Effect of thermal pretreatment on anaerobic digestion of sewage sludge by anaerobic membrane bioreactor

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Introduction

The effective utilization of sewage sludge is an important part of municipal solid waste reuse and plays a pivotal role in establishing a recycling society. Anaerobic digestion is accomplished in converting organic wastes such as sewage sludge into biogas, achieving waste reduction and resource utilization at the same time. However, conventional anaerobic digestion technology has the disadvantages of slow growth of microorganisms, poor effluent quality, sensitivity to reactor pH, temperature and environmental conditions, etc. Moreover, hydrolysis of sewage sludge becomes a rate-limiting step due to complex floc structure and hard cell walls during the anaerobic digestion. The method of improving efficiency of sludge anaerobic digestion becomes an important issue.

In this research, low-temperature thermal pretreatment was integrated into anaerobic membrane bioreactor (AnMBR) to stimulate the decomposition of organic matter in sludge for the sake of improving anaerobic digestion efficiency and reducing energy requirement. AnMBR combines anaerobic digestion and membrane separation technology, which offers plenty of merits including separating HRT and SRT, low sludge production and energy production. Well-known is that AnMBR retains microorganisms in the reactor through efficient membrane filtration, and improving the quality of the effluent. At present, the application of AnMBR in anaerobic digestion of high solid organic waste is extremely prevalent.

Besides, thermal pretreatment is widely used in improving in anaerobic digestion efficiency through accelerate hydrolysis process. In this study, low-temperature treatment(70℃) was applied to upgrade bioconversion efficiency because high-temperature treatment entails huge energy consumption and places strict demands on devices. Based on the above consideration, the present study evaluated the performance of mesophilic anaerobic digestion of excess sludge by high solid AnMBR and the effect of low-temperature thermal pretreatment. Additionally, membrane fouling behaviour and the COD mass balance were carried out to in-depth evaluate the potential and sustainability of AnMBR system.

Material and Methods

The AnMBR used in this study consists of a continuous stirred reactor (CSTR) and a separate submerged membrane unit, with a total effective volume of 15L. The average pore size of the membrane is 0.1μm, and the effective filtration area is 0.1 m^2. The bottom of the membrane unit is equipped with an aeration pipe, which can continuously aerate the biogas from the top of the CSTR at a rate of 5 L min^{-1} in terms of cleaning membrane surface and reducing membrane fouling. A digital pressure sensor is connected to the membrane unit to monitor the transmembrane pressure (TMP) in real time.

Long term experiment was divided into six phases. The substrate of phase 1 and phase 5 was steam injector treatment (70℃) excess sludge while venturi nozzle treatment (70℃) excess sludge was used during phase 2 and phase 4. The HRT of phase 1-3 was 30d and the HRT was improved to 15d from phase 4. The performance of reactor operation, biogas production, organic matter removal rate and mass balance due to the utilization of thermal pretreatment were evaluated. Besides, the concentration of sludge in AnMBR was 2.5% and 3.0% respectively during phase 1-3 and phase 4-6 in order to investigate the maximum sustainable flux at different high solid concentrations. The continuous operation management factors of AnMBR are summarized in table 1.Additionally, the resistance-in-series model (Cheng, 2020) was applied to analysis membrane fouling.

Table 1. Experimental condition at different phases.

Items	Unit	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
Duration	days	1-60	61-81	82-133	134-169	170-210	211-255
Substrate		Steam injector	Venturi nozzle	Raw	Venturi nozzle	Steam injector	Raw
HRT(days)	days	30	30	30	15	15	15
Organic loading rate	g-COD/L/d	1.56	2.00	1.72	3.64	4.03	4.44
VS loading rate	g-VS/L/d	0.99	1.08	1.13	1.79	1.72	2.08
TS concentration	%	2.5	2.5	2.5	3.0	3.0	3.0
Membrane operation		4 min filtration/1 min relaxation			1 min filtration/1 min relaxation		
Average flux	L/m^2/h	9.6	9.6	9.6	4.5	4.5	4.5

Results and discussion

(1) Long-term performance

During phase 1-6, the pH of sludge was in the neutral range of 6.9-7.5, the VFA concentration is very low and there was no VFA accumulation. The alkalinity was about 3600-5000 mg-$CaCO_3$ / L, and the ammonia nitrogen concentration was in the range of 1100-1800 mg / L, which was below the anaerobic digestion ammonia inhibitory concentration.

In phase 1-3, the biogas production rates were 0.50, 0.47, and 0.34 L / g-VS, respectively, and the effect of the thermal pretreatment was remarkable. The biogas production rate of steam injector treatment and venturi nozzle treatment were increased 47.9% and 37.8% respectively comparing with untreated excess sludge. In addition, the methane concentration at each stage was 64.36%, 61.91% and 60.31%, respectively, indicating that the methane concentration was improved a little by pretreatment. The COD removal rate reached 97% at each stage, demonstrating excellent removal ability by membrane filtration. From day 134, HRT was adjusted to day 15d and the effect of different thermal treatment methods on AnMBR under high loading conditions was evaluated. In stag 4-6, the biogas production rates of steam injector treatment and venturi nozzle treatment excess sludge were 0.50 and 0.49 L / g-VS, respectively.

(2)Membrane operation

During phase 3, AnMBR realized stable operation with high average flux (9.6LMH) when the MLTS concentration was 2.5%. The average flux was adjusted to 4.5LMH after MLTS concentration increased to 3.0% after phase 4. Membrane operated smoothly at phase 4-6 when MLTS improved indicating that reducing average flux can retain good performance to a long period. Phase 5 and 6 were operated for about 28 days and 37 days, respectively. The TMP increasing tendency of phase 5 and 6 was divided into two periods. The flux and TMP were stable from the beginning of the experiment, and a sharp increase of TMP was observed in the latter half of experiment. This experiment achieved stable long-term continuous operation with high average flux in high solid AnMBR.

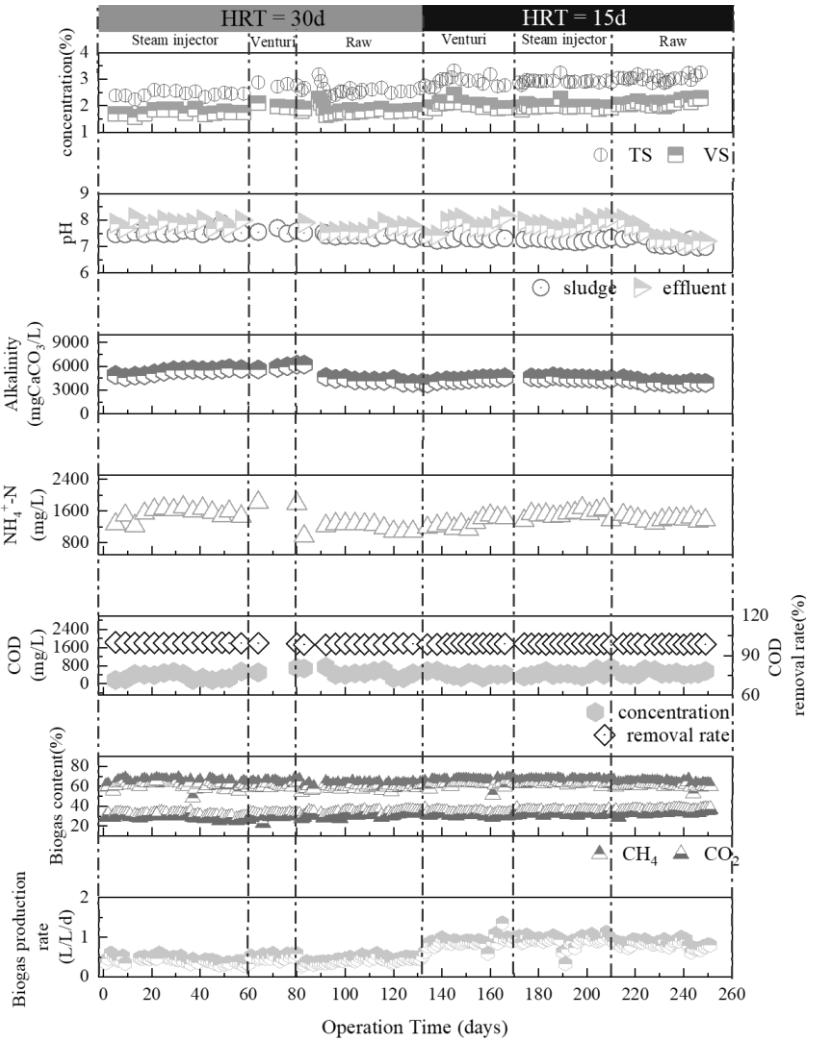

Figure 1. Operation performance of the entire experiment

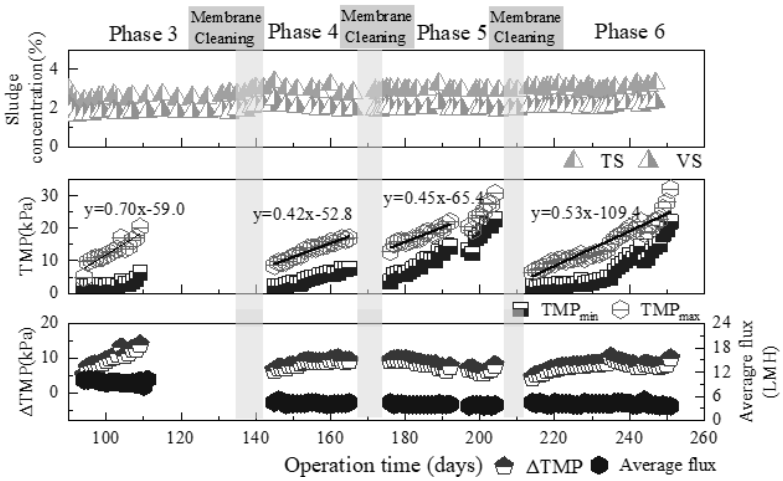

Figure 2. Result of membrane operation

Conclusion

This research focus on anaerobic digestion of sewage sludge through high solid AnMBR and integrate AnMBR with low-temperature thermal pretreatment in terms of improving hydrolysis of sewage sludge. The biogas production rates were improved 25% because of thermal pretreatment. The COD removal rate of the AnMBR system is higher than 97%, and only 0.5% of the COD remains in the effluent on the base of COD mass balance. The experimental results show that AnMBR realizes the separation of HRT and SRT, retain high concentration of microorganisms through membrane filtration and improve the quality of effluent. Moreover, stable operation was achieved with a sludge concentration of 3.0% and average flux of 4.5LMH. This study demonstrated the great potential of the utilization of AnMBR in promoting sewage sludge treatment and methane bioconversion.