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論　文　の　要　旨
Abstract of thesis

Biofuel generation from renewable resources can solve the energy shortage as well as the associated environmental problems. Anaerobic digestion (AD) of lignocellulosic biomass is a promising approach for bioenergy production, which has been widely applied to make up the overuse of fossil fuels. However, the low energy conversion efficiency limits its application mainly due to the low metabolic activity of microbes and the rigidity and recalcitrant structure of lignocellulose. To cope with these problems, various pretreatments including physical, chemical and biological methods have been attempted to enhance biogas production from AD of lignocellulosic biomass. However, the improvement of methane production is difficult to balance the additional energy consumption, high processing cost and secondary pollution potentials brought about by the additives addition. Thus, environment-friendly methods are still urgently required to meet the sustainable development goals (SDGs). This research investigated the effects of nanobubble water (NBW) addition with high mobility and fast mass transfer on AD of lignocellulosic biomass in order to realize the enhanced methane production without chemicals addition and potentially secondary pollutions.

This dissertation is divided into 6 chapters. In Chapter 1, The author addressed the current situation and existing problems about energy crisis and environmental pollutions. After a summary of the composition of lignocellulosic biomass and its conversion technologies, the author discussed the properties, characteristics and application of NBW, pointing out the advantages of the novel NBW-based AD systems. Then the author arrived at the research objectives and thesis structure. In Chapter 2, the author investigated the effect of NBW addition on the hydrolysis and acidification of high loading cellulose. During 35 days' storage NBW was evidenced by its high mobility and diffusion of water molecules. Higher volatile fatty acids (VFAs) were yielded at the hydrolysis-acidification stage under NBW addition. Methanogenesis tests showed that Air-NBW and CO_2-NBW

supplementation accelerated the utilization of crystalline cellulose, achieving methane yields of 242 and 225 NmL/g-VS, increasing by 18% and 10% compared to deionized water addition (the control), respectively. In addition, under NBW addition the cellulose crystallinity reduction was enhanced by 14–20% with microbial community being enriched with hydrolytic and methanogenic bacteria. In Chapter 3, the author examined the enhancement effect of O_2-containing gas NBW on methane production from AD of cellulose. The cumulative methane yields from the reactors with Air-NBW (193 NmL/g-VS), N_2-NBW (196 NmL/g-VS) and O_2-NBW (233 NmL/g-VS) addition were increased by 8-30% in comparison to the control (179 NmL/g-VS). In the NBW-based AD systems, the reductions in cellulose content and cellulose crystallinity were respectively enhanced by 8-14% and 9-21%, with cellulase activity being elevated by 10-21%. The O_2-NBW reactor was found to have the highest electron transport system activity, increasing by 1.7 times compared to the control, most probably due to the collapse of O_2-nanobubbles and release of O_2 resulting in a micro-oxygen environment under the test AD condition. Besides, microbial community analysis suggested that the direct interspecies electron transfer could be quickly established with the addition of NBW. In Chapter 4, the author reported the methane production from corn straw by using anaerobically digested sludge pre-augmented by NBW. About 20%, 33% and 38% of cellulose and 29%, 35% and 35% of hemicellulose were reduced respectively from the control, N_2-NBW and O_2-NBW pre-augmented sludge reactors. N_2-NBW and O_2-NBW ones achieved methane yields of 127 and 142 NmL/g-VS, about 10% and 22% higher than that from the control. Results show that use of NBW pre-augmented anaerobically digested sludge as inoculum can remarkably enhance methane yield from corn straw. In Chapter 5, the author analyzed the mechanisms involved in the NBW-based AD system. The high mobility and mass transfer in addition to negative charged surface possessed by nanobubbles play an important role in the enhancement effect on the NBW-based AD system, in which the major microbes including hydrolytic bacteria and methanogens were greatly enriched, especially under the addition of O_2-NBW. The created micro-oxygen environment is conductive to the improved hydrolysis of lignocellulose and then methane production. Finally, in Chapter 6, the author summarized the major conclusions, and proposed the future research directions.

審　査　の　要　旨
Abstract of assessment result

Anaerobic digestion (AD) of lignocellulosic biomass is promising for bioenergy production, which has been widely applied to make up the overuse of fossil fuels. This study for the first time attempted the addition of nanobubble water (NBW) on refractory cellulose degradation for methane production. The author examined CH_4 production from AD of cellulose at a high loading of 3.5 under NBW addition, and found that the micro-oxygen environment created by Air-NBW addition might contribute to the shift of microbial community and promoted CH_4 formation. In addition, the author achieved desirable methane production from the sole substrate, corn straw using the anaerobically digested sludge pre-augmented by N_2-NBW and O_2-NBW without the need of increasing AD reactor volume. This research provides a new alternative to acquire more methane as renewable energy from lignocellulosic biomass with NBW supplementation. This research also demonstrates the concept and fundamentals of the NBW-based AD systems. Results from this study show that the pre-augmentation of anaerobically digested sludge and then the improvement of methane production from corn straw can target no increase of AD reactor volume in practice and sustainable management of lignocellulosic biomass.

The final examination committee conducted a meeting as a final examination on 13 July, 2020. The applicant provided an overview of the 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.