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Effect of anionic surfactant inhibition on sewage treatment by a submerged anaerobic membrane bioreactor: Efficiency, sludge activity and methane recovery

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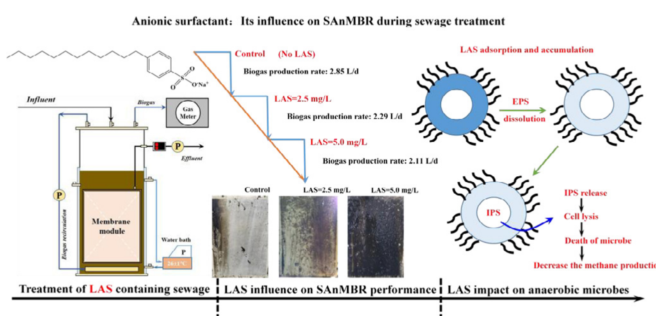
HIGHLIGHTS

- LAS caused a lower sewage treatment efficiency but a higher membrane fouling rate.
- Biogas production rate decreased by 26%: 2.11 L/d with LAS vs. 2.55 L/d in control.
- LAS was removed by adsorption rather than degradation with an efficiency of 30–70%.
- LAS adsorption had a more negative effect on methanogen than acidification microbe.
- SAnMBR is not suitable to treat LAS containing sewage with higher concentration.

GRAPHICAL ABSTRACT



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ABSTRACT

The effect of linear alkylbenzene sulfonate (LAS), a typical anionic surfactant, on the sewage treatment by a submerged anaerobic membrane bioreactor (SAnMBR) was investigated by a 243 days operation. The changes of treatment efficiency, methane recovery and sludge activity due to the presence of LAS in sewage was studied in detail. Compared with control (96.8% and 2.87 L/d), lower COD removal (95.2%) and biogas production rate (2.11 L/d) were found at a LAS dosage of 5 mg/L. Besides, LAS was removed by adsorption rather than degradation on the sludge (30–70%). Its adsorption can lead to significant loads in sewage sludge, which then decrease the methane production activity. The recovery efficiency of potential bioenergy was decreased by 20% and 26% at LAS of 2.5 mg/L and 5.0 mg/L, respectively. The results indicated that LAS had a more negative effect on the acetoclastic methanogens than acidogenic microbiota and the LAS inhibition to methanogen activity was responsible for the decrease of SAnMBR performance. Moreover, LAS caused a higher membrane fouling rate than the control experiment due to the microbial self-protection behavior in coping with the LAS in sewage. SAnMBR was hence not suitable to dispose LAS containing sewage with higher concentration.

Abbreviations: LAS, linear alkylbenzene sulfonate; SAnMBR, submerged anaerobic membrane bioreactor; HRT, hydraulic retention time; OLR, organic loading rate; UASB, up-flow anaerobic sludge blanket; EGSB, expanded granular sludge blanket; AFBR, anaerobic fluidized bed reactor; SDS, sodium dodecyl sulfate; EPS, extracellular polymeric substances; SMP, soluble microbial products; TMP, trans-membrane pressure; SMA, specific methanogenic activity; CMP, cumulative methane production; COD, Chemical Oxygen Demand; BOD, Biochemical Oxygen Demand; VFA, Volatile Fatty Acid; SS/VSS, suspended solid/volatile suspended solid.

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1. Introduction

At present, the conventional processes for sewage treatment, such as aerobic and anoxic techniques, are not sustainable due to their energy intensive, large qualities of residuals production and failure to recover the potential resources available in wastewater [1–3]. The submerged anaerobic membrane bioreactor (SAnMBR) provides an alternative strategy for sewage treatment due to its nearly absolute biomass retention, potential to generate a higher quality effluent, lower energy consumption and biogas generation [4–6]. It has been successfully studied for the treatment of high strength wastewater, such as food and beverage industry wastewater and swine manure [5,7,8]. Only recently, SAnMBR started to be used for sewage treatment and the influence of temperature, HRT, OLR, membrane characteristics on the treatment efficiency has been investigated in detail [9]. However, studies on the surfactant effect on SAnMBR in sewage treatment and sludge activity for methane production are still limited.

Recently, due to the domestic usage of household and laundry detergents, hand dishwashing liquids, shampoos and other personal care products [10], large amount of anionic surfactant, for example linear alkylbenzene sulfonate (LAS), was discharged into sewage. However, LAS in wastewater is only removed by sorption and aerobic biodegradation but not under anaerobic conditions because of the hydrophobic character and restricted metabolic routes [11]. While other studies proved that LAS degradation was possible and microbial enrichment cultures have also been established [12]. Although, various anaerobic arrangements such as UASB, EGSB and AFBR et al. have been used to dispose LAS containing wastewater [13–15] with a removal rate ranged from 40–90%, this disappearance does not imply unequivocally that an anaerobic degradation process is taking place because no LAS metabolites have been identified or quantified (the value was mainly obtained according to the LAS mass balance calculation) [16]. If the microbes towards LAS degradation existed in reactor, the adsorbed LAS can be finally degraded after long-term operation. Hence, it need to clarify whether LAS was indeed degraded and converted into methane or just adsorbed on the sludge in sewage treatment by SAnMBR since the HRT was always below 12 h.

Besides that, the anionic surfactant can also affect the anaerobic microbes in reactor and the methane production activity. LAS was reported to promote a lower methane production rate due to the inhibition to the methanogenic and the acidogenic steps in anaerobic process [17,18]. The higher LAS concentration results in the lower methane production, which may be attributed to the lower growth rate of anaerobic microorganism [19]. On the other side, the surfactant sorption will lead to significant loads in sewage sludge. Sodium dodecyl sulfate (SDS) with lower concentration can enhance the waste activated sludge fermentation by removing the EPS to increase the effectiveness of subsequent bacterial treatment [20]. While higher dosage will inhibit the cell activity due to the impaired structure of anaerobic microbial membrane [21]. Since one of the advantages of SAnMBR in sewage treatment is to recover methane as bioenergy, to explore the LAS effect on the methanogenic potential of anaerobic sludge is of great importance.

Hence, the main purpose of this study is to investigate the LAS influence on the SAnMBR performance in sewage treatment via long-term operation including COD removal, biogas production, pH, membrane fouling, SMP, EPS and SS/VSS. The fate of LAS and its influence on the sludge activity of methane production were also studied in detail according to the results from reactor and batch experiments. The results indicated that LAS was rather adsorbed on the sludge surface than degraded and its adsorption indeed led to significant loads in sewage sludge. The methane recovery efficiency in sewage treatment decreased due to the presence of LAS in the wastewater. Finally, the influence mechanism of LAS on the anaerobic process in sewage treatment by SAnMBR was proposed according to all the experimental results. The findings in this study are expected to provide some useful information that whether SAnMBR is suitable to dispose LAS containing sewage or not.

2. Methods

2.1. SAnMBR setup and operation

As shown in Fig. 1, a submerged anaerobic membrane bioreactor (SAnMBR) with a working volume of 6 L was operated at 25 ± 1 °C using a flat-sheet submerged membrane (Kubota Corporation, Osaka, Japan). The membrane that fixed in the lower part of SAnMBR was made of chlorinated polyethylene with a non-woven fibrous support (polyethylene terephthalate: PET), which has a normal pore size of 0.2 μm and a total area of 0.116 m^2. A coarse tube diffuser was located below the membrane. Biogas in the headspace was recirculated by a pump at a flow rate of 5 L/min to provide membrane hydrodynamic shearing and reactor mixing. Permeate was suctioned by a peristaltic pump. Trans-membrane pressure (TMP) was measured by a pressure sensor located on the permeate line. The reactor was warmed by water circulation. A wet gas meter was used to measure the amount of daily biogas. The characteristics and composition of the synthetic sewage were shown in Table S1. The substrate tank was stirred (200–300 rpm) to keep the substrate at a uniform state. The reactor was inoculated with waste activated sludge from the municipal sewage treatment plant (Sendai, Japan).

The long-term experiment was divided into stage I (without LAS, 80 days, 2 phases) and stage II (with LAS, 167 days, 3 phases). The reactor operation at different phases were summarize in Table 1. Fig. S1 showed the structure of used LAS (sodium dodecyl benzene sulfonate, Wako Pure Chemical Industries, Ltd.).Membrane was changed once the TMP reached to 30 kPa. After putting back the cleaned membrane, air in the reactor headspace was replaced by nitrogen gas.

2.2. Specific methanogenic activity and batch experiment

The specific methanogenic activity (SMA) of sludge and batch experiments were all carried out in 120 mL serum bottles using

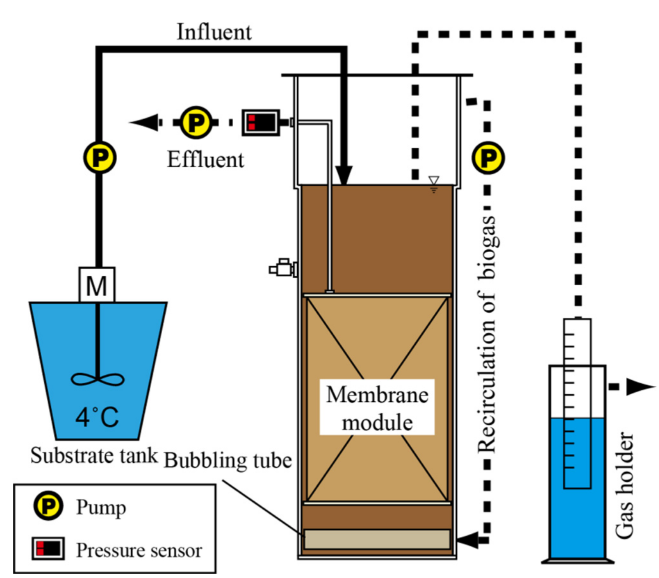

Fig. 1. Schematic diagram of the used SAnMBR.