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Synthetic white spirit wastewater treatment and biomass recovery by photosynthetic bacteria: Feasibility and process influence factors

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ABSTRACT

Photosynthetic bacteria (PSB) can assist with wastewater purification and useful biomass recovery without excess sludge. The feasibility of using PSB to treat white spirit wastewater was studied. The effects of the crucial process factors were also tested. The results demonstrated that using PSB to treat white spirit wastewater was feasible, and biomass production was achieved. PSB exhibited the ability to acclimatize to white spirit wastewater: they were tolerant of a high COD of 9100–25,600 mg l^{-1} and an ethanol concentration of 0.5–2.0% (v/v). In addition, PSB were able to adapt to a pH of 5.0–8.0 and adjust the effluent pH. These characteristics were favorable for white spirit wastewater treatment. In performance improving study, dilution (reflux) was used as a strategy to improve the degradation effectiveness. Refluxing with a ratio of 300% was the optimal method. A similar treatment effect as an anaerobic process was achieved: the COD removal reached 76.02%, and valuable biomass instead of excess sludge was simultaneously obtained.

1. Introduction

Photosynthetic bacteria (PSB) are widely distributed microbes and have existed for a long time in nature. PSB can survive under light-anaerobic or dark-aerobic conditions. Japanese researchers found that PSB had the capability to purify polluted water in the 1970s' (Kobayashi and Tchan, 1973). Since then, PSB have been used to treat various wastewaters such as wastewater from chicken abattoirs, food processing wastewater, dairy wastewater, fermented starch wastewater, and sugar wastewater (Silva and Lacava, 1996; Chitapornpan et al., 2013; Kaewsuk et al., 2010; Prachanurak et al., 2014; Zhou et al., 2014). In these studies, the wastewater treated by PSB had chemical oxygen demand (COD) values ranging from 500 to 9800 mg l^{-1}, and the effectiveness of the COD reduction was satisfying. Apart from the ability to degrade pollutants under a high COD load, PSB are nutrition-rich and contain high-value substances, such as coenzyme Q10, 5-aminolevulinic acid and polyhydroxyalkanoate (Sasaki et al., 2005; Fradinho et al., 2013). Therefore, the biomass production during the wastewater treatment is beneficial. The recovered biomass can be utilized in aquaculture and agriculture (Idi et al., 2015). Consequently, the process of excess sludge treatment is eliminated. PSB wastewater treatment technology has the ability to treat wastewater and recover biomass.

Recently, there has been an increased production of wine or liquor in the world accompanying high-strength wastewater. In particular, the production of white spirits is a huge Chinese industry. The production of white spirits was nearly 12.6 million tons in China in 2014. Correspondingly, a large quantity of wastewater was produced (a ton of white spirits creates approximately 15–25 tons of wastewater) (Li et al., 2010) with a high COD up to 20,000 mg l^{-1}. It is necessary to treat the wastewater to avoid environmental pollution. Generally speaking, wine or liquor wastewater treatment uses the anaerobic process as the first step and then combines other processes to achieve the treatment goal (Pant and Adholeya, 2007). Anaerobic treatment followed by aerobic treatment is a common method to treat white spirit wastewater in China. The method can purify wastewater effectively, but it produces a large amount of excess sludge. Excess sludge causes secondary pollution and its treatment increases the cost. By contrast, white spirit wastewater treatment by PSB because it assists with COD removal and biomass recovery under high COD loads

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without excess sludge.

However, as mentioned above, studies on PSB wastewater treatment technology have barely touched on white spirit wastewater. In this study, PSB were used to treat white spirit wastewater to examine the feasibility of COD removal and biomass accumulation. Crucial factors were tested to examine their influences on the process, and dilution (reflux) was used to improve the treatment performance. The aim of this study was to broaden the application areas of PSB wastewater treatment technology.

2. Materials and methods

2.1. Materials

The PSB strain (*Rhodopseudomonas*) used in this study was isolated from a local pond. It was cultured in a thermostat shaker (120 rpm, 26–30 °C) with improved RCVBN medium for 48 h before use (Lu et al., 2013). The PSB was in the logarithmic growth phase and the activity of the bacteria was the best at that time.

Synthetic white spirit wastewater was prepared with ethanol, n-propyl alcohol, acetic acid, propionic acid, lactic acid, DL-malic acid, glucose, maltose, ammonium sulfate, and monopotassium phosphate. It had a COD of 9000–26,000 mg l^{-1}, ammonia nitrogen (NH_3–N) of 130 mg l^{-1}, and total phosphorous (TP) of 30 mg l^{-1}. These characteristics were similar to the real white spirit wastewater with a high COD concentration, relatively low nitrogen and phosphorus concentration and acid characteristics. The initial pH was adjusted to 7.0 unless stated otherwise.

2.2. Methods

The bioreactors were sterilized at 121 °C for 30 min before use. For all of the experiments, PSB were added into the synthetic white spirit wastewater with a ratio of 20:80 (v/v) in 500 ml flasks as the bioreactors. The PSB were inoculated during the exponential growth phase and the initial concentration of the bacterial suspension was 280.00 mg l^{-1}. The bioreactors in the experiments were put into a shaker with rotating speed of 120 r/min and a temperature at 26–30 °C. The PSB were illuminated by fluorescent lamps to explore the effect of natural light.

2.2.1. Feasibility study

In the feasibility study, the light-anaerobic condition with a light intensity of 3000–4000 lux and the dissolved oxygen (DO) of 0–0.2 mg l^{-1} were used. The white spirit wastewater contained 1.0% (v/v) ethanol.

2.2.2. Influences of process factors

In the process influence factors study, a single factor was examined each time. Three sets of experiments were conducted. The variables were as follows:

The four levels of ethanol concentrations tested were 0.5%, 1.0%, 1.5%, and 2.0% (v/v),.

The tree classical light-oxygen conditions were set as follows. a) Light-anaerobic condition: the light intensity was 3000–4000 lux and the DO was 0–0.2 mg l^{-1} b) Natural light-microaerobic condition: the light intensity depended on the natural environment and the DO was 0.2–1.0 mg l^{-1}. c) Dark-aerobic condition: the bioreactor was covered with a black plastic bag and the DO was approximately 2.0 mg l^{-1}.

The five levels of the initial pH tested were 4.0, 5.0, 6.0, 7.0, and 8.0. NaOH and HCl were used to adjust the initial pH.

2.2.3. Performance improving study

In the degradation effectiveness improving study, dilution with reflux was used. The three levels of the reflux ratios were 0%, 100%, and 300%.

2.3. Analysis methods

The samples were collected from the bioreactors and were centrifuged at 11,000 r/min for 10 min to obtain the supernatant and test the COD. The COD was tested according to the national standard method (HJ/T 399-2007). The collected PSB were then used to measure the biomass production. The pH was measured by a pH tester (PHS-3C, Inesa Instrument Inc., Shanghai, China). The DO was measured by a dissolved oxygen meter (JPB-607A, Inesa Instrument Inc., Shanghai, China). The temperature was measured by a centigrade thermometer.

2.4. Statistical analysis

Each reported value was the average of three or more experimental data by parallel experiments, parallel samples, and parallel detections.

3. Results and discussion

3.1. Feasibility study

In this study, the feasibility of using PSB to treat synthetic white spirit wastewater was studied. The results are shown in Fig. 1.

As Fig. 1 shows, under a high initial COD load up to 14,200 mg l^{-1}, PSB degraded the pollutants and grew normally in the white spirit wastewater. The biomass increased from 280 to 685 mg l^{-1} with time and showed a 150% increase. These results indicate that for PSB, utilizing the organic pollutants dominated by alcohols in white spirit wastewater was practical. Therefore, it is feasible to use PSB to treat white spirit wastewater and recover biomass. The COD decreased more significantly in the 0–72 h than in 72–120 h treatment. Therefore, 72 h was the optimal treatment time.

In this study, the COD removal was 23% after 72 h of treatment. In some previous studies, PSB were used to treat various wastewaters and COD removal was in the range of 60–95% (Zhou et al., 2014; Wu et al., 2015; Azad et al., 2003; Prachanurak et al., 2014). By comparison, the COD removal was low in this study. This might be attributed to the very high initial COD and disordered C/N/P ratio in white spirit wastewater. What's more, the ethanol in the white

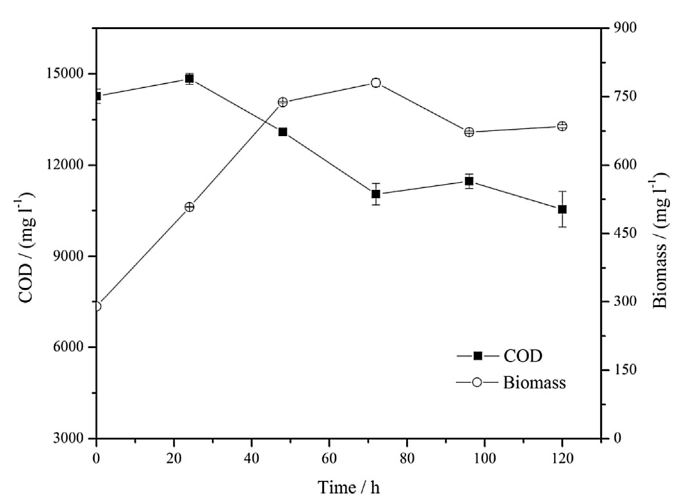

Fig. 1. COD removal and PSB biomass growth in white spirit wastewater, 1.0% ethanol.