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EVALUATION OF *IN-SITU* EXTERNAL CARBON SOURCES FOR HIGH PERFORMANCE OF DENITRIFICATION IN GRAIN DISTILLERY WASTEWATER TREATMENT PLANT

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Abstract : The influent organic carbon-to-nitrogen (C/N) ratio of 0.45-3.27 g BOD_5/g TKN for the extended aeration process at the grain distillery wastewater treatment plant in P distillery company was lower than the theoretical value of 3.71 g BOD_5/g TKN for successful denitrification due to anaerobic pre-treatment when it is considered to be retrofitted to biological nutrient removal system. The impure alcohol produced during the alcohol distillation as a by-product and the raw wastewater decanted with centrifugal decanter (CDE) were evaluated as *in-situ* external carbon sources for successful denitrification. The high specific denitrification rates (K_D) of 254 mgN/gVSS/day and 215 mgN/gVSS/day were observed when the impure alcohol and the CDE characterized as high content of organics and low content of nitrogen were used as external carbon sources. Although higher specific denitrifiation rate for the impure alcohol was achieved, the production rate of the impure alcohol is 0.33~0.67 L/m^3 based on the grain distillery wastewater which is short for high performance of nitrogen removal. The CDE was designed to use as a main external carbon source while the impure alcohol was designed to use for flushing of residual oxidized nitrogen. After investigation of denitrification rate equivalent to the CDE dosing by respirometry, the optimum C/N ratio for the CDE was 3.0-4.5 g BOD_5/g NO_3-N. The Bardenpho (4 stage) system was operated with dosing of the CDE and the impure alcohol in the pre-anoxic chamber and the post-anoxic chamber with the dosing rates of 5.7% (v/v) of the CDE based on influent flowrate (1,427 mg BOD_5/L influent/day) and 0.025% (v/v) of the impure alcohol based on influent flowrate (157.5 mg BOD_5/L influent/day). After dosing of the CDE in influent, the BOD_5/TKN ratio was increased from 2.55 to 4.10. High denitrification efficiency of 90.1% was achieved with maintenance of high BOD_5 removal efficiency of 99.4%.

Key Words : external carbon source, denitrification, nitrogen removal, C/N ratio, grain distillery wastewater

INTRODUCTION

High-strength organic wastewater treatment system is generally configured with anaerobic pre-treatment followed by aerobic treatment process. Due to the high removal efficiency of organics in anaerobic process, the imbalance between carbon and nitrogen concentration in the influent of biological nitrogen removal process is generally occurred. The nitrogen concentrated wastewater in maize starch production plant is taken into consideration to show the influence of anaerobic pretreatment on the following aerobic stage. It can be shown that the relation of organic carbon-to-nitrogen (C/N) ratio is moved into a range smaller than 100:33 by the anaerobic treatment, which is not favorable for nitrogen elimination in the aerobic stage.[1)]

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Generally, the influent BOD_5 (Biochemical Oxygen Demand)/TKN (Total Kjeldahl Nitrogen) ratio of the aerobic process in grain distillery wastewater treatment plant is less than the theoretical value of 3.71 g BOD_5/g TKN required for successful denitrification. The BOD_5/TKN ratio is also varied severely depending on the raw materials used for alcohol fermentation. Due to the relatively low biodegradable carbon content in the influent, a supplementary carbon source must be added artificially to facilitate denitrification performance in the grain distillery wastewater treatment plant.[2)] The finding of suitable *in-situ* external carbon source is one of the key factors to solve the problem of unbalanced C/N ratio for successful nitrogen removal in grain distillery wastewater treatment plant.

There is wasted-carbonaceous liquor which has been burnt off in grain distillery plant. The wasted liquor called as an impure alcohol is produced as a by-product during the distillation of alcohol as a final product. The organic concentration of the impure alcohol is very high while nitrogen concentration is low, relatively. As another carbon source in the grain distillery plants, the raw wastewater decanted with centrifugal decanter (CDE) that is the influent of the anaerobic process can be used to make up a deficit of an impure alcohol. The evaluation of the CDE and impure alcohol as *in-situ* external carbon sources was conducted in this study.

MATERIALS AND METHODS

Installation and Operation of Bardenpho System

A plexi-glass reactor with the effective volume of 24.0 L which was scaled down with the rate of 1/113,167 from the full-scale aerobic process in P grain distillery wastewater treatment plant operated with 6 days of hydraulic retention time (HRT) was installed in the laboratory. The system configuration called as Bardenpho 4 stage system is shown in Figure 1. Influent flowrate was 4.0 L/day with the internal recirculation (from the pre-oxic chamber to the pre-anoxic chamber) ratio of 300% based on influent flowrate. Sludge recycle from the settler to the pre-anoxic chamber was conducted with the ratio of 200% based on influent flowrate, continuously. Diffuser and bubbler were installed at oxic chamber. Impeller-type mixers with variable speed controller were installed at the anoxic chambers. The pH in nitrification chamber was controlled, if necessary, with automatic pH controller (Chemdet pH meter/controller®, Model No. 5652-00, Cole-Parmer Instrument Co., Chicago, IL) using 0.1 N NaOH. Metering pump (Masterflex®, Model No. 7521-40, Cole-Parmer Instrument Co., Chicago, IL) was used for influent feeding, sludge recycle, and recirculation of nitrified mixed liquor. A mixer with variable speed controller and a magnetic stirrer were installed at the influent reservoir made of glass for equalization of feed. The feed for Bardenpho system was sampled once a week from the effluent port of the DAF (Dissolved Air Flotation) process (coagulant: aluminum sulfate) which followed the anaerobic filter and anaerobic contact process in P distillery plant.

Dissolved Oxygen (DO), Temperature, and pH were measured daily, and alkalinity, MLSS (Mixed Liquor Suspended Solids), and MLVSS (Mixed Liquor Volatile Suspended Solids) were

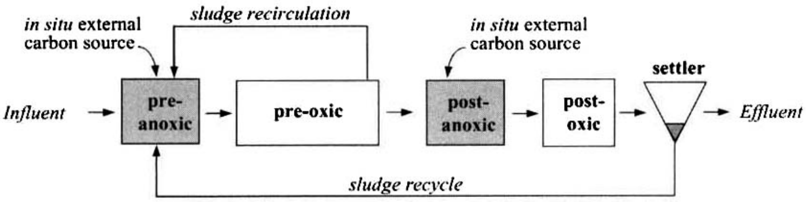

Figure 1. System configuration of Bardenpho system.

analyzed intermittently. At steady state, effluent BOD_5 (Biochemical Oxygen Demand), $TCOD_{Mn}$ (Total Chemical Oxygen Demand tested with per manganese method), $SCOD_{Mn}$ (Soluble Chemical Oxygen Demand tested with per manganese method), $TCOD_{cr}$ (Total Chemical Oxygen Demand tested with dichromate method), $SCOD_{cr}$ (Soluble Chemical Oxygen Demand tested with dichromate method), SS (Suspended Solids), TKN (Total Kjeldahl Nitrogen), Org-N (Organic-nitrogen), NH_4-N (Ammonium-nitrogen), NO_2-N (Nitrite-nitrogen), NO_3-N (Nitrate-nitrogen), and TP (Total Phosphorus) were analyzed. The specific oxygen uptake rate, nitrification rate, and denitrification rate were also measured.

Analytical Methods

As a tool for evaluation of *in-situ* external carbon sources, denitrification rate was measured using respirometer (CHALLENGE ANR-100, Challenge Environmental System, Inc.). The specifications of the respirometer is as follows; minimum flowrate detection < 0.16 mL, maximum flow capacity 1,500 mL/hr, calibration precision < 2% Cv, sensitivity < 0.16 mL, and measurement precision < 3% Cv. To increase the measuring precision, the flow cells and reaction vessels were maintained at a constant temperature of 25°C in an incubator. The measurement of respirometric denitrification rate was followed the procedure reported by Kim *et al.*.[3] The analytical methods for water quality analyses are listed in Table 1.

RESULTS AND DISCUSSION

Influent C/N Ratio of the Extended Aeration Process in Grain Distillery Plant

The grain distillery wastewater selected as a feed in this study has high content of organics and nitrogen. In grain distillery industries, tapioca, naked barley, barley, corn, potato, and sweet potato, etc. are used as raw materials for alcohol fermentation. These raw materials are used individually or with mixture for alcohol production. The characteristics such as C/N ratio of the raw wastewater and the influent of the

Table 1. Analytical methods and references

Parameter	Analytical methods	References
pH	TOA pH meter, model HM-7E	-
ORP	Orion ORP meter, model 525A	-
DO	YSI Oxygen meter, model 51B	-
Alkalinity	Titration method (to pH 4.5)	APHA *et al.*[4] 2320 B
$TCOD_{cr}$	Closed reflux, Titrimetric method	APHA *et al.*[4] 5220 C
$SCOD_{cr}$	Closed reflux, Titrimetric method (filtered with 0.45µm GF/C)	APHA *et al.*[4] 5220 C
$TCOD_{Mn}$	Permanganate method	Korean Ministry of Environment[5] Chapter 4, Section 6
$SCOD_{Mn}$	Permanganate method (filtered with 0.45µm GF/C)	Korean Ministry of Environment[5] Chapter 4, Section 6
BOD_5	Azide modification method	APHA *et al.*[4] 4500-O C
TSS	Dried at 103~105°C	APHA *et al.*[4] 2540 D
VSS	Ignited at 550°C	APHA *et al.*[4] 2540 E
Org-N	Macro-Kjeldahl method	APHA *et al.*[4] 4500-N_{org} B
NH_4-N	Titrimetric method	APHA *et al.*[4] 4500-NH_3 E
NO_2-N	Ion chromatographic method	APHA *et al.*[4] 4500-NO_2^- C
NO_3-N	Ion chromatographic method	APHA *et al.*[4] 4500-NO_3^- C
TP	Stannous chloride method (sulfuric acid-nitric acid digestion)	APHA *et al.*[4] 4500-P D

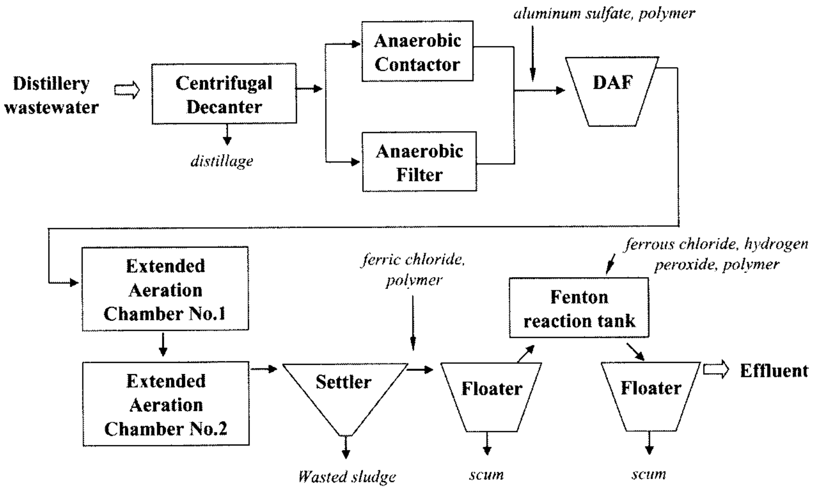

Figure 2. Grain distillery wastewater treatment plant in P distillery company.

aerobic process are fluctuated according to the raw materials used for fermentation and their mixing ratio. The schematic diagram of the grin distillery wastewater treatment plant in P distillery company is shown in Figure 2.

Due to the high removal efficiency of organics (without removal of nitrogen compounds) in the anaerobic process the C/N ratio in the influent of the extended aeration process in P distillery company is much lower than the optimum range for completion of denitrification. When tapioca is used as a raw material the C/N (BOD_5/TKN) ratio is in the range of 0.45~2.06 (average 1.19). When the mixed raw materials of tapioca-naked barley and tapioca-barley are used the C/N ratio is in the range of 0.99~3.27 (average 2.13) and 1.26~2.02 (average 1.51), respectively. Table 2 shows the characteristics of the influent of the extended aeration process.

Characteristics of *in-situ* External Carbon Sources

The characteristics of the CDE and the impure alcohol are seriously fluctuated and thoroughly depend on the raw materials used for fermentation and their mixing ratio. The typical

Table 2. Influent characteristics of the extended aeration process in P distillery company

	Raw materials for fermentation of alcohol			
Parameter	Tapioca	Tapioca + Naked-barley	Tapioca + Barley	Tapioca + Corn
pH	7.15~8.25	7.00~7.10	7.10~8.25	7.1~7.4
Alkalinity as $CaCO_3$	2,500~3,000 (2,736)	-	2,200~3,400 (2,625)	-
BOD_5	568~988 (689)	900~1,980 (1,440)	1,003~1,353 (1,115)	-
TCOD	1,964~2,990 (2,462)	3,019~3,484 (3,252)	1,947~3,832 (3,163)	2,920~3,806 (3,363)
SCOD	1,520~1,943 (1,670)	1,978~2,303 (2,141)	1,403~2,533 (1,973)	1,280~2,140 (1,710)
SS	700~1,160 (932)	-	1,030~2,167 (1,377)	-
NH_4-N	247~633 (452)	445~549 (497)	434~791 (636)	165
Org-N	92~686 (210)	160~361 (261)	63~198 (132)	245~260 (253)
NO_x-N	ND	ND	ND	ND
TP	37~66 (53)	42~142 (92)	31~92 (59)	164
BOD_5/TKN	0.45~2.06 (1.19)	0.99~3.27 (2.13)	1.26~2.02 (1.51)	-

Note: average values are given in parentheses, units are mg/L except pH and BOD_5/TKN

Table 3. Characteristics of in-situ external carbon sources

Parameter	Impure alcohol	CDE(1)
pH	11.9	3.1~4.4
Alkalinity as $CaCO_3$	2,340	-
BOD_5	630,000	15,000~65,000
TCOD	122,900	40,700~173,000
SCOD	117,800	25,600~137,000
Org-N	104	620~1,410
NH_4-N	11.9	64~262
NO_2-N	13.2	ND
NO_3-N	55.3	ND
TSS	235	3,500~24,800
VSS	210	3,300~21,000

Note: units are mg/L except pH
(1) raw distillery wastewater decanted with centrifugal decanter

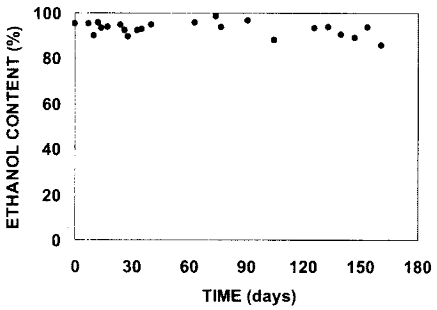

Figure 3. Ethanol content in the impure alcohol.

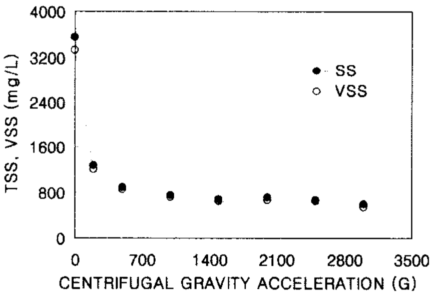

Figure 4. Solid reduction of the CDE according to the increasing of centrifugal G.

characteristics of these *in-situ* external carbon sources are summarized in Table 3. The BOD_5 concentration of the impure alcohol and the CDE are 630,000 mg/L and 15,000~65,000 mg/L, respectively. The impure alcohol and the CDE have also high content of ethanol. Ethanol contents of the CDE and the impure alcohol are 0.01~0.04% (v/v) and 86~99% (v/v), respectively. Figure 3 shows the daily variation of ethanol content in the impure alcohol. The total suspended solids (TSS) concentration of the impure alcohol is 135 mg/L. However, the TSS concentration of the CDE is 3,500~24,800 mg/L which is required to be decanted before dosing to the aerobic process. The TSS reduction of the CDE according to the variation of centrifugal G (gravity acceleration) was tested and plotted in Figure 4. The test result showed that the solid-liquid separation efficiency is getting lower after 500 G. The centrifugal gravity of 500 G is, therefore, required for economic solid-liquid separation.

Evaluation of in-situ External Carbon Sources

For evaluation of the *in-situ* external carbon sources of the CDE and the impure alcohol, the specific denitrification rates (K_D) were measured and compared with the rates when other external carbon sources were used. The biomass seeded for this test was taken from the pre-anoxic chamber of Bardenpho system acclimated with the grain distillery wastewater and operated with 30 days of solids retention time (SRT) at 25°C in the laboratory.

The K_D for various external carbon sources are shown in Figure 5. These values are comparable to that of control group without external carbon source (used the influent of the aerobic process as carbon source). When the impure alcohol and the CDE are used as external carbon sources, the K_D values are 254 mgN/gVSS/day and 215 mg N/gVSS/day, respectively. The rate of 142 mgN/gVSS/day when methanol is dosed as an external carbon source is lower than 210~320 mgN/gVSS/day[6] measured at 25°C using the same carbon source. The lower rate obtained in this study attributes that the seed sludge incorporated for this test was sampled from Bardenpho system operated with long SRT of 20 days. The K_D values using the impure alcohol and the CDE were 8.3 and 7.0 times greater than the rates of control group (33 mgN/gVSS/day). The K_D value of 33 mgN/gVSS

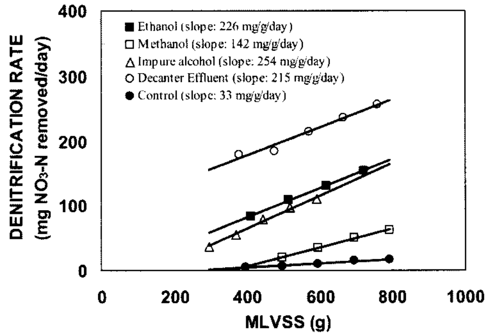

Figure 5. Specific denitrification rates for various carbon sources.

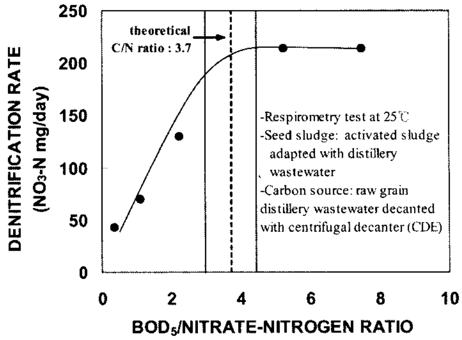

Figure 6. Optimum BOD$_5$/nitrate-nitrogen ratio for denitrification with an external carbon source of the raw grain distillery wastewater decanted with centrifugal decanter (CDE).

/day using internal carbon source is in the range of 30~110 mgN/gVSS/day measured at 15~27°C[6] and 17~48 mgN/gVSS/day measured at 12~20°C.[6] It is also similar with 34 mgN/gVSS/day measured at 20°C[7] tested with the seed sludge under endogeneous metabolism. The K_D of 43 mgN/gVSS/day[8] in BNR process configured with anaerobic-anoxic-oxic chambers and fed with sewage was also similar with the value obtained in this study.

When ethanol was used as an external carbon source K_D was 226 mgN/gVSS/day which was the similar level of the CDE and the impure alcohol containing high content of ethanol. Denitrifiers adapted with the grain distillery wastewater can uptake ethanol more easily than methanol as an electron donor. The K_D values with various external carbon sources measured for this study are relatively lower than the values of 270~300 mgN/gVSS/day[9] when acetic acid was used as an external carbon source.

Denitrification Rate Equivalent to CDE Dosing

Over dosing of external carbon source causes over loading of organics in biological organics and nitrogen removal system, and results in deterioration of effluent quality. Carley and Mavinic[10] operated a single-sludge nitrification-denitrification system fed with sanitary landfill leachate having high-ammonia (170~240 mg/L) and low BOD$_5$ (10~60 mg/L). They used methanol, acetate, glucose, and brewery waste as external carbon sources with different C/N ratios. All four carbon sources supported denitrification, but the glucose-supplemented system was erratic and ultimately failed at a COD-to-NOx ratio of about 23:1. Figure 6 shows the optimum C/N ratio at the pre-anoxic chamber for denitrification with the main external carbon source of the CDE.

The denitrification rate (nitrate-nitrogen removal rate) is increased according to increase the C/N (BOD$_5$/nitrate-nitrogen) ratio ranged from 0.4 to 4.0. The maximum rate is maintained at the BOD$_5$/nitrate-nitrogen ratio of above 4.0. The BOD$_5$/nitrate-nitrogen ratio is, therefore, required to maintain 3.0~4.5 as a design dosing rate of the CDE as an external carbon source for the pre-denitrification camber. The dosing of 5.7% (v/v) of the CDE based on influent flowrate (1,427 mg BOD$_5$/L influent/day) was conducted in the pre-anoxic chamber. Table 4 shows the increase of C/N ratio with the designed dosing rate of the CDE and the influent when three kinds of raw materials were used for alcohol fermentation. After addition of CDE in feed, the BOD$_5$/TKN ratios could be maintained at 3.0, 3.6, and 3.2 when tapioca, tapioca and naked-barley, and tapioca and barley were used as raw materials. The impure alcohol was also provided in the post-anoxic chamber with the rate of 0.025% (v/v) based on influent flowrate (157.5 mg BOD$_5$/L influent/day) in order to sweep

Table 4. C/N ratios with designed dosing rate of the raw grain distillery wastewater decanted with centrifugal decanter (CDE) and influent flowrate

Parameters	Raw materials for fermentation of alcohol		
	Tapioca	Tapioca+Naked-barley	Tapioca+Barley
Influent of the extended aeration process in field			
Flowrate (L/day)	3.784	3.784	3.784
BOD_5 (mg/L)(1)	689	1,440	1,115
TKN (mg/L)(1)	662	758	768
BOD_5/TKN ratio	1.0	1.9	1.5
External carbon source of CDE			
Dosing rate of CDE (L/day)	0.216	0.216	0.216
BOD_5 (mg/L)(2)	25,000	25,000	25,000
TKN (mg/L)	560	560	560
BOD_5/TKN ratio	44.7	44.7	44.7
After control of C/N ratio			
BOD_5 (mg/L)	2002	2712	2405
TKN (mg/L)	656	747	757
BOD_5/TKN ratio	3.0	3.6	3.2

(1) Average value, (2) Typical value,

away the residual oxidized nitrogen.

Denitrification performances in Bardenpho system The laboratory-scale Bardenpho system was operated for simultaneous removal of organics and nitrogen from the grain distillery wastewater. During the operation of the system, the raw materials used for manufacturing of alcohol were mixture of tapioca and naked-barley with the mixing ratio of about 1:1.

The reactor temperature was maintained at 27~29°C at steady state. The MLSS concentration was in the range of 3,978~4,567 mg/L for all chambers of Bardenpho system. Relatively low fraction of MLVSS against MLSS of 0.71~0.74 was observed due to the long SRT of 21(28 days. The DO was maintained at 2.0~3.5 mg/L and 0.2~0.4 mg/L at the oxic chamber and the anoxic chamber, respectively. The pH was in the range of 8.1~8.7 through all chambers. The oxidation-reduction potential (ORP) was 90-115 mV in the oxic chambers, -74 mV in the pre-anoxic chamber, and 31 mV in the post-anoxic chamber. The alkalinity of 1,220~1,740 mg/L as $CaCO_3$ was similar at all chambers. The influent BOD_5/TKN ratio of Bardenpho system was 2.55 when external carbon sources were not dosed. The CDE was dosed in the pre-anoxic chamber for pre-denitrification, while the impure alcohol produced during the distillation of alcohol was dosed in the post-anoxic chamber for post-denitrification. Dosing rates of the CDE and the impure alcohol were 216 mL/day (5.7% v/v based on influent flowrate; 1,427 mg BOD_5/L influent/day) and 1.0 mL/day (0.025% v/v based on influent flowrate; 157.5 mg BOD_5/L influent/day), respectively. After dosing of the CDE, the BOD_5/TKN ratio of influent was increased to 4.1.

At steady state, the BOD_5/MLVSS loading of 0.06~0.08 day^{-1}, and the volumetric BOD_5 and TKN loading rates of 0.245 g/L/day and 0.091 g/L/day were maintained. The alkalinity/TKN ratio of influent was 3.4. The operation performances of the laboratory-scale Bardenpho system are summarized in Table 5. High BOD_5 removal efficiency of 98.6~99.8% (average 99.4%) was observed while considerable portion of hard-to-biodegradable organics ($SCOD_{cr}$ 349~449 mg/L) is remained in effluent without biological oxidation. The hard-to-biodegradable organics is

Table 5. Operation performances of Bardenpho system

Item	Feed (mg/L)$^{(1)}$	CDE (mg/L)	After control of C/N ratio (mg/L)	Effluent (mg/L)	Removal efficiency (%)
pH	8.3	4.4	-	8.34~8.51	-
Alkalinity (as $CaCO_3$)	1,880	-	-	1,288~1,460	-
BOD_5	1,390	17,500	2,260	4.5~31.5 (13)	98.6~99.8 (99.4)
$TCOD_{Mn}$	1,206	13,467	1,868	235~321 (278)	82.8~87.4 (85.1)
$SCOD_{Mn}$	789	9,233	1,245	200~280 (245)	85.0~89.3 (86.9)
$TCOD_{cr}$	3,367	31,488	4,886	368~594 (489)	87.8~92.5 (90.0)
$SCOD_{cr}$	2,778	18,423	3,623	349~449 (423)	90.8~92.9 (91.4)
NH_4-N	226	63	217	3.3~7.9 (5.8)	-
Org-N	320	497	329	28.3~59.8 (43.3)	81.8~91.4 (86.8)
NO_2-N	ND	ND	ND	ND	-
NO_3-N	ND	ND	ND	20.5~33.2 (26.1)	-
TKN	546	560	546	36.2~63.7 (49.1)	88.3~93.4 (91.0)
TN	546	560	546	56.7~92.6 (75.2)	83.1~89.6 (86.2)
BOD_5/TKN	2.55	31.3	4.1	-	-

(1) The effluent of the dissolved air floatation (DAF) process followed by the extended aeration process in the grain distillery wastewater treatment plant.

Note: average values are given in parentheses.

associated with color causing pigments. Alkaline pH during processing and high temperatures used for crystallization of sugars lead to the formation of caramels, melanoidins, and a variety of sugar composition products, which in turn, polymerize to form yellowish color.[11] The high total nitrogen (TN) removal efficiency of 83.1~89.6% was obtained when nitrogenous mixed liquor is recirculated with the recirculation ratio of 3 times based on influent flowrate. High nitrification and denitrification efficiencies of 88.3~94.3% (average 92.3%) and 76.1~96.0% (average 90.1%) were also observed. The averaged volumetric denitrification rate in the system was 227.4 (180.0~258.9) mg NO_X-N removed/L/day when oxidized-nitrogen loading rate was 195.5~308.5 mg NO_X-N/L/day. In the system, the volumetric nitrification rate was observed in the range of 122.1~206.2 mg TKN/L/day.

The behaviors of ammonium-nitrogen, nitrite-nitrogen, and nitrate-nitrogen in the individual chambers are shown in Figure 7. Influent ammonium-nitrogen is diluted with the nitrogenous mixed liquor recirculated from the second pre-oxic chamber and is rapidly nitrified in the following first pre-oxic chamber. The nitrate-nitrogen recirculated from the second pre-oxic chamber is denitrified completely in the pre-anoxic chamber in which the CDE is dosed as an external carbon source. The nitrate-nitrogen produced in the first and second pre-oxic chambers is partly denitrified in the post-anoxic chamber. It seems that the low denitrification efficiency in the post-anoxic chamber causes that the impure alcohol is not used effectively as carbon source for denitrification due to dosing of the impure alcohol by manual once a day. The K_D measured by respirometry were 166.8 and 123.3 mg NO_3-N removed/gVSS/day in the pre-anoxic and the post-anoxic chambers, respectively, when methanol (This carbon source was used in order to compare the K_D with the values reported by other researchers) was used as an external carbon source. The rates were similar with the values of 40~150 mg/gVSS/day reported by U.S. EPA.[12]. The rates were also in the range of 120~900 mg/gVSS/day (at 20°C) measured at the pre-anoxic chamber when methanol was used as an external carbon source.[6] Carley and Mavinic[10] reported the specific denitrification rate of

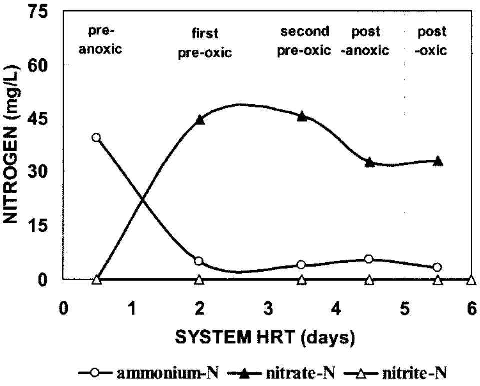

Figure 7. Behaviors of nitrogen in individual chambers.

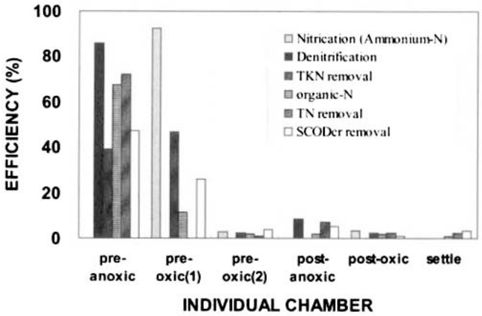

Figure 8. Distribution of treatment efficiencies in individual chambers.

70~240 mg/gVSS/day (at COD-to-NOx: 6.2:1) when single-sludge system fed with sanitary landfill leachate was operated using methanol as external carbon source.

The distribution of nitrification, denitrification, TKN (filterable) removal, organic-nitrogen (filterable) removal, TN (filterable) removal, and $SCOD_{cr}$ removal efficiencies in the individual chambers of Bardenpho system is illustrated in Figure 8. Based on TKN (filterable) level in the individual chambers, unexpected TKN removal of 39.2% is observed in the pre-anoxic chamber due to high concentration of particulate organic-nitrogen (calculated from total TKN) in feed. In the first pre-oxic chamber, 46.5% of TKN is oxidized while high nitrification efficiency of ammonium-nitrogen (92.6%) is achieved. The low oxidation efficiency of TKN in the first pre-oxic chamber attributes to the low removal efficiency of organic-nitrogen. The denitrification efficiency in the pre-anoxic chamber is 85.9% while the efficiency in the post-anoxic chamber is 8.4%. When oxidized nitrogen is denitrified, the carbon source is required for an electron donor. The organics ($SCOD_{cr}$) removal efficiency of 47.3% in the pre-anoxic chamber is the greatest among the individual chambers.

Through this investigation, the CDE and the impure alcohol which can be provided easily in the place are useful for successful denitrification in the grain distillery wastewater treatment plant.

CONCLUSIONS

The impure alcohol and the raw wastewater decanted with centrifugal decanter (CDE), which were characterized as high and low in contents of organics and nitrogen and could be provided in the place, were evaluated as alternative carbon sources for successful denitrification in the grain distillery wastewater treatment plant.

The high specific denitrification rate (K_D) of 254 mgN/gVSS/day and 215 mgN/gVSS/day for the impure alcohol and the CDE were observed. Although both of the impure alcohol and the CDE are readily useable in-situ carbon sources, the CDE is suitable for use as a main carbon source for pre-denitrification due to low production rate of the impure alcohol. The optimum C/N ratio for the CDE was 3.0~4.5 g BOD_5/g NO_3-N. High denitrification efficiency of 90.1% was achieved with maintenance of high BOD_5 removal efficiency of 99.4% at the influent BOD_5/TKN ratio of 4.1 when the CDE and the impure alcohol were introduced to the pre-anoxic chamber and the post-anoxic chamber of Bardenpho 4 stage system.

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