

Sustainable Water Recycling System Using Membrane and Advanced Oxidation Process in Complex

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If wastewater can be reused, both the demand for water and the amount of wastewater can be reduced. Wastewater originating from all sources in residential homes other than the toilet is defined as graywater. In this study, graywater was treated through a microfiltration membrane and oxidation process, and the efficiency of the removal of color, turbidity, COD, suspended solids, *E.coli*, *total coliform*, *Salmonella* and *Staphylococcus* was studied. The treated graywater was reused for purposes other than drinking and bathing, such as fire fighting, water for plants, water for the toilet and car washing. The pH of the treated graywater was 7-7.7. The efficiency of the removal of each factor with the micro filtration membrane was as follows: color (98%), turbidity (99%), COD (99%), suspended solids (99%), *E.coli*, *total coliform*, *Salmonella* and *Staphylococcus* (30%). Following the membrane filtration process, the efficiency of the removal of each factor using the oxidation process was as follows: color (100%), turbidity (99%), COD (99%), suspended solids (99%), *E.coli*, *total coliform*, *Salmonella* and *Staphylococcus* (100%). The quantity and quality of the graywater was sufficient to establish a sustainable water circulation system for the reuse of residential graywater. The A₂O-MF membrane-AOP system showed good treatment capacity. The A₂O-MF membrane system could effectively remove COD, turbidity, color, and suspended solids, while AOP was effective for the removal of *E.coli*, *total coliform*, *Salmonella* and *Staphylococcus*.

Keywords: graywater, A₂O-MFmembrane, advanced oxidation process, residential complex,

1. Introduction

Most countries lack sufficient regulations or specific guidelines on the reuse of graywater, as frequently the health risks are overestimated while the environmental risks are underestimated. With the development of industry, urbanization and the diversification of lifestyles, there is currently a high demand for water. In addition to this, with the recent construction of many large-scale multi-unit complexes, there have been problems relating to the increased demand for water and the increased amount of wastewater. Indoor domestic water demand (excluding garden irrigation and other external uses) in developed countries usually ranges between 36 and 66 m³/y per capita [1,3,6,7], comprising 30-70% of the total urban water demand. Aside from a minor quantity, most consumed water is transformed into wastewater, which can be classified into two major categories:

- Graywater: originating from all household “water-generating” appliances except for toilets, comprising 60-70% of the in-house water demand.
- Blackwater: originating from toilets, comprising 30-40% of the in-house water demand.

In urban areas, the most feasible graywater reuse option is water for toilet flushing, which can reduce individual in-house net water demand by 40-60%. If this practice becomes widespread, a reduction of up to 10-25% in urban water demand can be achieved. However, graywater can be quite polluted

and thus may pose health risks, as well as having negative aesthetic factors (such as an offensive odor and color) and environmental effects [1,2,5,8]. Consequently, the reuse of graywater requires highly efficient and reliable conveyance, storage and treatment systems. A wide variety of treatment systems have been reported in the literature and these vary greatly in complexity and degree of treatment [1,5,10-13]. Ramon et al., (2004) studied graywater treatment using ultrafiltration membrane and nanofiltration membrane. Garland et al., (2004) studied graywater treatment using hydroponic plants. Gross et al., (2006) studied graywater treatment using a vertical flow constructed wetland. However, all studies have concluded that additional disinfection is required for the reuse of graywater. Even when reused for purposes other than drinking and bathing, such as fire fighting, water for plants, water for the toilet and car washing, a certain standard of reused water quality must be satisfied. In Korea, the quality standard for reused water is as follows: COD of less than 20 mg/L, turbidity of less than 2 NTU, color less than 20 Pt-Co, suspended solids less than 5 mg/L, and zero *E.coli*. The objectives of this study are (1) evaluation of the A₂O-MF(Micro Filtration)membrane-Advanced Oxidation Process(AOP) system for graywater treatment in complex, (2) analysis of the pathogenic micro organisms which can cause health risk in graywater.

2. Materials and method

2.1 Sampling

The area of each apartment in the complex studied was 55.45m², and 170 apartments were studied in total. The apartment complex studied is located at Bundang-Gu, Kyungki-Do, Korea.

2.2 Analysis methods

pH was determined using a glass electrode pH meter (Orion, Model 525A). COD_{Cr}, turbidity and color were measured using the HACH digestion vials (HACH, DR/2012). Measurement of MLSS followed the 2540D method in Standard Methods for the Examination of Water and Wastewater, 20th edition, Clescerl et al., (1998). *E.coli* and *Coliform* was estimated using CHROMagarTM ECC. *Salmonella* was estimated using Desoxycholate citrate agar. *Staphylococcus* was estimated using Mannitol salt agar. Microbial community was analyzed using DNA extraction & PCR. According to the results of PCR, T-RFLP was used. To detect *E.Coli*, *Coliform*, *Salmonella* and *Staphylococcus*, the following method was used: First, the specimen was inoculated directly on the surface of the medium. Second, the plate was incubated at 35 ± 2 °C for 18-24hours. To analyze the microbial community, the Powersoil DNA Isolation Kit (MO BIO) was used for DNA extraction, and MJ mini (BioRad) was used for the detection of PCR. According to results of PCR detection, T-RFLP was performed. Amplification was performed with a pair of universal bacterial primers

(27F[5'AGAGTTTGATCATGGCTCAG3'] and 1492R[TACGGTTACCTTGTTACGACTT3'] for T-RFLP (27F-FAM 5'-FAM-AGA])

2.3 A₂O-MF membrane-AOP system

2.3.1 A₂O-MF membrane

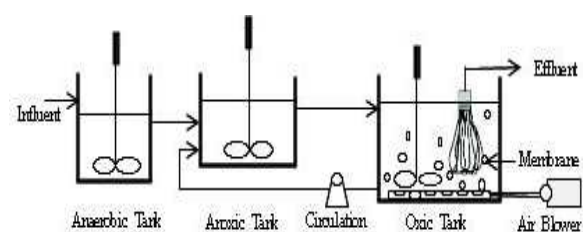


Figure 1: Schematic diagram of A₂O-MF membrane system

Fig. 1 represents the experimental system used in this study, which consists of an anaerobic bioreactor, an anoxic bioreactor and an aerobic submerged MF membrane. The volume of the anaerobic bioreactor is 2.5 L. The anoxic bioreactor and oxic bioreactor are connected by circular columns with working volumes of 2L and 8L, respectively. The mixed liquid of the oxic bioreactor was returned to the anoxic bioreactor with an internal recycle ratio of 1.5Q by a pump. During the 60 days of the experiment, total HRT was maintained at 6 h (1.2 h/anaerobic reactor, 0.96 h/anoxic reactor, 3.84 h/oxic reactor). F/M ratio was maintained at 0.11-0.17 kgBOD/MLVSS/d. MLSS was maintained at 4500 mg/L. The module type of membrane was hollow fiber, and its pore size was 0.4 μm. The material was polyvinyl difluoride. The operation type of membrane was the submerged type, and urethane & epoxy resin was used for bonding. The

model name of the membrane was SuperMAK®.

2.3.2 Advanced oxidation process

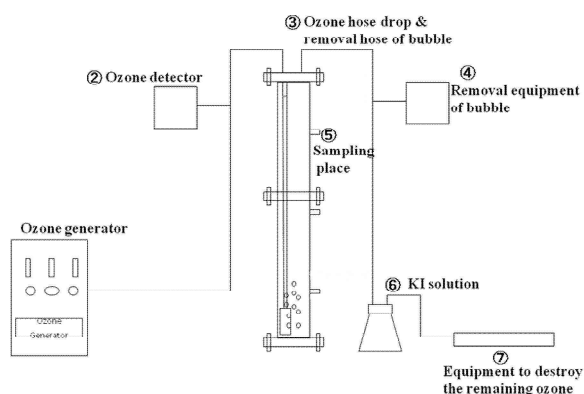


Figure 2: Schematic diagram of ozone experimental system

Fig. 2 shows the ozone experimental system used in this study. This process was performed after the graywater had passed through the A₂O-MF membrane system. The ozone reactor consisted of an ozone generator, an ozone detector, an acrylic reactor, equipment for the removal of bubbles, KI solution, and equipment to destroy the remaining ozone. Ozone contacted the graywater in the cylindrical type batch reactor by bubbling. The reactor was made of acrylic to avoid oxidation and to allow the easy observation of changes in the water's color. A ceramic air distributor was located at the bottom of the cylinder, and the ozone bubble was generated from the distributor. Ozone was generated by flowing the oxygen into the ozone generator. The results of the experiments were estimated at 10min, 20min, and 30min after contacting ozone. To determine optimal O₂ flow rates and output voltages in terms of the efficiency of the removal of color, turbidity and organic

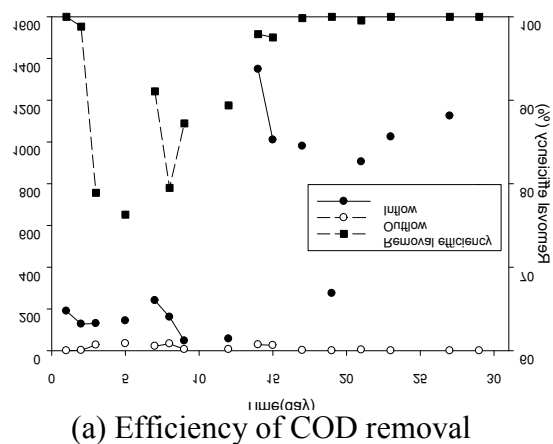
matter, a total of nine experiments were performed, and 2.5 LPM and 7 kv were determined to be the optimal O₂ flow rate and output voltage, respectively.

3. Results and discussion

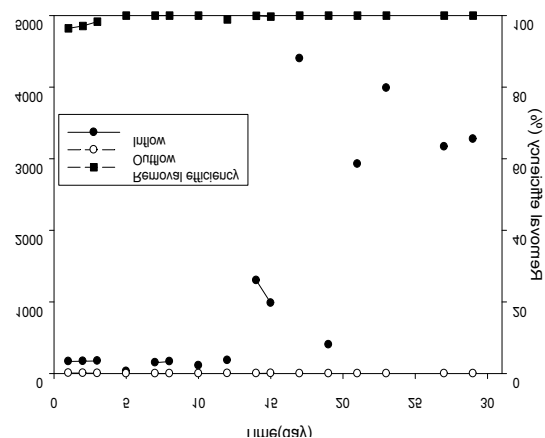
3.1 Evaluation of A₂O-MF membrane

Fig. 3 (a) shows the efficiency of COD removal by the A₂O-MF membrane system. The maximum value of influent was 1600 mg/L (29th day), and the minimum value of influent was 42 mg/L. Removal efficiency of COD was about 75% ~ 100%. Although the removal efficiency was 75% at the 5th day, the actual level of COD in effluent was 12 mg/L. As the legal standard for water reuse is less than 20 mg COD/L in Korea, this value satisfies the legal standard. By the 15th day, the efficiency of COD removal was 100%. Ramon et al., (2004) have conducted experiments of low strength graywater treatment using ultrafiltration(UF) membrane and nanofiltration(NF) membrane. Depending on the membrane used, UF removed 45-70% of COD as well as 92-97% of turbidity. Depending on the membrane used, NF removed 93.3% of COD as well as 98.1% of turbidity. Fig. 3 (b) and (c) show the efficiency of the removal of turbidity and suspended solids by the A₂O-MF membrane system. Maximum value of influent was 4,300 NTU, and the minimum value of influent was 31 NTU. Maximum value of suspended solids in the influent was 4,200 mg/L, while the minimum value was 72 mg/L. Due to the activated sludge and MF membrane, suspended solids were removed very effectively. The efficiency of turbidity removal was 98~100%. Fouling of the MF membrane did not occur in this study. Fouling is a major issue in the membrane process. For example, Lodge et al., (2004) have compared wastewater with graywater in UF following biological treatment and found similar fouling behavior, reasoning that the difference could be explained with a higher SS concentration in wastewater in that case.

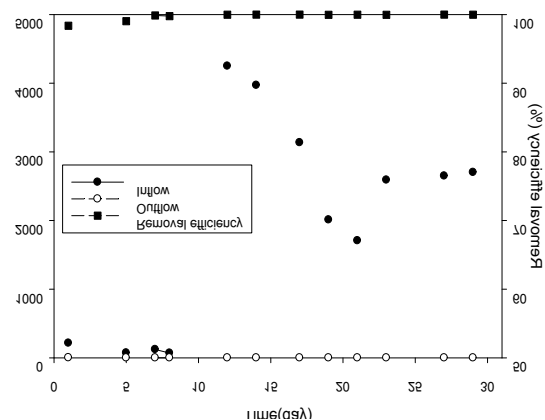
In this study, because suspended solids were removed effectively through the A₂O process, it seems that fouling of the MF membrane occurred. Fig. 3 (d) shows the efficiency of color removal by the A₂O-MF membrane system. Maximum value of influent was 51 Pt-Co, and the minimum value of influent was 15.8 Pt-Co. As a result of the activated sludge and MF membrane, organic matter, suspended sludge and DOM (Dissolved Organic Matter) were removed effectively. Efficiency of color removal was greater than 90% from the 5th day. The decolorizing of wastewater using various membrane-based pressure driven processes has been investigated by several researchers [9, 11, 12]. MF and UF are low pressure membrane processes that separate suspended solids, macromolecules and colloids from a feed stream [7]. As a pretreatment step, MF can significantly enhance water quality for a reasonable cost. Decolorizing textile wastewater [10], municipal wastewater and groundwater supplies [12] are some examples of the applications of membranes in this area.



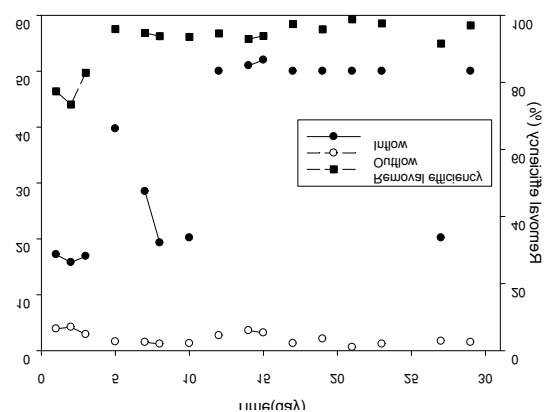
(a) Efficiency of COD removal



(b) Efficiency of turbidity removal



(c) Efficiency of SS removal



(d) Efficiency of color removal

Figure 3: Removal efficiency of COD, turbidity, color, SS (The lack of a line connecting two points on the graph indicates that consecutive sampling has not been performed)

There were large amounts of *E.coli* & *Coliform*, *Salmonella* and *Staphylococcus* detected in both influent and effluent. The A₂O-MF membrane could not remove *E.coli* & *Coliform*, *Salmonella* and *Staphylococcus* from the graywater, regardless of concentration.

3.2 Analysis of micro organism

Fig. 4 shows the results of analysis of the microbial community. At the phylum level, *E.coli* & *Coliform*, *Salmonella* in the effluent of A₂O-MF membrane are classified as proteobacteria. *Staphylococcus* is classified as firmicutes. At the class level, *E.coli* & *Coliform*, *Salmonella* are classified as gammaproteobacteria and *Staphylococcus* is classified as bacilli. Through these results, the analysis of pathogenic micro organism can have more accuracy.

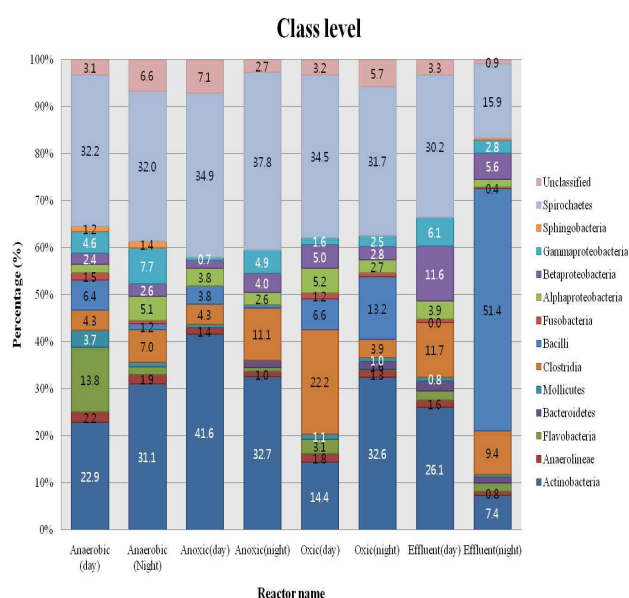
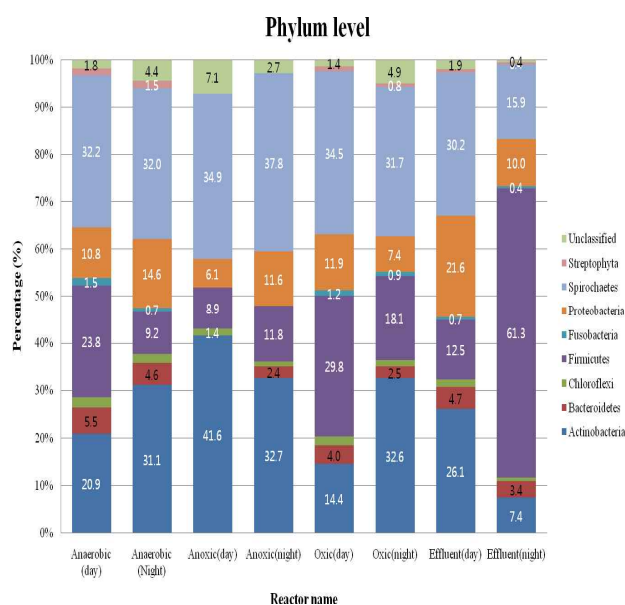


Figure 4: Analysis of microbial community

3.3 Evaluation of advanced oxidation process

Fig. 5 shows the removal tendency of COD, turbidity, color, and SS according to residence time in the ozone reactor. The values on the graph are the means of total experimental values using AOP. At 0 minutes, although graywater was treated by the A₂O-MF membrane system, the concentration of each factor was not good (more than the accepted standard for water reuse in Korea). Because the A₂O-MF membrane system showed insufficient removal efficiency until the 5th day of the experiment, the mean of all experimental values did not meet the standard for water reuse in Korea. At 10 minutes, the concentration of color was changed from 40 Pt-Co to 20 Pt-Co and that of COD was changed from 44 mg/L to 14 mg/L. Concentration of turbidity was changed from 14 NTU to 3 NTU and that of suspended solids was changed from 20 mg/L to 5 mg/L. At the range of 0-15 min, reduction of each factor was almost performed. These results have already been reported in several journals [9, 12]. At 20 minutes, the concentration of color was slightly changed, and the other factors showed similar results considering the margin of error. At 30 minutes, concentration of suspended solids

was slightly changed, and the other factors were showed almost identical removal performance.

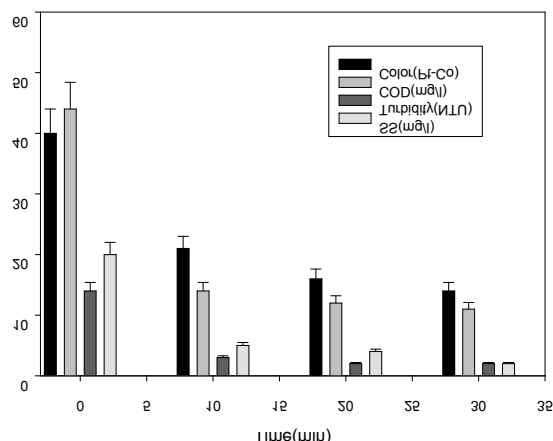


Figure 5: Removal tendency of COD, turbidity, color and SS removal

The efficiency of *E.coli*, *total Coliform*, *Salmonella* and *Staphylococcus* removal was 100%. Although the A₂O-MF membrane system could not efficiently remove *E.coli*, *total Coliform*, *Salmonella* and *Staphylococcus*, the AOP unit showed good treatment in terms of removing *E.coli*, *total Coliform*, *Salmonella* and *Staphylococcus*. In addition, all pathogenic microorganisms were removed at the range of 0-15 min.

4. Conclusion

Graywater is often used without any significant pretreatment, a practice that is mistakenly considered safe. The results reported in this study indicate that an A₂O-MF membrane-AOP system shows good treatment capacity. The A₂O-MF membrane system studied could effectively remove COD, turbidity, color, and suspended solids, while the AOP was effective for the removal of *E.coli*, *total Coliform*, *Salmonella* and *Staphylococcus*. As the MF membrane could not completely remove *E.coli*, *total Coliform*, *Salmonella* and *Staphylococcus*, a

disinfection system was required. If graywater is reused for a human-contact purpose, a disinfection system has to be installed. The A₂O-MF membrane-AOP system satisfies the Korean standards for the reuse of water, which are: COD of less than 20 mg/L, turbidity of less than 2 NTU, color concentration of less than 20 Pt-Co, suspended solids of less than 5 mg/L, and zero detection of *E.coli*. Since the MF membrane was very effective for the treatment of COD, turbidity, color and suspended solids, it was unnecessary to employ UF membranes or NF membrane. The MF membrane was also more economic than the UF membrane or the NF membrane. Friedler et al., (2006) reported that if the practice of on-site graywater reuse becomes widespread, the costs of the systems will obviously decrease, making them more appealing to individual consumers. In addition, under typical conditions on-site graywater reuse is a feasible solution for decreasing overall urban water demand, not only from an environmental standpoint, but also in economic terms. Treated graywater can be used as water for the toilet, for fire fighting, for car washing, for green space, and for constructed wetlands and ponds. Prathaper et al., (2005) reported that it would be beneficial to individuals and to society, if the building industry can be persuaded to install graywater treatment systems (a) in new houses; (b) in new apartment complexes; and (c) in public buildings, such as mosques and schools, where existing plumbing could easily be modified to separate graywater from blackwater. Ultimately, a sustainable water circulation system can be accomplished.

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