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Research paper

Characteristic of high temperature fermentation for ammonia production

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ABSTRACT

This study investigated ammonia production and recovery under high temperature conditions. A reactor with a working volume of 2.0 L was fed with synthetic wastewater, and then the temperature was increased at 1 °C d^{-1} at HRT (Hydraulic Retention Time) of 4 days. The effects of sludge return, temperature (50–80 °C), HRT (4–10 days) and influent TS (Total Solids) levels (3.02–4.83%) on ammonia fermentation were studied in this work. In the ammonia production phase, the maximum ammonia concentration was obtained for runs with the sludge return method at 72 °C. With increased HRT and influent TS up to 4.23%, the ammonia concentration was increased. The ammonia stripping flow rate ranged from 0.10 to 0.25 L L^{-1} min^{-1}. With an increased flow rate, the ammonia removal efficiency was increased. In this study, if all of the removed ammonia was recovered, 0.431 L d^{-1} liquid ammonia would be achieved.

1. Introduction

Unavoidable consequences of the extraction of fossil fuels and their excessive use in the transportation sector have resulted in harmful effects on human health and welfare as well as on the environment all over the world. Therefore, there is a strong need to develop environmentally benign and sustainable alternatives. The use of anaerobic digestion is a carbon neutral process (Wang and Wan, 2009) and has been recently noted as a means of energy production. In the process of anaerobic digestion, organic matters are converted to volatile fatty acids (VFAs). The VFAs are subsequently converted into acetate and H_2, and finally CH_4 and CO_2 are produced by the use of methanogens (McCarty and Smith, 1986). Anaerobic digestion has been widely used for the treatment of organic wastes including sewage sludge. Anaerobic decomposition of uric acid and proteins resulted in the production of high amounts of unionized ammonia and ammonium ions (Chen et al., 2008). Excessive amount of ammonia can inhibit the anaerobic microbial activity, which are crucial for the production of methane (Nielsen and Angelidaki, 2008). Therefore, several attempts have been made to avoid the accumulation of ammonia during anaerobic digestion.

However, ammonia has the potential to generate energy as biofuel because ammonia can be decomposed into hydrogen and nitrogen and is carbon-free (Rong et al., 2012). Ammonia is easy to transport and store due to its liquefaction at conditions of 20 °C and 0.857 MPa. The extraction of hydrogen from ammonia and its application to a fuel cell system was proposed by Saika (2009). Therefore, if ammonia is produced by ammonia fermentation and recovered before anaerobic digestion, both ammonia and methane as sources of energy will be efficiently obtained.

It was reported that the continuous production of methane was achieved when the accumulated ammonia was removed (Nakashimada et al., 2008). However, no research regarding the optimum condition for ammonia fermentation was reported. Ammonia fermentation was defined as ammonia production by the microorganisms in this paper. As a result, the optimum conditions for ammonia production must be analyzed. It is reasonable that the controlling factors for the optimal conditions include temperature, HRT and influent TS.

It was reported the high microbe concentration was able to be kept for the sludge return process (Kafle and Kim, 2011). The sludge return process separated the solid from the fermentation liquor and returned the substrate. The advantage of this process was supposed

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that the fermentation could not be inhibition under the organic matter loading rate.

Regarding the recovery, it was reported that the volatilization of the free ammonia that is dissolved in water can be facilitated at high temperature and pH (Saracco and Genon, 1994). The ammonia gas will be discharged at high temperature such as 80 °C (Bonmati and Flotats, 2003). Additionally, the hydrolysis of solid matters could be promoted under high temperature.

However, ammonia stripping from wastes in a liquid form was previously attempted as a useful means of removing ammonia, for example, from the anaerobic digestion effluent (Lei et al., 2007). Ammonia exists in two forms in liquid: ammonium ions and volatile ammonia. Because the volatility of ammonia is temperature-dependent, the substrate temperature and air temperature should be maintained at sufficiently high levels. Therefore, temperature and pH are identified as the most cost sensitive ammonia stripping parameters (Jianf et al., 2014). The air flow rate also should be controlled appropriately because an excessive high air to waste-sludge ratio could cause a reduction of ammonia volatility. The absorption process was important when suitable flow rate and pH were maintained (Jianf et al., 2014). Maintenance of pH at higher levels is also important for the volatilization of ammonia because ammonium ions are converted to ammonia at high pH.

In this study, our first task was to research ammonia production from synthetic wastewater under thermophilic conditions. The comparison with the sludge return method and no sludge return method, and the effects of temperature, HRT and influent TS on ammonia fermentation were studied. The optimum condition of ammonia fermentation was determined. The second task was to investigate and simulate the ammonia stripping and to combine ammonia fermentation with stripping. The flow rate of ammonia stripping in this study was adjusted at high pH and temperature. The simulation of the ammonia stripping and recovery was performed.

2. Materials and methods

2.1. Materials

The sludge of thermophilic anaerobic digestion (50 °C) obtained from the Tokyo Morigasaki Water Reclamation Center (Tokyo, Japan) was used as a seed sludge in this study. The soluble protein powder (active protein 100, ORIHIRO Co, Ltd, Gunma, Japan) dissolved in distilled water was used as a substrate. Their chemical compositions are summarized in Table 1.

2.2. Experimental set up

Experiments were conducted in a 3.0 L glass reactor with a working volume of 2.0 L. The experimental reactor for semi-continuous ammonia fermentation used in this study is outlined in Fig. 1. The temperature in the reactor was controlled using a thermostat bath and heater. The sludge was mixed at a rotation rate of 50 rpm. The water trap for the ammonia recovery was connected through a tube to the reactor. The effluent was drawn into a beaker in a bell jar connected with a vacuum pump.

2.3. Experimental procedure

2.3.1. Effects of temperature on ammonia fermentation

In the startup phase, the seed sludge and the substrate were mixed at a volume ratio of 3:1 and acclimated at 50 °C for 15 days. For the first 10 days, the semi-continuous ammonia fermentation was in the form of conduction without sludge return. For the next 5 days, the experimental method was divided into the no sludge return method and the sludge return method. In the sludge return method, the effluent was centrifuged at 700× *g* for 5 min, and the obtained sludge was diluted to the substrate volume of 0.5 L and returned to the reactor. The HRT was set at 4 days. The operation was maintained until the ammonia concentration became nearly constant and achieved to steady state. Starting from the 16th day, the temperature was increased at 1 °C day^{-1} up to 80 °C. The operational conditions of the different experiments are summarized in Table 2.

2.3.2. Effect of HRT on the ammonia fermentation

The fermentation liquor of the sludge return method was used as the seed sludge of this experimental material. In the sludge return method, the effluent was centrifuged at 700× *g* for 5 min, and the obtained sludge was returned to the reactor with the feedstock. The volumes of the feedstock were 0.50, 0.33, 0.25 and 0.20 L for the runs with the HRT of 4, 6, 8 and 10 days, respectively. The experiment was performed under the constant condition of 80 °C after the experiment to the effects of temperature on ammonia fermentation. The influent TS level was 4.83%. Ammonia fermentation was performed at HRTs of 4, 6, 8 and 10 days. When the ammonia concentration was stable for 3 days, the average data were used.

2.3.3. Effect of influent TS on the ammonia fermentation

The fermentation liquor of the sludge return method was used as the seed sludge of this experimental material. The experiment was performed at 70 °C with the HRT of 4 days using the sludge return method, based on the research results obtained from changing the temperature of ammonia fermentation in 3.1. In the start up, the seed sludge and the substrate were mixed at a volume ratio of 3:1 and acclimated at 50 °C for 12 days. The temperature was increased at 1 °C day^{-1} up from 50 to 70 °C. Ammonia fermentation was performed at the influent TS levels of 3.02, 3.62,

Table 1
Characteristics of the seed sludge and the substrate.

Parameter	Unit	Seed sludge	Substrate			
Influent TS	%		3.0	3.6	4.2	4.8
pH	–	7.9	7.6	7.6	7.6	7.6
Ammonia concentration	g L^{-1}	1.2	–	–	–	–
VS	%	1.1	2.9	3.5	4.1	4.7
SS	g L^{-1}	3.9	11.9	14.3	16.7	19.1
VSS	g L^{-1}	3.4	11.3	13.6	15.9	18.1
VA	g L^{-1}	1.1	–	–	–	–
TN	%TS	7.1	17.8	17.8	17.8	17.8

TS-Total solids, VS-Volatile solids, SS-Suspended solids, VSS-Volatile suspended solids, VA- Volatile acid, TN- Total nitrogen.

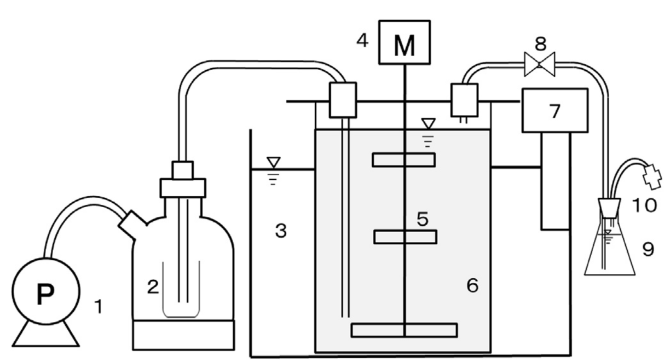

Fig. 1. Schematic drawing of the apparatus for semi-continuous ammonia fermentation. (1) Vacuum pump, (2) bell jar, (3) thermostat bath, (4) stirring motor, (5) stirring device, (6) reactor, (7) heater, (8) Valve, (9) water trap, and (10) one-way valve.