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論 文 の 要 旨
Abstract of thesis

Energy shortage and organic solid waste management are hot issues nowadays, prompting researchers to investigate applicable technologies for renewable energy recovery and ecological environment protection. Anaerobic digestion (AD) is a widely applied technology for waste activated sludge (WAS) reduction, stabilization and renewable energy (mainly methane (CH_4)) recovery. Previous research works attempted various approaches like optimization of operating parameters, pretreatment methods and additives addition to improve AD efficiency. Recently, ultra-fine bubble water (UFBW) with special physicochemical characteristics of stability and longevity has drawn intensive attention in many research fields including agriculture, medicine and wastewater treatment. Few studies, however, tried the application of UFBW to microorganisms, especially its effects on AD for CH_4 production. In addition, little information is available about the influencing factor on AD performance, and the mechanisms involved in its possibly significant effects in the UFBW-AD systems remain unknown. This research explored the distinctive characteristics of UFBW and investigated the effects of UFBW on the AD of WAS with the primary mechanisms being revealed. The results of this study are expected to provide scientific data for the application of UFBW in AD systems.

This dissertation is divided into 5 chapters. In Chapter 1, the author introduced the research background and significance based on the literature review. The author narrated the disposal and conversion methods for biomass energy and the current technologies for improving AD efficiency in addition to their problems of secondary pollution and environmental-friendliness issues. Then the author explained the novel UFBW technology as well as its successful applications in various fields. At the end of this chapter, the author arrived at the objectives and framework of the thesis. In Chapter 2, the author explored the characteristics of UFBW, including particle size distribution and concentrations as well as zeta potential, produced by respectively introducing air, N_2, CO_2 and H_2 gases under different preparation time and storage duration. The stability of ultra-fine bubbles (UFBs)

followed a descending order as H_2 > Air > N_2 > CO_2. The UFBs concentration increased with prolonging preparation time until 20 min and then the bubble size and its distribution remained relatively stable when preparation time was longer than 20 min. The number of Air-UFBs is around 2.25×10^8 particles /ml with 144.2 nm as the dominant size, which decreases to 1.87×10^8 and 1.00×10^8 particles/ml after one and two weeks' storage at room temperature, respectively. The UFBs could exist in the produced UFBW even after storage for several weeks. The zeta potentials of the four kinds of UFBs would be affected by pH value. At a wide range of pH (from 3.0 to 12.0), all the zeta potential values of UFBW were negative with the highest value at pH 10.0, suggesting the most stable state. The zeta potential value was found to be positively correlated with the number and concentration of UFBs but no relation with the bubble diameter. In Chapter 3, the author conducted a series of batch AD experiments at initial pH 7 and 36±2°C in order to investigate the effects of the above-mentioned UFBW addition on the hydrolysis-acidification process and the whole process of AD of WAS. Results show that in the hydrolysis-acidification process, an average enhancement about 32.4% was obtained for the biogas production from UFBW groups, which is remarkably higher than the DW group. In addition, the reductions of proteins and polysaccharides in all the experimental groups were higher than those in the control group. The average reductions in volatile solid (VS) increased to 7.05% and 11.53% on day 3 and day 7, respectively under UFBW addition, higher than that in the control group. As for the whole AD process, all the UFBW addition groups exhibited an enhancement effect on biogas and CH_4 production, especially CO_2-, H_2- and Air-UFBW, achieving 20% higher biogas and CH_4 productions than those from the control tests. While compared to the control groups, the activities of dehydrogenase and the content of coenzyme F_{420} were slightly higher under UFBW addition conditions. More specifically, the VS reduction rates in the UFBW groups seemed to be much faster than those in the control groups during the first 3 and 6 days (6.7-11.88% vs. 4.59%, and 16.03-22.44% vs. 14.30%, respectively); however, no obvious difference in VS reduction rate was discerned at the end of AD process. In Chapter 4, the author used acetate-enriched seed culture to investigate the uptake and mass transfer of trace metals by CH_4 producing bacteria under UFBW addition. Much difference in biogas production was noticed between the UFBW and control tests during the 1st period, while no obvious difference was observed in the 2nd and 3rd period. All UFBW groups showed an enhancement effect on CH_4 production, especially Air-UFBW which achieved a 26.8% increase in comparison to the control. Results from inorganic compounds analysis reflected some increase in the trace metals content contained in the inoculum, following a descending order as Fe>Zn>Co>Ni>Cu in the cells. The contents of trace metals in the methanogens were higher in the UFBW groups, especially for the metal of Fe, about 48.97% higher than that in the control. As the metals, especially Fe may also precipitate onto the cells or co-aggregate with other components in the culture, the real reason or mechanism involved in this complicated system is still under investigation. Finally, in Chapter 5 the author summarized the major conclusions of the thesis, and also pointed out the future research directions.

審 査 の 要 旨

Abstract of assessment result

In this research, the UFBW with unique physicochemical properties was introduced into the AD system of WAS and then evaluated its effects. The addition of UFBW was found to be beneficial for the hydrolysis-acidification process and the whole AD process with respect to the rapid reduction of VS, the increase of biogas and CH_4 production, the higher activities of dehydrogenase and the content of coenzyme F_{420}, the stable pH and alkalinity conditions. With the mechanism preliminarily discussed, results from the current research suggest the potential of UFBW application in the AD system of WAS, which may enhance CH_4 production with high efficiency energy recovery from WAS and high environmental-friendliness.

The final examination committee conducted a meeting as a final examination on 23rd July, 2019. The applicant provided an overview of dissertation, addressed questions and comments raised during Q&A session. All of the committee members reached a final decision that the applicant has passed the final examination.

Therefore, the final examination committee approved that the applicant is qualified to be awarded the degree of Doctor of Philosophy in Environmental Studies.