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論文題目	Pilot-scale anaerobic digestion of municipal biowaste with thermal hydrolysis pre-treatment （水熱前処理を用いた有機性廃棄物のパイロット-スケール嫌気性消化に関する研究）		

（論文内容の要旨）

In this research, anaerobic digestion of municipal biowaste was studied in a pilot-scale plant in Beijing, China. Thermal hydrolysis (TH) was applied as pre-treatment to improve digestibility of the biowaste. Its effects on properties of the biowaste and digestion performance were then evaluated. This research consists of eight chapters. Except for improving solid hydrolysis, thermal hydrolysis was found able to improve settling performance of the biowaste. According to this, anaerobic sequencing batch reactor (ASBR), in which a solid settling phase is designed, was used as a digester. Solid settling behaviors in the ASBR were studied and ASBR was compared with continuously stirred tank reactor (CSTR) for digester stability and performance. Furthermore, a model was established to predict organic removal and microorganism growth in both ASBR and CSTR from an importation parameter, solid retention time (SRT). At last, systematic evaluation was made to the TH-ASBR combined technology from the aspects of energy, economy, and environment. All these contents are aimed to provide experiences and suggestion for future studies on this TH-ASBR combined technology for the treatment of municipal biowaste. Results were also compared with lab studies and other studies for verification. Major contents are as following:

1) 38.3% of volatile suspended solids (VSS) in the municipal biowaste were hydrolyzed by TH pre-treatment. Volatile fat acids (VFAs), which are important inhibitors in the digestion process, also increased by 42%. As buffering ability of the biowaste was also improved by TH, digestibility was not affected by the VFA increase. Biochemical methane potential (BMP) test showed maximum methane production rate was improved by 115%. These results were greater than those obtained in lab studies, as the pilot plant used steam for heating while the lab studies used electricity. The latter may cause unequal heating in the biowaste and thus weaken hydrolysis performance. TH also improved fluidity of the biowaste. Viscosity was decreased. Settling and dewatering performance was improved. These resulted from interaction of molecule destruction, particle size variation, dilution, and so on. Especially, improvement on settling performance indicated that application of ASBR become possible.

2) Pilot-scale digesters with and without TH pre-treatment were compared for their stability and performance under organic loading rates (OLRs) of about 1.5 and 3 kg VS/(m^3·day). Itwas found that thermal hydrolysis improved digester stability, especially under a higher OLR of about 3 kg VS/(m^3·day). Obvious difference was not found for performance of the two digesters on organic removal and daily biogas production. However, batch monitoring results revealed that reaction in the digester without TH pre-treatment was lagged for about 4-6 h. It implied digestion was accelerated when TH pre-treatment was applied. When digestion time is shortened (under a lower hydraulic retention time (HRT)), digesters without TH may get unstable easier than those with TH pre-treatment.

3) Solid settling behaviors in ASBR were studied. At lower OLRs of 1.6-1.8 kg VS /(m^3·day), settling behaviors can be described by combination of zone settling and compression settling. Settling viscosity can be predicted from suspended solids (SS) concentration by Vesilind equation. Viscosity, which was easier to be determined than SS, was found relate to (SS) and able to predict the settling viscosity. However, at a higher OLR, settling performance was interrupted by biogas production and could not be explained by the classical theory. ASBR was found outperforming CSTR in many aspects. It had better stability, lower effluent strength, better removal of organics, and more biogas production than CSTR. Especially, ASBR performance showed

better resistance to HRT decrease than CSTR, which indicated digester capacity can be improved when ASBR is applied.

4) A model developed from the hypothesis of hydrolysis limitation was established for prediction of substrate removal and microorganism growth in both ASBR and CSTR. Effluent concentrations and solid accumulation in ASBR can also be predicted from this model. Another well-proved model was also used for comparison. It was found the model established in this chapter corresponded with the experiment data, and were also comparable with the simulation results from the other model. It showed that SRTs should be longer than about 20 days to obtain relative stable removal of the organics in MBW, which also corresponded with common suggestion from other studies. This result indicated an advantage of ASBR over CSTR, as longer SRTs can be obtained in ASBR than CSTR when they are operated under the same HRT.

5) Systematic evaluation was made to the TH-ASBR combined technology from the aspects of energy, economy, and environment. Treatment of municipal biowaste by TH-ASBR before incineration, were compared with TH-CSTR, CSTR, and direct incineration. Results showed the energy consumption and greenhouse gas (GHG) emission is TH-ASBR + incineration< TH-CSTR+ incineration< CSTR + incineration < incineration, while running cost is contrary. It indicated anaerobic digestion of biowaste before final disposal by incineration can help to reduce energetic, economic, and environmental loads of the whole system. Both application of TH and ASBR can help to reduce these loads further, which makes the system be energetically, economically, and environmentally friend. It implies promising future to use this TH-ASBR combined technology for the treatment of MBW.

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（論文審査の結果の要旨）

本論文は、廃棄物の適正処理、エネルギーの有効利用および地球温暖化防止の観点から、エネルギー回収可能で、効率の良い有機性廃棄物の嫌気的処理方法の開発に関する研究で、中国北京において排出される食品残渣や下水汚泥などの都市型有機性廃棄物を水熱前処理し、嫌気性逐次回分反応器（ASBR）により処理する技術をパイロットスケール規模の実験装置を主に用いて検討したものである。得られた主たる研究成果の以下のとおりである。

1）有機性廃棄物の水熱処理により 38.3%の固形物が可溶化され、メタン発生速度が 2 倍以上増加した。さらに、水熱処理は有機性発酵溶液の粘性を減少させ、固形物の沈降性および消化後汚泥の脱水性を改善させた。このことから、通常の連続槽型反応器（CSTR）ではなく ASBR を適用できる可能性が示された。

2）ASBR の適用においては固形物の流出を防ぐことが重要であり、固形物の沈降性について実験的に検討した。有機物負荷が大きくない場合は沈降速度が固形物との関係式である Veslind の式により表現できること、有機物負荷が大きい場合はバイオガスによる妨害により理論的な沈降式では表現できないことを明らかにした。直接測定することが難しい固形物濃度を制御するため、粘性との関係を検討して反応容器内固形物濃度の予測式を算出した。

3）水熱処理した有機性廃棄物の CSTR および ASBR による処理を固形物滞留時間に注目してモデル化し、基質除去速度、流出濃度、固形物蓄積状況を予測した。実験結果を比較した結果、固形物の挙動が採用したモデルにより表現でき、ASBR が CSTR よりリアクターとして有利なことが示された。

4）有機性廃棄物の処理システムにおいて、水熱処理の有無および CSTR と ASBR の採用の有無、直接焼却などの 4 つのケースについて、物質収支およびエネルギー収支、温室効果ガス排出量を計算し、システムの評価を行った。水熱処理と ASBR を適用したケースにおいて経済面およびエネルギー面、環境負荷面ともに他ケースに比べ優れており、水熱処理と ASBR の実施可能性が示された。

以上、本論文は、都市における有機性廃棄物の適正処理およびエネルギー利用技術として水熱処理を前処理にした嫌気性逐次回分反応器の適用をパイロットスケールで実証したものであり、経済面、エネルギー面、環境負荷面ともに提案しているシステムが有効であることを明らかとしており、学術上、実際上寄与するところが少なくない。よって、本論文は博士（工学）の学位論文として価値あるものと認める。また、平成 25 年 2 月 27 日、論文内容とそれに関連した事項について試問を行って、申請者が博士後期課程学位取得基準を満たしていることを確認し、合格と認めた。