Water Reuse Technology Trains for Medium-level Water and Industrial Cooling Water in South Korea

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Abstract
Wastewater is considered as stable and substantial amount of alternative water resource. In case of South Korea, it is known that 73.2 percents of supplied water discharge 16 million m^3/day of treated effluent from municipal wastewater treatment plants. Calculation simply tells that 0.58 billion m^3/year can be available if only 10 percent of wastewater could be reused. In this study, a pilot MBR was applied for the reclaimed water of flush toilet water from sewage. The effluent of MBR satisfied the medium level water regulation in South Korean except total coliform and residual chlorine. The chlorine disinfection could easily satisfy the others. The residual chlorine in the regulation could limit the various alternated disinfectants. Further research is required for the alternative disinfections such as UV and ozone in the water reuse strategy considering economic aspects. Water quality standards were suggested for the purpose of industrial cooling water generation from wastewater in South Korea. The item of turbidity, suspended solids, DOC, T-N, T-P, alkalinity, pH, hardness and conductivity were suggested. The results of membrane technology trains with MBR-RO and MBR-NF suggested the NF had great potential for the water reclamation and reuse.

Keywords
Water reuse, MBR, reverse osmosis, nanofiltration, reuse standards

INTRODUCTION

Water is one of the most essential components in natural lives and basic resource for all industrial activities. However, there are many serious problems related to water shortages over the world. Many solutions to secure water resources have been recommended such as dam, ground water, desalination of seawater and so on. Especially, water reuse from wastewater has been suggested as one of promising solutions for alternative water resource in the future.

Wastewater is considered as stable and substantial amount of alternative water resource. In case of South Korea, it is known that 73.2 percents of supplied water discharge 16 million m^3/day of treated effluent from municipal wastewater treatment plants (Korea Ministry of Environment, 2002). Calculation simply tells that 0.58 billion m^3/year can be available if only 10 percent of wastewater could be reused.

Medium-level water is defined as the reclaimed water between tab water and waste water in South Korea. It is applied where low/medium water quality is necessary such as flush toilet water, sprinkle water (road washing, construction site), washing water (car wash, cleaning), recreation water (artificial pond and waterfall fountain), and so on.

Water quality for the industrial usage depends on the specific industry, which determine reuse processes. The membrane process seems to be most predominant technology for the various industrial reuse; textile (Ciardelli *et al.*, 2000), semiconductor (You *et al.*, 2001), fertilize (Karabelas *et al.*, 2001), scooter and motorbike (Marcucci and Tognotti, 2001) and so on. For example, NEWater project in Singapore has been supplied recycled water to wafer fabrication plants and other industries

for non-potable use. The total capacity of the 3 NEWater factories is 92,000 m^3/day in 2004. The main process of the factories is reverse osmosis after the microfiltration pretreatment.

One of the most promising water reuse technology is the combination process of biological treatment and membrane separation, what we call "membrane bioreactor (MBR)". MBR has gained considerable attention due to their potential advantages over those of conventional biological treatment processes. In comparison with the activated sludge system, the MBR has merits with respect to the complete removal of solids from an effluent, superior nutrient and organic removals, a high loading rate capability, low/zero sludge production and small land requirement.

In case of low/medium water quality is required, only MBR directly or MBR with disinfection process could be applied for the water reuse. If the higher water quality is necessary, reverse osmosis or nanofiltration membrane could be considered after the MBR. In this study, a pilot MBR operation was applied for medium-level flush toilet water and technology train with membrane technologies and Korean water quality standards regulations were suggested for the purpose of industrial cooling water generation from wastewater.

MATERIALS AND METHODS

Medium-level Water Regulation

Table 1 shows the regulation for the medium-level water in Korea Water Code (Korea Ministry of Construction and Transportation, 2001). The medium-level water regulation in South Korea is divided by the usage; flush toilet, sprinkle, recreation, washing and restricts nine water quality items.

Table 1. The regulation for the medium-level water reuse in South Korea (Revised in 2001)

Item	Flush Toilet Water	Sprinkle Water	Recreation Water	Washing Water
Total coliform (colony/mL)	N.D.	N.D.	N.D.	N.D
Residual chlorine (mg/L)	> 0.2	> 0.2	-	>0.2
Appearance	Don't be unpleasant	Don't be unpleasant	Don't be unpleasant	Don't be unpleasant
Turbidity (NTU)	< 2	< 2	< 2	< 2
BOD (mg/L)	< 10	< 10	< 10	< 10
Odor	Don't be unpleasant	Don't be unpleasant	Don't be unpleasant	Don't be unpleasant
pH	5.8-8.5	5.8-8.5	5.8-8.5	5.8-8.5
Color (Hazen)	< 20	-	-	< 20
COD_{Mn} (mg/L)	< 20	< 20	< 20	< 20

Industrial Water Reuse Regulation for Cooling Water

Water reuse in the industrial usage depends on specific processes and types of industry. Most of industrial water is used as cooling water, water for boiler, material transportation and process operation. There are no regulations yet for the reuse of industrial cooling water in South Korea. For the cooling water, the followings are considered to determine specific water quality standards.

No scale on the surface of heat transfer.
No cause corrosion with metals in the equipment.
No contain nutrients that enhance microorganism growth.
No produce excess foam.

Table 5 shows the suggested water quality standards for the reuse of industrial cooling water. The scale and corrosion are reciprocal notions. In the scale forming conditions, the corrosion can be prevented and vise versa. The conditions of scale and corrosion can be calculated by Langelier

Saturation Index (LSI; Langelier, 1936). It is closely related with alkalinity, hardness and pH. Also, the growth of microorganism can cause the corrosion. Even though water quality is satisfied the suggested regulations, it is suggested that evaluate the saturation conditions for the prevention of scale and corrosion. The dissolved organic carbon (DOC), total nitrogen (T-N) and total phosphorus (T-P) were suggested to prevent microorganism growth and foaming problem.

Pilot Operations for Medium-level Water of Flush Toilet Water

The pilot submerged MBR (PSMBR) was operated with sewage from a dormitory of GIST. The effective volume of the aeration reactor was 2.44 m^3, with a submerged microfiltration membrane module. Table 3 shows the summary of PSMBR. Permeate was produced at a rate of 10.5 $L/m^2 \cdot hr$, in the constant flux mode. Intermittent suction was applied; 7 minutes suction, 3 minutes release. The chemical cleaning was conducted when the trans-membrane pressure leached 200 mmHg, which was achieved using NaOCl. The pH was controlled within the range of 6.8-7.5 with the use of $NaHCO_3$. The denitrification reactor was operated with an external carbon source (methanol, COD/Nitrogen=5). The effective volume of the denitrification reactor was 0.87 m^3. The circulation flow from the aeration reactor to denitrification reactor was 3 times higher than that of influent flow. Post disinfection tests of chlorine (3 ppm as NaOCl), ultraviolet lamp (254 nm wavelength, 4W, 1 minutes) and ozone (1.5 ppm) were applied with the effluent of PSMBR.

Table 3. The summary of PSMBR operation conditions.

Item	Conditions
Membrane	Microfiltration
Membrane Manufacturer	Pure-Envitech co., Ltd, Korea
Membrane Material	Polyvinylidene fluoride (PVDF)
Pore Size	0.4 μm
Module Type	Plate and Frame
Flux	10.5 $L/m^2 \cdot hr$
Operation Mode	7 min Suction, 3 min Release
Hydraulic Retention Time (HRT)	7.85 hours
Solids Retention Time (SRT)	20 day
Chemical Cleaning	When TMP > 200 mmHg

Pilot Operations for Industrial Cooling Water

Figure 1 represents the technology train for the production of industrial cooling water from reclamation of municipal wastewater. Two types of module; reverse osmosis (RO) and nanofiltration (NF) connected parallel series were applied with the effluent of MBR as influent. Table 4 shows the speciation of the modules. Both two membranes are commercialized ones offered from Saehan Industries Inc., Korea. MF cartridge filters with pore size of 10μm were equipped prior to RO and NF membranes to prevent the accident from MBR. The capacity of each module was 21.6 ton/day and recoveries of the system were 15 and 18 % for RO and NF membranes, respectively. In addition, temperature was controlled by cooling system. The system maintenance was conducted by membrane cleaning such as hydraulic washing, chemical cleaning with NaOH and citric acid. Hydraulic washing was performed in every week, and chemical cleaning and MF cartridge filter change were conducted in several times during 1 year operation based on water production rate from daily monitoring data.

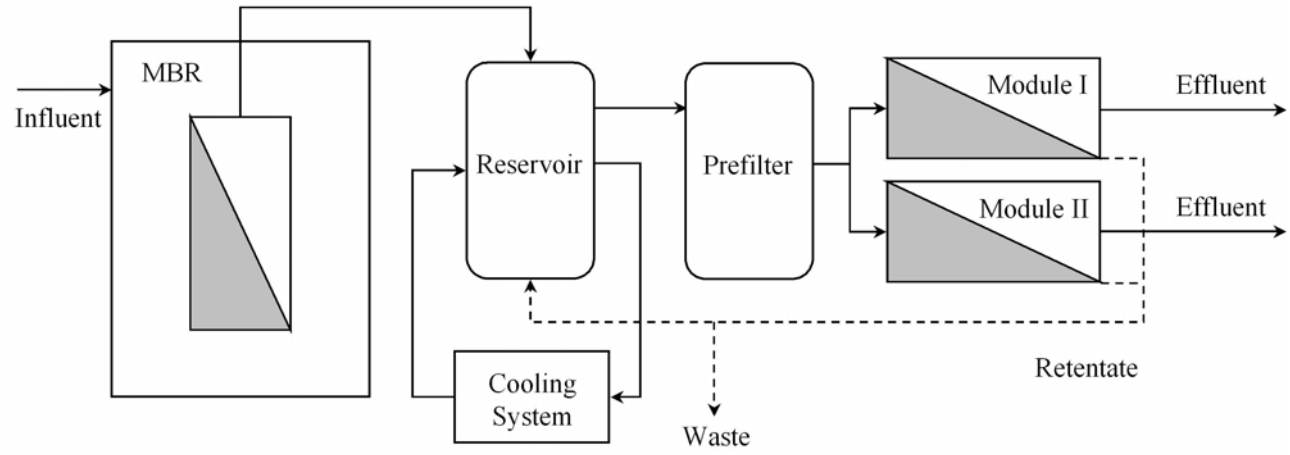

Figure 1. Schematic of membrane pilot water reuse system.

Table 4. The speciation of membrane modules for the industrial cooling water

Item	Module 1	Module 2
Membrane	RO (RE4040-FL)	NF (NE4040-90, RF)
Manufacturer	Saehan Industries Inc., Korea	
Material	MPD base polyamide TFC	
Salt Rejection	99.5% (NaCl)	85~90% ($MgSO_4$) 40% (NaCl)
Pore Size (MWCO)	-	200~500 Da
Module Type	Spiral-wound	
Dimension	Length 40inch/ diameter 4inch, 2modules in parallel	
Water Production	2.9 ton/day	3.6 ton/day
System Recovery	16%	20%
System Temperature	18~23℃	

Analysis

The alkalinity, hardness and suspended solids were measured following the Standard Methods (APHA, 1998). The pH measurement was performed using a pH meter (model 205A, Thermo, USA). DOC (Dissolved Organic Matter), conductivity and turbidity were measured by Total Organic Carbon Analyzer (Sievers 820, USA), CyberScan (Human Science Con 200, Korea) and Turbidimeter (DRT-15CE, HF Scientific, Inc., USA), respectively. The COD chromium (Chemical Oxygen Demand), total nitrogen (T-N) and total phosphorous (T-P) were analyzed using a Humas kit (KIT, Humas, Korea).

RESULTS AND DISCUSSION

Pilot Operations for Medium-level Water of Flush Toilet Water

Table 4 shows the operational results of PSMBR. The BOD and COD manganese methods (KME, 1995) were replaced by COD chromium method. Usually, the values of BOD and COD manganese are lower than those of COD chromium because the chromium is strong oxidant. The effluent of MBR satisfied all the regulation except total coliform and residual chlorine. Theoretically, coliform should be rejected by microfiltration of 0.4μm pore size, considering the normal size about 1μm of bacteria. However, the effluent pipelines could be contaminated in the pilot system and there were possibilities of smaller size bacteria and larger membrane pore size than it was expected.

The item of residual chlorine is the question at issue. The chlorine is strong, cheap and prevail disinfectant in the world. However, the regulation of residual chlorine limits the various alternated disinfectants. The ultraviolet lamp (UV) and ozone was applied as alternative disinfection for water reuse system. They showed good disinfection capability, but have the problems of residual and economic consideration. In case of UV, installing another UV system just before the reuse tap can solve the residual problem. Further research is required for the disinfection systems in the water reuse strategy considering economic aspects.

Table 4. The operation results of PSMBR for the flush toilet water (average values)

Item	Regulation	MBR effluent	Chlorine	UV	Ozone
Total coliform (colony/mL)	N.D.	Detected	N.D.	N.D.	N.D.
Residual chlorine (mg/L)	> 0.2	N.D	0.39	N.D	N.D
Appearance	Don't be unpleasant	Not unpleasant	Not unpleasant	Not unpleasant	Not unpleasant
Turbidity (NTU)	< 2	0.2* <	0.18	0.18	0.23
BOD (mg/L)	< 10	-	-	-	-
Odor	Don't be unpleasant	Not unpleasant	Not unpleasant	Not unpleasant	Not unpleasant
PH	5.8-8.5	7.49	7.88	7.43	7.68
Color (Hazen)	< 20		-	-	-
COD_{Mn} (mg/L)	< 20	< 20	-	-	-
COD_{cr} (mg/L)	-	8.3	8.8	12.3	9.0

Pilot Operations for Industrial Cooling Water

Table 5 shows the operational results of membrane pilot system. Both of modules 1 and 2 satisfied the suggested water quality. Except DOC and T-P, all of the items were satisfied by MBR treatment. However, very low alkalinity and hardness of reclaimed water (around pH 6.5) might make corrosion when it met metals. It was suggested that the addition of NaOH or aeration to remove CO_2 were required to increase pH. The results showed the nanofiltration had great potential for the water reclamation and reuse instead of reverse osmosis.

Table 5. The operation results of membrane pilot water reuse system for industrial cooling water

Item	Suggestions	Influent	After MBR	Module 1	Module 2
Turbidity (NTU) (mg/L)	5	>50	0.08±0.01	0.03±0.02	0.06±0.02
SS (mg/L)	5	79±38	N.D.	N.D.	N.D.
DOC (mg/L)	0.5	43±1.22	7.36±0.90	0.28±0.08	0.28±0.15
T-N (mg/L)	10	36.5±0.90	8.3±0.89	<0.5*	<0.5*
T-P (mg/L)	1	3.61±0.61	2.15±0.71	0.01±0.01	0.03±0.01
Alkalinity (mg/L as $CaCO_3$)	100	172±0.11	61.7±20.3	9.33±2.30	10.7±2.08
pH	6.5-8.5	7.49±0.11	7.46±0.30	6.61±0.25	6.49±0.07
Hardness (mg/L)	400	44.7±2.30	44.0±1.73	2.33±0.60	2.33±0.60
Conductivity (μS/cm)	3,000	-	636±134	19.7±10.4	32.8±24.7

±: Standard deviation, N.D.: Not detected, *Below detection limit.

CONCLUSIONS

In this study, a pilot MBR was applied for the reclaimed water of flush toilet water from sewage. The effluent of MBR satisfied the medium level water regulation in South Korean except total coliform and residual chlorine. The chlorine disinfection could easily satisfy the others.

The residual chlorine in the regulation limits the various alternated disinfectants. Further research is required for the alternative disinfections such as UV and ozone in the water reuse strategy considering economic aspects.

Water quality standards were suggested for the purpose of industrial cooling water generation from wastewater in South Korea. The item of turbidity, suspended solids, DOC, T-N, T-P, alkalinity, pH, hardness and conductivity were suggested.

The results of membrane technology trains with MBR-RO and MBR-NF suggested the NF had great potential for the water reclamation and reuse.

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