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Improvement of the activity of anaerobic sludge by low-intensity ultrasound

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Abstract

This paper aims to study the enhancement effect of low-intensity ultrasound on anaerobic sludge activity and the efficiency of anaerobic wastewater treatment. Dehydrogenate activity (DHA) and the content of coenzyme F_{420} were detected to indicate the change of activity of anaerobic sludge induced by ultrasound at 35 kHz. Single-factor and multiple-factor optimization experiments showed that the optimal ultrasonic intensity and irradiation period were 0.2 W/cm^2 and 10 min, respectively, and the biological activity was enhanced dramatically under the optimal condition. The chemical oxygen demand (COD) removal efficiency was increased by ultrasonic treatment and the COD in the effluent was 30% lower than that of the control (without exposure). The hypothetical mechanism of biological activity enhancement by ultrasound was also discussed according to the results.

Keywords: Low-intensity ultrasound; Anaerobic sludge; DHA; Coenzyme F_{420}; Ultrasonic intensity; Irradiation period

1. Introduction

Increasingly strict environmental legislation is forcing water and sewerage companies to undertake more advanced levels of wastewater treatment, which leads to greater energy use and sludge production at sewage treatment processes. Anaerobic wastewater treatment processes may offer a solution to the increasing energy use and sludge production at sewage treatment for their small amounts of stabilized sludge and additional methane produced (Leitão et al., 2006). But the development and implementation have not been as quick as was expected by numerous researchers and practitioners. This delay appears for several reasons (Switzenbaum, 1995; Zakkour et al., 2001). Anaerobic reactors are often hard to start up for the tough culturing of anaerobic microorganisms. Anaerobic processes may not treat sewage to levels suitable for direct discharge, and post-treatment following anaerobic treatment is required in certain instances. Therefore, methods for enhancing the bioactivity of anaerobic organics and improving the efficiency of anaerobic wastewater treatment are required urgently.

Many researchers have found that ultrasonic stimulation has the function of promoting the activity of enzyme, cell growth and cell membrane permeability (Barton et al., 1996; Liu et al., 2003; Pitt and Ross, 2003). Lin and Wu (2002) have found that the low power ultrasonic exposure can significantly stimulate the shikonin biosynthesis of the *Lithospermum erythrorhizon* cells at certain ultrasound doses (power density $\leq$113.9 mW/cm^3 and irradiation periods 1–8 min). Meanwhile, the shikonin excreted from the cells also increased due partially to the increase of the cell membrane permeability induced by sonication. Pitt and Ross (2003) found that ultrasound with low frequency of 70 kHz and low acoustic intensity of lower than 2 W/cm^2 increased the growth rate of the *Staphylococcus epidermidis* cells compared to those without ultrasonic irradiation. Liu et al. (2003) found that ultrasonic stimulation could promote the growth and proliferation of *Oryza sativa* Nipponbare cells in the suspension culture with

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the optimal stimulation of 5 s, while with longer agitation, its growth and proliferation were inhibited. Schläfer et al. (2002) have applied ultrasound to enhance a wastewater treatment process for the food industry, and the improvement of biological activity was successfully demonstrated at the frequency of 25 kHz and the power input of 0.3 W/l.

To sum up, the optimal ultrasonic intensity and irradiation period are varied in each biological process enhanced by ultrasound. Thus the aim of this paper is to explore the feasibility of using low-intensity ultrasound to intensify anaerobic biological treatment of sewage and indicate the change of activity of anaerobic sludge induced by ultrasound. The sonication conditions containing ultrasonic intensity and irradiation period were optimized and the efficiency of organic removal enhanced by low energy ultrasonic irradiation was also observed. This paper also presented the hypothetical explanation of the mechanism of biological activity enhancement stimulated by ultrasound.

2. Materials and methods

2.1. Instrument of ultrasonic irradiation

The schematic diagram of ultrasonic irradiation system is shown in Fig. 1. An ultrasonic cleaning bath (Model DL-60D, Shanghai ZhiSun Instruments Co., Ltd., Shanghai, China) was used to treat the anaerobic sludge in the serum bottle. The bath has a fixed frequency of 35 kHz and variable powers from 0 to 80 W.

2.2. Materials

Anaerobic condensed sludge without digestion from a municipal sewage treatment plant (Beijing area) was used for this study, and the concentration of this sludge was as follows: mixed liquor suspended solids (MLSS) was 36.11 g/l, mixed liquor volatile suspended solids (MLVSS) was 15.32 g/l. The samples were preserved at 4 °C before use.

The real sewage used for this study was taken from the university eatery with the COD of over 10,000 mg/l.

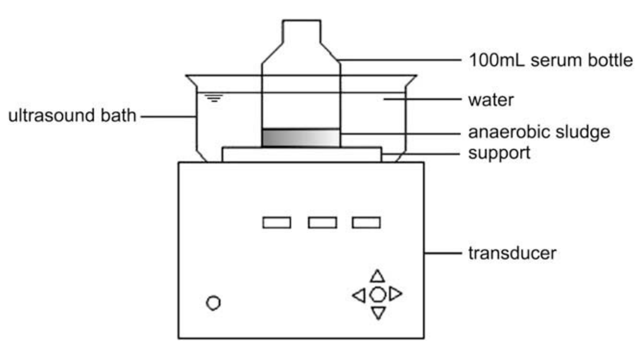

Fig. 1. Schematic diagram of ultrasonic irradiation system.

2.3. Experimental procedures

Anaerobic sludge samples were put into six serum bottles (100 ml) which were cleaned by 99.5% N_2 for several minutes, each bottle took 40 ml sludge. All the bottles were then capped with rubber stoppers and fixed at the center of the ultrasonic bath. All treatments were triplicate and each data point reported in the results was the mean of three reduplicate measurements.

2.3.1. Single-factor optimization experiment

The sludge samples were irradiated with different ultrasonic intensity from 0 to 1.0 W/cm^2 with the same irradiation period of 10 min, and then these sludge samples were incubated at 35 °C with shaking. DHA and the content of coenzyme F_{420} were detected after the incubation to determine the optimal ultrasonic intensity. Then, other sludge samples were stimulated at the optimal ultrasonic intensity with different irradiation periods, and the same operation as above was repeated to determine the optimal irradiation period.

2.3.2. Uniform design method

Uniform design was proposed by Fang (1980), based on quasi-Monte Carlo method or number-theoretic method. The uniform design has its own features, such as its functional agility of arranging experiment runs and its robustness against model uncertainty (Liang et al., 2001). So it would be a good candidate for this study. The ultrasonic intensity and irradiation period were considered to be the main factors influencing the sludge activity. Based on the single-factor optimization experiment as mentioned above, $U_5(5^2)$ (Table 1) was chosen for the experimental design.

Five sludge samples were exposed to different ultrasonic intensity and irradiation periods according to Table 1, and then they were incubated at 35 °C with shaking. DHA and the content of coenzyme F_{420} were detected to determine the optimal ultrasonic intensity and irradiation period.

2.3.3. Real sewage disposal

Three sludge samples were exposed to ultrasound with the optimal intensity and irradiation period, while other three without ultrasonic exposure were treated as control. Real sewage was put into these six serum bottles to be treated and the removal efficiency of COD was determined.

Table 1
$U_5(5^2)$

No.	Irradiation period	Ultrasonic intensity
1	1	2
2	2	5
3	3	3
4	4	1
5	5	4