間欠接触酸化法の適用における脂質分解挙動

Lipid Degradation Behavior in the Application of the Intermittent Contact Oxidation Process

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1. Background and Objectives

Wastewater treatment systems are comprised of the treatment technology and the collection system. The collection system collects and transports wastewater from the source to the end-of-pipe treatment facility. During transport, biological degradation of pollutants can occur in the sewer pipe through a process called sewer self-purification. The capacity for self-purification was shown to be improved by the modification of the inner pipe walls which allows biomass retention. The modification increases surface available for biomass growth which subsequently increases the pipe's self-purification capacity. Shoji et al. [1] studied pollutant removal using a modified pipe wherein sponges were installed. The study produced encouraging results prompting the proposal of a novel wastewater treatment technology termed as "in-sewer treatment". Even though in-sewer purification successfully demonstrated its capacity to degrade organic pollutants, there is a concern for the accumulation of substances like lipids which are present in sewage. These can accumulate within the sponge media and cause performance deterioration.

Lipids – comprised of fats, oils, greases, and free fatty acids – make up 10 – 80% of the total chemical oxygen demand (COD) of municipal wastewater [2]. When discharged, these lipids exist in a water-insoluble suspension which can accumulate and cause fouling in the sponge.

Here, the application of the Intermittent Contact Oxidation Process (ICOP), an oxygen supply mechanism observed in in-sewer purification, was explored for lipid removal capacity within a simulated sewer pipe. The ICOP uses fixed sponge media to support microbial growth. This active biomass is then intermittently exposed to wastewater wherein at a high wastewater flow, substrate is supplied and at low flow, the fixed media is exposed to air while retaining moisture. This study explored the performance of ICOP for the degradation of lipid load focusing on the effect of intermittent wastewater flow intermittency.

2. Materials and Methods

2.1. Experimental setup

Air-tight closed pipe reactors (working vol. 1.75L) fitted with oxygen detectors were operated at 20-21°C (**Fig. 1a**). Margarine (**M**), calcium oleate (**CO**), and 5% methyl oleate in hexadecane (**5% MO-HD**) were used as lipid substrates. Three substrate sponge sheets (0.3

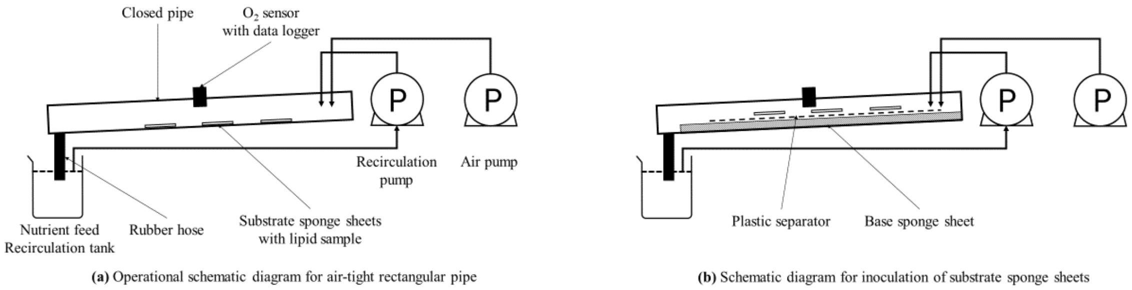

Fig. 1 Schematic diagram for air-tight rectangular channel.

cm depth, 3.5 cm width, and 7 cm long) were placed into each reactor wherein the substrate sponge sheets containing the same lipid substrates were placed together in one reactor. Each reactor contained a total of 3 g of substrate. The substrate sponge sheets were inoculated by incubating them for 7 days together with base sponge (1 cm depth, 7 cm width, and 40 cm long) (**Fig. 1b**). The base sponge was inoculated using return activated sludge from a municipal wastewater treatment plant.

After inoculation, the base sponge was removed and the respiration of the substrate sponge sheets was monitored. Nutrient medium, containing only nitrogen and phosphorous, was recirculated by operating the recirculation pump in 8-hour cycles as follows: 5 minutes operation every 25 (**B**), 55 (**C**), 115 (**D**), 235 (**E**), 475 (**F**) minutes, and continuous flow operation (**A**). Fresh air was reintroduced into the reactor for 2 minutes every 8 hours via the air pump. The air pump had a maximum capacity of 5 L/min.

2.2. Estimation of degradation rate

Lipid degradation rate was estimated from the oxygen consumption rate. The mass of oxygen consumed was taken directly as the mass of lipid COD oxidized by aerobic metabolism. The lipid degradation rate was expressed as mass of COD oxidized per total volume of substrate sponge media per day.

3. Results and Discussion

3.1. Effect of media headspace-gas exposure

The change in oxygen concentration in the headspace-gas for margarine is plotted in **Fig. 2**. The profile shows the linear decrease of oxygen concentration. The section within the broken lines spanned by double-headed arrows were the durations per cycle considered in taking the oxygen consumption rate of each reactor. The oxygen consumption rate was estimated from the linear slope gathered from the middle 6 hours of each recirculation pattern.

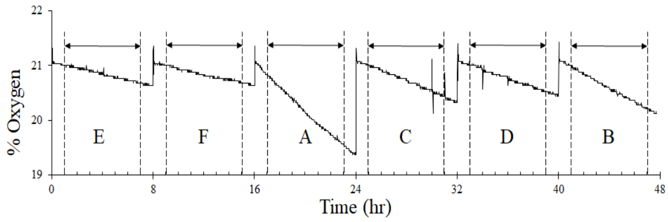

Fig. 2 Oxygen concentration change over time per applied nutrient feed recirculation pattern (margarine as substrate).

The rate profile (**Fig. 3**) illustrates that extended periods of media headspace-gas exposure decreased degradation rate. The results suggests that the degradation is affected by the supply of dissolved oxygen (DO) present during conditions with water flow.

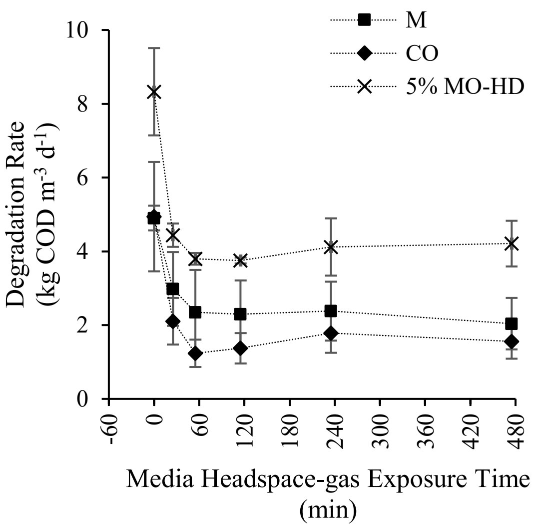

Fig. 3 Degradation rate of different lipid substrates with various extents of media headspace-gas exposure (n = 3 for all points, except for 235 minutes headspace-gas exposure time where n = 2).

The theoretical explanation on the observed increase in rate with continuous water flow lies in how the biofilm acquires oxygen. With water flow, the water layer that is exposed to air flows in and around the sponge media and the biofilm. Because this layer is cycled, it can be exposed to the gas-phase intermittently allowing it to replenish DO while supplying oxygen to the biofilm.

The degradation observed during extended conditions without water flow can be explained similarly. Without water flow, the stationary water layer allows oxygen dissolution from the gas phase to the biofilm only through slow molecular diffusion thereby allowing sustained but decreased degradation rates.

3.2. Effect of lipid substrate composition

The differences in the observed rates between substrates can be attributed to their properties where stability, chain length, and unsaturation dictate the biodegradability of the lipid source [3]. To prove this, the general hydrocarbon profile of each lipid substrate was compared as seen in **Fig. 4**.

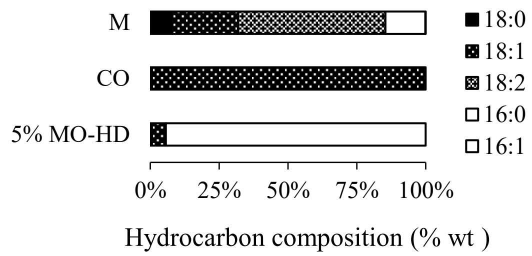

Fig. 4 Lipid substrate hydrocarbon chain saturation profile.

It was shown that the M and CO samples had similar degradation rates. The slight difference where CO degraded faster can also be explained by the degree of saturation of the C18 species found in each substrate. However, it could not be concluded for both samples because the margarine sample also contained C16 species. As the 5% MO-HD sample contained 95% hexadecane, it was inferred and confirmed that the sample would degrade fastest because of its high content of straight chain C16 hydrocarbon.

3.3. Effect of initial headspace-gas oxygen concentration

The degradation rates of various lipid samples were estimated from the slope of the 2 h evaluation under different initial oxygen concentrations in the headspace-gas (**Fig. 5**). There were two different trends that could be seen from the figure: (1) there was a general increase in degradation rate with increasing headspace-gas oxygen concentration, and (2) there was a general decrease in degradation rate with increasing duration of media exposure under various initial headspace-gas oxygen concentrations. The second result is consistent with the trend found in the previous section.

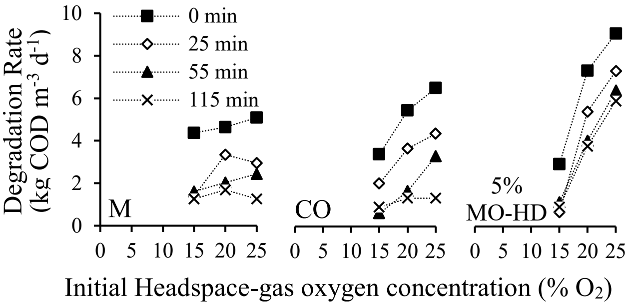

Fig. 5 Change of degradation rate with oxygen concentration under various extents of media headspace-gas exposure.

The results showed that maintaining headspace-gas oxygen concentration at normal levels is enough to give a reliable degradation performance which is not stringent because the gas-phase oxygen concentration in long sewer pipes only vary between 20 – 21 $\%O_2$ [4].

3.4. Effect of nutrient concentration

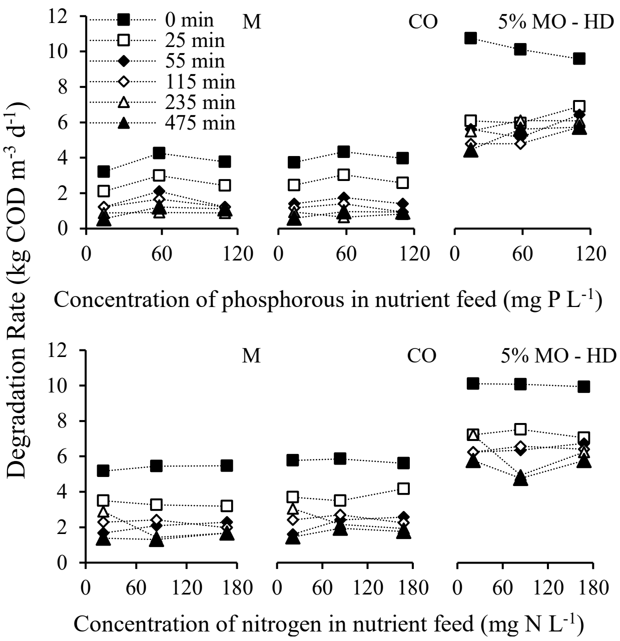

Fig. 6 Change of degradation rate with various nutrient concentrations.

The effect of various nutrient concentrations in the nutrient feed was explored by varying the nutrient feed make-up. The degradation rates of the six preparations, P1, P2, P3, N1, N2, and N3, per lipid substrate used are plotted against various nutrient concentrations (**Fig. 6**). The rate profiles for all preparation sets showed a consistent trend for all substrates where extended periods without water flow decreased degradation rate which agreed with the trend found for the effect of media headspace-gas exposure time. There were no dramatic differences in the observed degradation rates found per set per substrate.

4. Concluding Remarks

1) The experimental lipid COD degradation rate that ranged between 1. 1 – 8.3 kg COD/(m^3 · day) was observed with potential reaeration with water flow and with reaeration through intermittent media headspace-gas exposure.

2) Intermittent media headspace-gas exposure affected degradation rate wherein extended conditions without water flow decreased but sustained degradation at 24 – 43% of the highest estimated degradation rate.

3) Setting initial headspace-gas oxygen concentration to 25 $\%O_2$ increased degradation rate by 9 – 50% compared to the degradation rates for normal initial oxygen concentration.

4) Substrate composition affected degradation rate where increased chain length and saturation of the lipids substrate decreased degradation rate.

5) Nutrient concentration in the nutrient feed did not affect lipid degradation rate within the given range.

5. References

[1] Shoji et al, *J. Water Envi. Tech.* **13(6)**, 427-439 (2015). [2] Sophonsiri et al, *Chemosphere*, **55**, 691-703 (2004). [3] Varjani, *Bioresour. Technol.*, **223**, 277-286, (2017) [4] Huisman et al, *Water Res.*, **38**, 1089-1100, (2004).