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Short communication

Effect of fatty oil dispersion on oil-containing wastewater treatment

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Abstract

The performance of an immobilized continuous fluidized reactor for salad oil-containing model wastewater was examined at a high loading rate using polyurethane as a support, to be applied in fat- and oil-containing wastewater treatment, generated by daily activities in restaurant kitchens. At an organic loading rate higher than 0.6 kg/m^3/day, there was a significant amount of white solid (WS), identified as a mixture of calcium di-stearate and di-palmitate, suggesting that saturated fatty acid degradation was limited at such a high loading rate, possibly due to its solubility in the wastewater. Increased oil dispersion by the addition of a surfactant ranging from 10 to 100 μm particle size could result in less than 30 mg/l oil concentration after the treatment at 5 kg/m^3/day.

Keywords: Fats; Oils; Immobilized reactor; Particle size; Dispersion; Saturated fatty acid; Waste

1. Introduction

Fats and oils are typically contained in wastewater generated from kitchens, e.g. in restaurants, and they tend to clump together and clog drain lines and grease traps. Fats and oils are essentially triglycerides consisting of straight-chain fatty acids attached, as esters, to glycerols. Biological triglyceride degradation is generally recognized as the hydrolysis of ester bonds by lipase followed by the degradation of the released fatty acids via beta-oxidation. Additional specificities (positional, fatty acid residues, or stereochemical) of microbial lipases and specificities in fatty acid degradation should be considered since fatty acid residues in the triglycerides of fats and oils are saturated or unsaturated, and may contain an odd or even number of carbon atoms. Nevertheless, few reports have focused on the substrate specificities in fat- and oil-containing wastewater treatment. Bioaugmentation technology [1–3] is also necessary after estimating the critical steps in fat and oil degradation.

In this report, we examined an immobilized fluidized reactor for salad oil-containing wastewater treatment at a high loading rate and found that long-chain saturated fatty acid degradation is critical but ester hydrolysis is not. Based on this finding, the oil particle size in the reactor was optimized to enhance saturated fatty acid degradation.

2. Materials and methods

2.1. Bioreactor

A schematic diagram of the continuous bioreactor (working volume 5 l) with artificial oil-containing wastewater is shown in Fig. 1. Commercially available porous polyurethane cubes were used for immobilization support. The activated sludge was obtained from the grease trap in our company restaurant.

2.2. Reactor operation

Polyurethane foam (No. QPB13, 1 cm × 1 cm × 1 cm, Bridgestone Kaseihin Co., Tokyo, Japan) was used for

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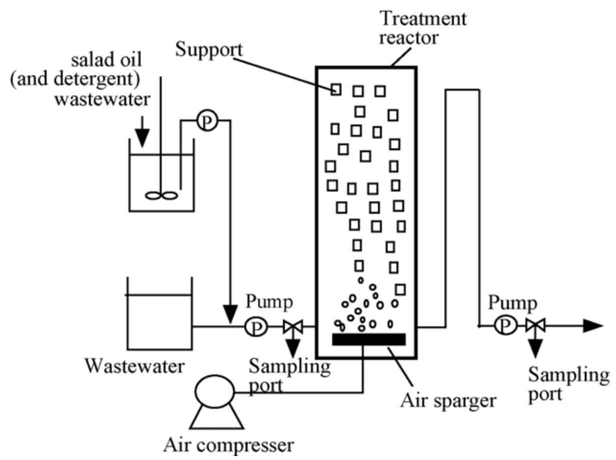

Fig. 1. Schematic system of oil-containing wastewater treatment with immobilized activated sludge.

immobilized support in the reactor (30 vol.%). Artificial wastewater (0.2% yeast extract (Difco, MD, USA), 0.2% Bacto-peptone (Difco, MD, USA), 0.04 ml Tween 80 (Tokyo Kasei Co., Tokyo, Japan), and 1000 ml of tap water, Biological oxygen demand 376 ± 21 mg/l) was introduced into the reactor with commercial salad oil (Nisshin Oil Co., Tokyo, Japan). All the operations were performed at 30 °C at an air flow rate of 0.5 vvm. Batch operation was performed before continuous operation to ensure that the activated sludge was immobilized on the support with fill-and-draw of the wastewater for about 7 days. After starting the continuous operation, the oil-loading rate was increased to the desired level by introducing salad oil-containing wastewater stirred at 300 rpm into the inlet. In order to control the oil particle size, a surfactant was added at 10 g/l with 3000 rpm mixing. The oil-loading rate (R) was defined as follows:

$$R = \frac{C_{\mathrm{FO}}\,(\mathrm{kg/m^3}) \times F\,(\mathrm{m^3/day})}{V\,(\mathrm{m^3})}$$

where R is the oil-loading rate, C_{FO} the oil concentration in the reactor, F the wastewater flow rate and V is the reactor volume. In this study, R was increased by increasing the C_{FO} with the residence time (V/F) of 4 h.

2.3. Sampling and analyses

The oil concentration in the effluent was estimated as the *n*-hexane-extract amount prepared according to the Japan Industrial Standard method (No. K010224). The oil-particle diameter distribution in the reactor was analyzed by Mastersizer X (Malvern Instrument Ltd., Worcestershire, UK), according to the manufacturer's instructions. Soluble BOD was estimated according to the Japan Industrial Standard method (JIS.K0102.21) using biosensor type a-1 (Central Kagaku Co., Tokyo, Japan).

2.4. White substance (WS) analysis

Infrared spectrum (IR), elemental composition and gas-chromatography/mass spectrum (GC/MS) were performed by the Japan Energy Analytical Center Co. (Saitama, Japan).

2.5. Chemicals

A commercial surfactant, Family (Kao Co. Ltd., Tokyo, Japan) was used to enhance the oil dispersion, and contains alkyl ether sulfate as the main component. All other materials were of the highest purity commercially available and were used without further purification.

3. Results and discussion

Fig. 2 shows the continuous treatment results of salad oil-containing wastewater using the fluidized reactor (Fig. 1) without a surfactant addition. At an oil-loading rate higher than 0.6 kg/m^3/day, the outlet oil concentration was gradually increased, and a white solid substance (WS) appeared in the final stage, reaching an outlet oil concentration higher than 100 mg/l. The WS was observed even when the support material was changed to polyester or polypropylene (data not shown). The WS was water insoluble but was soluble in diethyl ether at acidic pH, suggesting that it is an acidic substance. GC/MS analysis of the diazomethane methyl ester of the diethyl ether extract revealed that the extract consisted of stearic acid and palmitic acid but no unsaturated fatty acids such as oleic acid were detected. WS element analysis revealed that (%) C: 68.0, H: 12.7, O: 12.0, Ca: 6.6 (with minor elements of S, N, Mg and Na), giving a composition of $C_{30.2}H_{67}O_4Ca_{0.9}$. The IR profile of WS showed the typical spectrum for carboxylic acid salt at 1580 and 1360 cm^{-1} (Fig. 3c). In addition, it was identical to that of authentic calcium stearate. Based on the above data, it was concluded that the WS component is a mixture of calcium stearate and calcium palmitate. The fatty acid composition of the salad oil before treatment was determined as palmitate (16:0):7.8%, oleate (18:1):54.7, linolate (18:2):30.2, linoleate (18:3):7.2.

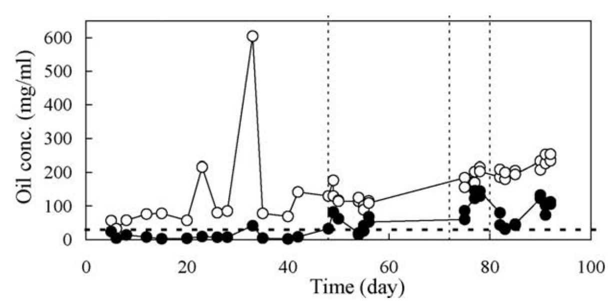

Fig. 2. Time course of continuous treatment of salad oil-containing wastewater using an immobilized reactor without surfactant addition. Open symbols: inlet oil concentrations. Closed symbols: outlet oil concentrations.

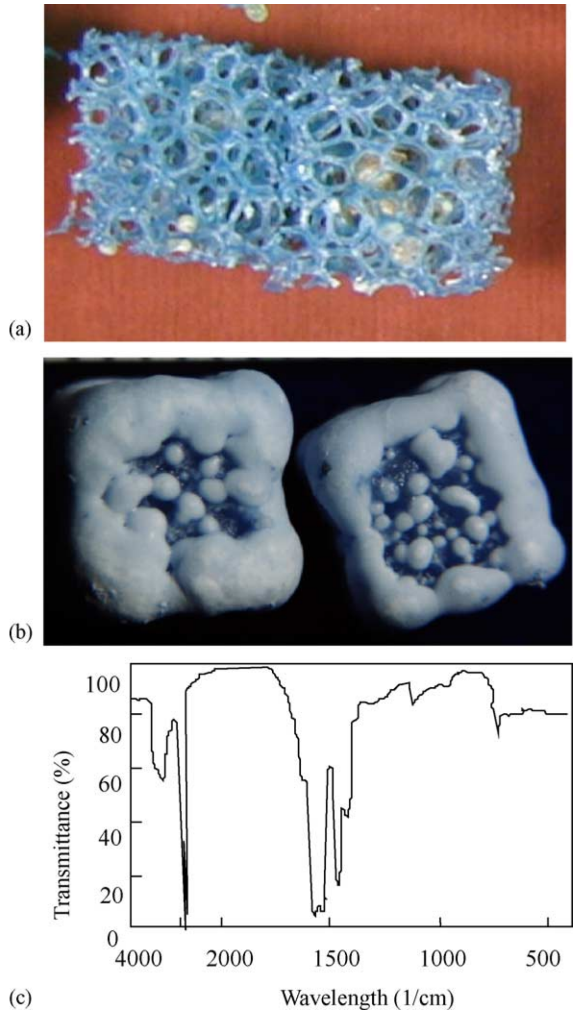

Fig. 3. Photograph of polyurethane support, (a) at initial treatment, (b) attached to the WS, (c) infrared spectrum of WS appeared at a high oil-loading rate.

As the minor component of palmitate or trace of stearate was accumulated as a calcium salt at a high loading rate, this suggests that long-chain saturated fatty acids are less degradable due to lower dispersion than unsaturated fatty acids. Again, it is clear that saturated fatty acid degradation, possibly by beta-oxidation, is more important than triglyceride hydrolysis by lipase, resulting in the appearance of WS, which may decrease oil treatment efficiency, as shown in Fig. 4.

To evaluate the effect of dispersion, emulsified wastewater was introduced by placing an emulsification vessel in front of the inlet (Fig. 1) as described in Section 2. As shown in Fig. 5, the emulsified oil particles ranged from 10 to 100 μm (98%), and were continuously introduced into the reactor. No WS developed and the outlet oil concentration was maintained below 30 mg/l even at a loading rate of 5 kg/m^3/day. Emulsification by alkyl ether sulfate-based commercial surfactant was more effective than sugar ester-type surfactant or saponin (data not shown), suggesting that the anionic

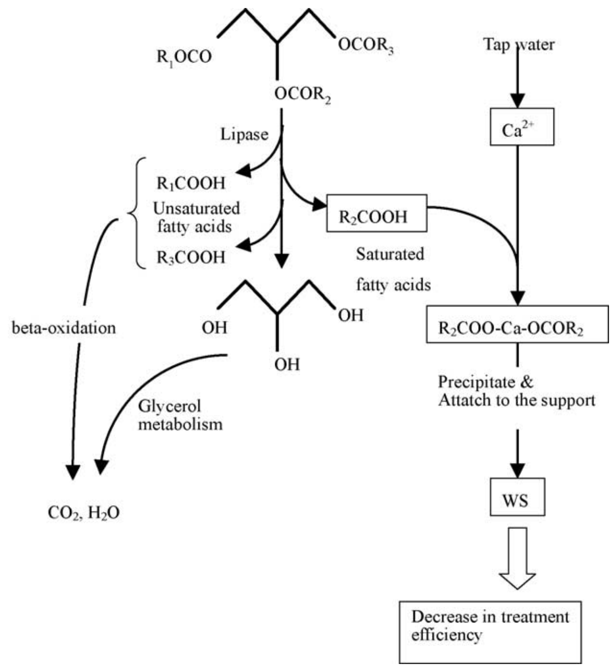

Fig. 4. Proposed mechanism for generating WS at a high loading rate.

detergent was more suitable than the non-ionic detergent. In contrast, for solubilizing oil and grease, not fatty acids, non-ionic, of the alkyl phenol or ethylene oxide type surfactants were used for greasy wool scouring wastewater under anaerobic biological treatment [4–6]. In addition, saponin was patented for treatment of oil in a grease trap (JP1999-267095). To our knowledge, there have been very few report on fat- and oil-containing wastewater treatment by immobilized reactor. Using a porous support may enhance the accumulation of the recalcitrant saturated fatty acid compared to the case in non-immobilized reactor although immobilization is regarded as a good system for maintaining high

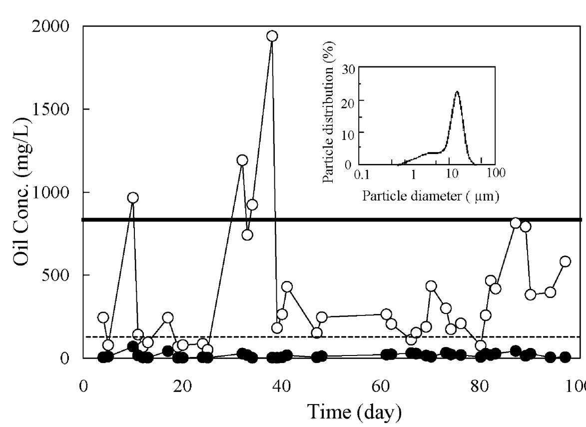

Fig. 5. Time course of continuous treatment of fat-containing wastewater using an immobilized reactor with surfactant addition. Inset: Particle-diameter distribution ratio in the inlet of the reactor. Symbols are identical to Fig. 2. Thick line corresponds to an oil-loading rate of 5 kg/m^3/day.

activated sludge concentration in the reactor. Alternatively, another emulsification method could be applied. Wakelin and Forster [7] reported that a reactor with mechanical mixing using free-activated sludge enhanced grease-containing fast-food restaurant wastewater. We are currently examining the possibility of biosurfactant addition to improve oil dispersion in oil-containing wastewater treatment.

4. Conclusion

The degradation of saturated fatty acids, such as stearate and palmitate, not ester hydrolysis, was found to be limited in fat- and oil-containing wastewater at a very high loading rate. Controlling the oil particle size in the range of 10–100 μm resulted in the successful operation of an immobilized fluidized reactor at a high oil-loading rate of 5 kg/m^3/day. This could be applied for practical fatty oil-containing wastewater generated from daily kitchen activities, such as from fast-food restaurants.

In addition, the use of microorganisms characterized by such saturated fatty acid degradation may lead to treatment at a higher loading rate.

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References

[1] D. Keenan, A. Sabelnikov, Biological augmentation eliminates grease and oil in bakery wastewater, Water Environ. Res. 72 (2000) 141.
[2] K. Tano-Debrah, S. Fukuyama, N. Otonari, F. Taniguchi, M. Ogura, An inoculum for the aerobic treatment of wastewaters with high concentrations of fats and oils, Bioresour. Technol. 69 (1999) 133–139.
[3] N.G. Wakelin, C.F. Forster, An investigation into microbial removal of fats oils and greases, Bioresour. Technol. 59 (1997) 37–43.
[4] G. Nakhla, M. Al-Sabawi, A. Bassi, V. Liu, Anaerobic treatability of high oil and grease rendering wastewater, J. Hazard. Mater. B102 (2003) 243–255.
[5] R.G. Stewart, Woolscouring and Allied Technology, second ed., Caxton Press, New Zealand, 1985.
[6] P. Becker, D. Koster, M.N. Popov, S. Markossian, G. Anlianieian, H. Markl, The biodegradation of olive oil and treatment of lipid-rich wool scouring wastewater whole anaerobic thermophilic conditions, Water Res. 33 (1999) 653–660.
[7] N.G. Wakelin, C.F. Forster, The aerobic treatment of grease-containing fast-food restaurant wastewaters, Trans IChemE. 76 (1998) 55–61.