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DISSERTATION ABSTRACT

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Anaerobic treatment of low-strength wastewaters at ambient temperature in upflow anaerobic sludge
blanket reactors
(上向流嫌気性汚泥床による低濃度排水の常温嫌気性処理)

Anaerobic wastewater treatment is a well-established and proven technology for the treatment of various categories of industrial wastewaters. This technology has numerous advantages, such as low energy requirement, energy recovery as methane gas (CH_4), low costs of aeration and sludge handling, over aerobic counterparts. Most anaerobic wastewater treatments have been conducted within mesophilic (30°C - 40°C) or thermophilic (45°C - 60°C) temperature ranges. This is attributed to the fact that most of the biological reactions responsible for anaerobic biodegradation of organic matters proceed slower under psychrophilic ($<20^\circ\text{C}$) condition than under mesophilic and thermophilic conditions. However, municipal wastewater is generally discharged at low ambient temperature under temperate climatic conditions. Furthermore, municipal wastewaters belong to the category of low-strength wastewater that has a chemical oxygen demand (COD) concentration of about 1.0g/L or lower. Therefore, a significant input of energy is required to heat a reactor to the treatment temperature. If anaerobic wastewater treatment without heating the reactor can be applied to low-strength wastewater, the cost of anaerobic wastewater treatment can be reduced, thereby making this technology an attractive option for the treatment of a variety of wastewaters. In this study, the technical feasibility of using an upflow anaerobic sludge blanket (UASB) reactor to treat low-strength wastewater at ambient temperature was investigated. Especially, the effects of temperature and hydraulic retention time (HRT) on the performance of a UASB reactor were investigated. Based on the results obtained, municipal wastewater was treated in a UASB reactor at ambient temperature. Furthermore, degasification with degassing membrane was applied to the UASB reactor to improve CH_4 recovery efficiency by collecting dissolved CH_4 (D- CH_4) from the reactor effluent. The degasification technology was compared with the other technologies for D- CH_4 collection.

We investigated the effects of temperature and HRT on the COD removal rate of a UASB reactor treating synthetic wastewater. We operated a bench-scale UASB reactor over 170 days. After COD removal efficiency reached a steady state, temperature of the reactor was changed from 35°C to 25°C and 15°C in a stepwise manner in the initial stage. In the latter stage, HRT was reduced from 10h to 6.6h and 3.3h by altering the hydraulic loading rate without changing COD loading rate. In the initial stage, the total COD (T-COD) concentration of the influent was 1480mg COD/L and the concentration of dissolved fraction of COD (D-COD) in effluent was 120mg COD/L, resulting in 92% of D-COD removal efficiency regardless of temperature. In the latter stage, D-COD removal efficiency was higher than 90%. It might be explained by the use of the synthetic wastewater without recalcitrant organic compounds, long HRT and the large amount of biomass retained in the reactor.

The technical feasibility of using a UASB reactor to treat real municipal wastewater at ambient temperature was investigated. The UASB reactor was operated from January 2010 to June 2011. T-COD and D-COD concentrations in the wastewater were in the ranges of 70-310mg/L and 50-160mg/L, respectively. The rate of the particulate fraction of COD (P-COD) to T-COD in the influent remained relatively constant (0.56) throughout the operation. HRT was changed in the range of 2-8h in response to changes in the COD removal efficiency. Temperature, which was not controlled, varied from 6°C to 31°C . A 20-cm-high filter media was installed in the upper part of the UASB reactor on June 22, 2010, to avoid biomass washout. T-COD was not removed during the first winter. Between July and October 2010, the T-COD removal efficiency was in the range of 50%-71%. The temperature ranged from 20°C to 31°C during this period, indicating that temperature was a critical factor for effective COD removal. Disintegration of the granules was observed during the operation and the average amounts of volatile suspended solids in the granular bed increased from 78 to 150g per reactor by installation of the filter media to prevent biomass washout. Enhancement of biomass retention by the installation of the filter

media and growth of biomass may contribute to the improvement in T-COD removal efficiency and increase in the CH_4 evolution rate into the UASB headspace during this period. The T-COD removal efficiency started to decrease at the beginning of November 2010 accompanying the temperature drop. This might be attributed to the low methanogenic activity at low temperature. Volatile fatty acids (mainly acetic acid) were detected in winter, but not in summer, indicating that acidogenic activity was not inhibited compared to methanogenic activity at low temperatures. These organic acids would be treated in aerobic posttreatment. Subsequently, the T-COD removal efficiency gradually increased from 10% to around 60% in April 2011 owing to the gradual increase in temperature. We concluded that municipal wastewater could be anaerobically treated at ambient temperature with greater than 40% of T-COD removal efficiency except in winter ($<10^\circ\text{C}$). The COD removal efficiency was lower ($<71\%$) in this study than those in UASB reactors treating high-strength wastewaters under mesophilic conditions in the previous studies. This might be because of the higher P-COD fraction of the municipal wastewater and the operation at ambient temperature in this study. We compared the operating parameters and T-COD removal efficiencies of the UASB reactor with ones treating low-strength wastewaters under psychrophilic conditions reported in the previous studies. The result indicates that the treatment of low-strength wastewaters at low temperatures results in low COD removal efficiencies. Therefore, an aerobic posttreatment is needed to achieve the appropriate T-COD removal efficiency.

When low-strength wastewaters are anaerobically treated at ambient temperature, it is important to consider D- CH_4 . It is because the solubility of CH_4 in the liquid phase increases with decrease in temperature, which represents loss of energy that may be recovered and release of greenhouse gas into the environment. We employed a hollow-fiber membrane to recover residual D- CH_4 in the effluent of UASB reactors by degasification. The liquid outlet of the UASB reactor was connected to another reactor for degasification (a degassing membrane (DM) reactor). Firstly, a bench-scale UASB reactor equipped with the DM reactor was operated to treat synthetic wastewater at different temperatures and HRTs. Under 35°C and HRT of 10h, average D- CH_4 concentration was reduced from 63mg COD/L to 15mg COD/L, resulting in an increase in the total CH_4 recovery efficiency from 89% to 97%. Average D- CH_4 concentration was as high as 104 mg COD/L at 15°C because of the higher solubility of CH_4 in the liquid and the average D- CH_4 concentration was reduced to 14 mg COD/L by degasification. Accordingly, the total CH_4 recovery efficiency increased from 71% to 97% at 15°C . Moreover, degasification tended to cause an increase in P-COD removal efficiency. In addition, the UASB reactor was operated at different HRTs. Although average D- CH_4 concentration in the UASB reactor was almost unchanged (ca. 70mg COD/L), the D- CH_4 discharge rate from the UASB reactor increased with decreasing HRTs because of increase in the hydraulic loading rate. Because the D- CH_4 concentration could be reduced down to 12 mg COD/L by degasification at an HRT of 6.7h, the CH_4 recovery rate was 1.5 times higher under degasification than under normal operation. Secondly, municipal wastewater was anaerobically treated with a UASB reactor at ambient temperature to investigate D- CH_4 recovery efficiency. D- CH_4 , which was detected in the UASB effluent throughout the operation, could be successfully collected with a degassing membrane over 18 months without membrane fouling. The ratio of the collection to recovery rates was 60% in summer and 100% in winter.

In summary, a UASB process is applicable to pretreatment of municipal wastewater at ambient temperature. T-COD removal efficiency was greater than 40% at temperatures higher than 10°C . Biomass retention is essential to reliable reactor operation. Since the ratio of D- CH_4 to CH_4 recovered from the UASB reactor was higher in municipal wastewater treatment than those in treatment of high-strength wastewater, D- CH_4 should be collected from the reactor effluent to prevent loss of energy and release of greenhouse gas. From an economic point of view, a further reduction in the energy required for degasification is needed.