS·hr, respectively). The SNRsofthe BJR in this study ranged from 27.5 to 78.4 mg NH4+-N/g MLVSS·hr (Fig. 4 b), which were 10-20 times higher than that in the typical biological nutrient removal plant (Research papers targeted onwastewatertreatment plant for biological nutrient removal (Randall et al., 1992), 7 C/N ration (Cho et al.,2001)and HASP process (Yoon et al.,2007) suggested 1.78-6.90 mg NH4+-N/g MLVSS·hr, 3.96 mg NH4+-N/g MLVSS·hr, 4.03 mgNH4+-N/g MLVSS·hr). Therefore, thesuitable internal recycle flow rate of 4.5-5.0 Qin was used to treat the influent piggery wastewater, which is considered more effective fornitrification by the BJR. The concentration of NH4+-N in this study showed higher than the typical piggery wastewater, so high SDNRs were forecasted, but maintaining high MLSS concentration and low NO3--N concentration (that means the NO3--N concentration in the internal recycle flow from BJR was diluted by raw wastewater) obtained these results.

Fig. 5a shows the changes in the TP concentration during the study period, with an influent flow rate of 4-6 m3/day in Phase 1 and 6-8 m3/day in Phase 2 of the pilot-scale plant operation. The average TP concentration of the raw piggery wastewater (into the influent-mixing tank) was 1,755 mg/L at the influent flow rate was 4-6 m3/day (Phase 1), which was about five times higher than that of the typicalpiggery wastewater.Moreover, the influent of the 1st anoxic reactor was 98.5 mg/L. The TP concentration of the final effluent of the activated carbon reactor was 39 mg/L, which showed an exceptionally high removal efficiency of 97.7% during the operation period. It should be noted that the TP concentration far exceeded the Korean effluent standard of 8 mg/L. To satisfy the TP concentration standard, the “alum” injection concentration was increased to 10 mL alum/m3 from 4.0 mL alum/m3. However, the pH of the BJR decreased to below 6.5when more than 6.0 mL alum/m3 was injected, as shown in Fig. 5b, which might have caused the decrease of the MLSS concentration mentioned earlier, resulting inmaintaining the alum injection concentration at 4.0-5.0 mL alum/m3. Moreover, the average TP concentration of the raw piggery wastewater was 390 mg/L at the influent flow rate was 6-8 m3/day (Phase 2), similar to the TP concentration in the typicalpiggery wastewater, and the influent of the 1st anoxic reactor was 47.5 mg/L. The average TP concentration of the final effluent of the activated carbon reactor was 7mg/L, which met the Korean effluent standard.

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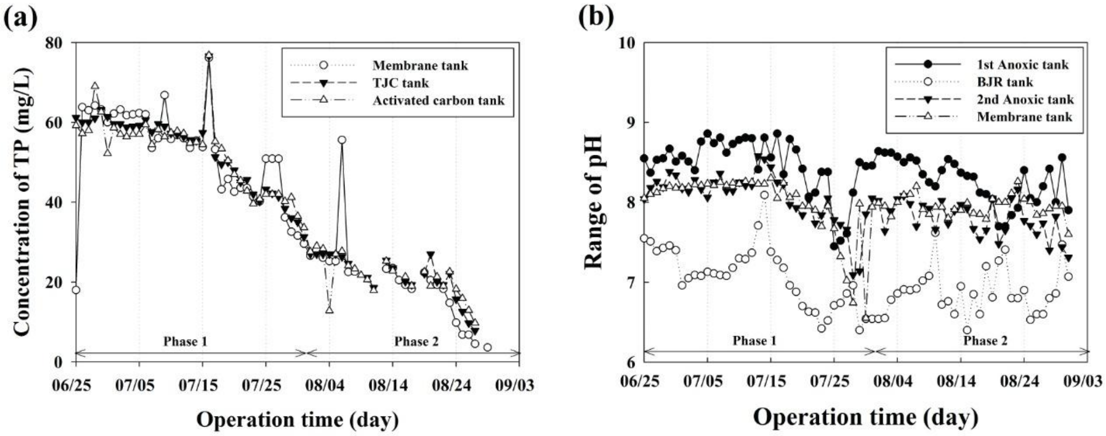

Fig. 5.Major constituents of the pilot-scale plant process for each phase: 4-6 m3/day influent flow rate with internal recycle rate of 3.5-5.0 Qin for Phase 1, and 6-8 m3/day influent flow rate with internal recycle rate of 4.5-6.5 Qin for Phase 2. (a) TP concentration profile of the effluents from the modified 4-stage Bardenpho process, TJC reactor, and activated carbon reactor; and (b) pH range in the 1st anoxic reactor, BJR, 2nd anoxic reactor, and membrane bioreactor with respect to the elapsed times.

Through this study and results shown above, the suitable operating parameters of the subject pilot-scale plant to satisfy the Korean effluent standards were found to be influent flow rate of 4-6m3/day, internal recycle flow rate 4.0-5.0 Qin and ozone dose of 0.124 kg/hr. Fig. 6 shows 95% confidence interval estimates of the CODMn, CODCr, TN, NO3--N, NH4+-N, TP, and PO43--P concentrations in the influent of raw piggery wastewater and of the effluentsfrom the BJR, membrane bioreactor, TJC reactor, and activecarbon reactor.The concentrations of CODMn and CODCr with 95% confidence interval in the raw piggery wastewater were 11,580±1,893.3 and 65,322±9729.7 mg/L, as shown in Fig. 6a. The CODMn and CODCr concentrations (with 95% confidence interval) of the effluent from the modified 4-stage Bardenpho process (membrane bioreactor) were 362.2±26.2, 694.5±13.9 mg/L and also effluent from the TJC reactor via ozone doses were 95.8±8.1, 254.5±26.1 mg/L, respectively. The CODMn and CODCr concentrations (with 95% confidence interval) of the final effluent from the active carbon reactor were 46±7.5 and 155±17.3 mg/L and the final concentration of CODMn met Korean effluent standard of 50 mg/L (The Korean effluent standard has not stipulate of CODCr). The concentrations with 95% confidence interval of TN, NO3--N, and NH4+-N in the raw piggery wastewater were 5,372±609.7, 83±15.8, and 4,455±487.0 mg/L, respectively (Fig. 6b).The TN and NH4+-N concentrations of the effluent from the BJR were decreased to 482±43.2 and 9±4.4 mg/L, but the NO3--N concentration was increased to 135±8.1 mg/L (about 62.7% increase) due to the nitrification process of NH4+-N. The TN, NO3--N, and NH4+-N concentrations (with 95% confidence interval) of the effluent from the modified 4-stage Bardenpho process were 70.2±7.1, 50.5±6.2, and 2.4±0.9 mg/L and the final effluent from the active carbon reactor dropped to 53±3.7, 29±4.0, and 3±1.1 mg/L, respectively, and the effluent concentration of TN satisfied the Korean effluent standard of 60 mg/L. The concentrations of TP and PO43--P with 95% confidence interval in the raw piggery wastewater were 1,213±260.5 and 929±195.4 mg/L, respectively, at the influent flow rate of 4-6 m3/day with internal recycle rate of 4.0-5.0 Qin. The TP and PO43--P concentrations (with 95 confidence interval) of the effluent to the modified 4-stage Bardenpho process were 51.4±4.1 and 47.8±4.0 mg/L and the final effluent from the activated carbon reactor were 49.7±2.9 and 45.2±3.3 mg/L, respectively. The final concentration of TP was not satisfied with the Korean effluent standard due to the fivefold higher concentration of the sample influent compared to that of the typicalpiggery wastewater. Therefore, in the case of operating the plant with raw piggery wastewater conditions used in this study, CODMn, CODCr and TN could be treated to satisfy the Korean effluent standards, and an additional process, such as a chemical treatment, is required to satisfy the TP concentration standard.

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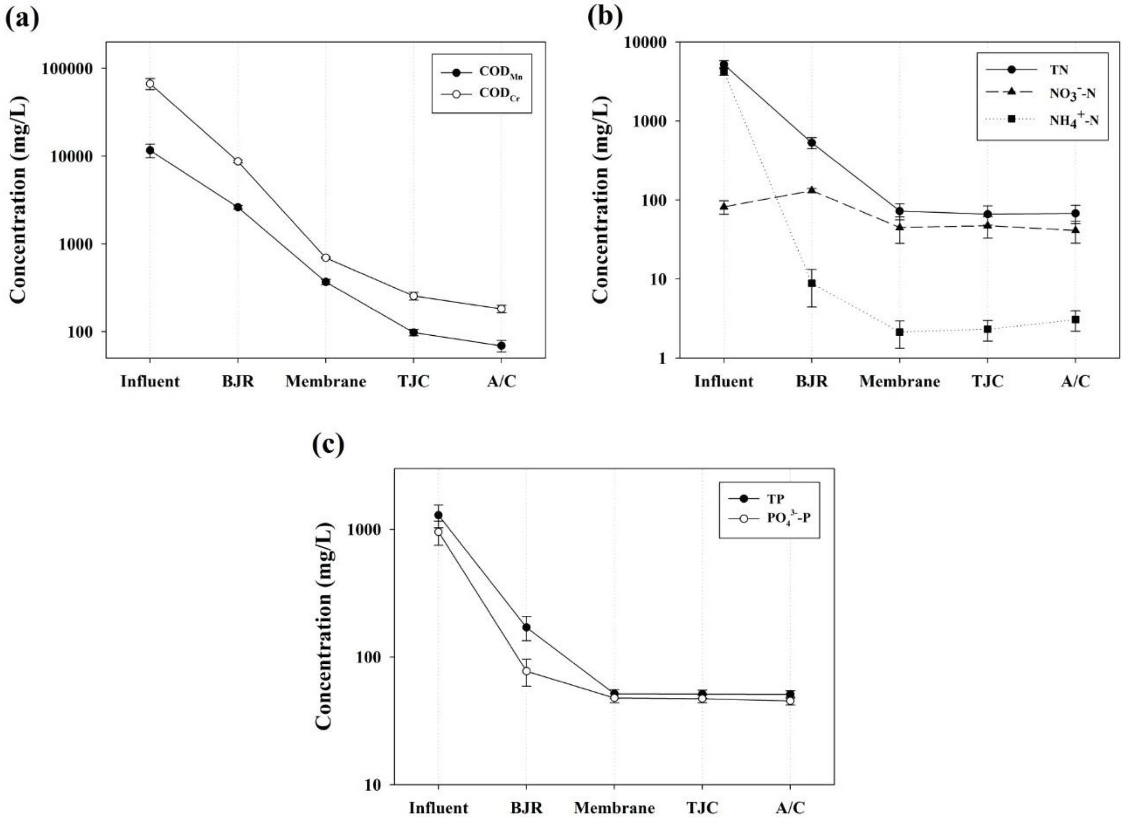

Fig. 6. Major constituents of the influent of raw piggery wastewater and of the effluents of the BJR, membrane bioreactor, TJC reactor, and activated carbon reactor: (a) concentration profiles of CODMn and CODCr; (b) concentration profiles of TN, NO3--N, and NH4+-N; and (c) concentration profiles of TP and PO43--P during all the elapsed times. Error bars, 95% confidence intervals.

IV. CONCLUSION

Under thesuitable operational conditionsof the influent flow rate of 4-6 m3/day, internal recycle flow rateof 4.5-5.0 Qinand ozone doseof 0.124 kg/hr, the average concentrations of CDOMn, CODCr, and TN in the final effluent were 48, 158, and 56 mg/L, respectively, which met the Korean effluent standards.The average TP concentration was 51 mg/L, which far exceeded the Korean effluent standard of 8 mg/L, thus necessitating an additional follow-up process. Treating the typicalpiggery wastewater to keep the TP concentration in line with the required standard, however, should not pose any problem.

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