論文の内容の要旨

論文題目 Characterization of Biodegradable Organic Matter in Reclaimed Water by Bacterial Growth Response (下水再生水における生分解性有機物の細菌増殖応答に基づく特性評価)

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Reclaimed wastewater has been considered to be a valuable resource for sustainable water management especially in arid zone and urban area. To promote water reuse, the reliability of reclaimed water is very critical. The comprehensive chemical and biological assessments of reclaimed water quality are prerequisite. Microbial regrowth induces problems to the water reuse including occurrence of opportunistic pathogen, deterioration of aesthetic quality, corrosion and biofouling in cooling system, interruption of water flow for aquifer treatment, and clogging of emitter for micro-irrigation. Microbial regrowth can be suppressed if the residual disinfectants are sufficiently maintained. However, the rapid dissipation of residual chlorine in reclaimed water distribution system is often observed due to the chemical constituents. Biodegradable organic matter (BOM) is found to be a limiting compound controlling the extent of microbial regrowth in drinking water and reclaimed water in the absence of residual chlorine. However; there is very limited information available on the BOM in reclaimed water.

The objectives of this study were; (1) to evaluate BOM and the removal by different water reclamation processes, (2) To study relation of microbial regrowth, AOC, and residual chlorine in a reclaimed water distribution system including storage tanks and a point-of-use, (3) to characterize bacterial isolates collected from wastewater and reclaimed water samples for analysis of BOM in reclaimed water, (4) to characterize the BOM quality and its change during reclaimed water treatments by the bacterial growth fingerprint.

BOM was evaluated in reclaimed water samples taken from six water reclamation plants having different tertiary treatment and disinfection processes. Assimilable organic carbon (AOC) technique, which originally developed to determine biological stability of drinking water, was used to assess BOM in reclaimed water. AOC is determined by measuring the maximum growth of reference strains (*Pseudomonas fluorescens* P17 and *Aquaspirillum* sp. NOX) inoculated in water samples. Number of cell is converted to organic carbon concentration by growth yield.

The quality of all reclaimed water samples at the point of entry to the distribution system was compiled with the Japanese standard for reclaimed water. The DOC and AOC concentrations in the secondary effluent ranged from 4.6 to 7.0 mg C/L and from 66 to 138 µg C/L, respectively. While, the DOC and AOC concentrations were 1.4–6.8 mg C/L and 36–446 µg C/L in the reclaimed water, respectively. AOC increased in most of the treatment processes. Especially, ozonation increased the AOC 2–5 times relative to the AOC in the secondary effluent. Both portions of AOC-NOX and AOC-P17 increased; although AOC-NOX increased larger in most case. AOC concentrations in the reclaimed water from the processes equipped with ozonation were in 195–446 µg C/L range, whereas others were in the 36–148 µg C/L. UV or chlorine slightly changed the AOC concentration. Reverse osmosis produced reclaimed water with the lowest AOC content. Membrane filtration was effective in removing seed microorganisms that enter the distribution system.

The temporal variations of DOC, AOC, and microbial abundances (HPC) along a treatment process equipped with ozonation were examined for one year. DOC was slightly removed by the tertiary treatment, while AOC was significantly produced. The AOC concentration was 41–122 μg C/L after sand filtration and it significantly increased to 125–418 μg C/L after ozonation ($p < 0.001$). Both the AOC-NOX and AOC-P17 portion increased similarly. Relation among microbial regrowth, AOC, and residual chlorine was also study in the distribution system downstream of the treatment process. The AOC reduction occurred simultaneously with regrowth, which suggests that AOC could support microbial growth in reclaimed water distribution systems. As the residual chlorine is often depleted during distribution and storage, it is essential to enhance the BOM removal by water reclamation treatment in order to suppress microbial growth. Especially for the process equipped with ozonation, biofiltration or sand filtration should be placed after ozone treatment as drinking water treatment.

Novel BOM characterization based on bacterial growth response was developed, as bacteria for AOC analysis may not consume BOM in reclaimed water well. The bacterial isolates were obtained from 8 water reclamation processes for 184 colonies. Based on the 16S rRNA gene sequence analysis, isolates were differentiated into 38 taxonomy groups. We obtained 34 representative heterotrophic bacterial strains covering a wide range of bacteria in reclaimed water systems. Substrate utilizations patterns of the representative strains investigated by the BIOLOG^{TM} microplate showed 4 distinctive groups. Various growth patterns were observed among the bacterial strains when they were inoculated in reclaimed water samples from different treatment processes indicating that the amounts of substrates used for the growth of a particular strain were different among the samples. The difference in composition could be mainly derived from different treatment processes and source of water. Information of bacterial growth patterns in reclaimed water, substrate utilization profiles in BIOLOG system, and phylogenic affiliations was gathered to select representative bacteria for characterizing BOM composition. Finally, 11 bacterial isolates were obtained for further investigation including *Pseudomonas sp., Nevskia sp., Acinetobacter sp., Herminiimonas sp., Methylobacterium sp., Mycobacterium sp., Microbacterium sp., Actinomycetales bacterium, Sphingobacteriaceae bacterium,* and *Riemerella sp.*

Bacterial growth fingerprint was established to be a tool for investigating BOM quality of reclaimed water. The test is based on evaluating cell numbers of 11 bacterial isolates grew in water sample. The growth patterns of these isolates varied among reclaimed water from different treatment processes or different sources. The maximum cell numbers of 11 isolates were different among samples which were used as a fingerprint reflecting BOM quality of reclaimed water. Multivariate statistical analysis clearly indicated the different in BOM quality from reclaimed water samples from different sources. Moreover it could suggest about the BOM character changes along the processes. Also the different in water quality treated with the same process, but from different plants. Bacterial growth fingerprint is a promising method to investigate efficiency and effect of water reclamation treatment on BOM content and composition which can contribute to further improvement on BOM removal.