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Brewery wastewater treatment and resource recovery through long term continuous-mode operation in pilot photosynthetic bacteria-membrane bioreactor

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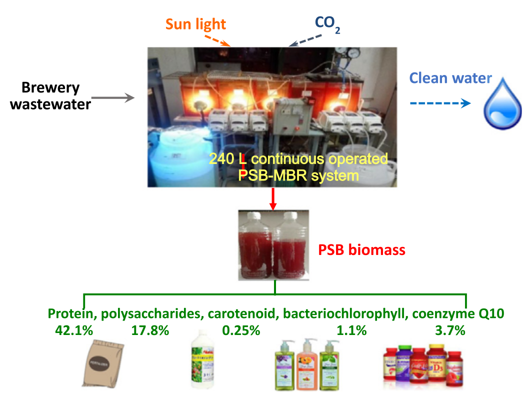
HIGHLIGHTS

- Continuous pilot PSB-MBR firstly used for brewery wastewater resource recovery.
- Operative parameters were determined for long-term pilot-continuous operation.
- PSB-MBR system showed strong robustness to water quality and environment changes.
- Good effluent quality with PSB cell production of 483.5 g L^{-1} d^{-1}.
- PSB cells were non-toxic, rich in protein and value-added substances.

GRAPHICAL ABSTRACT



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ABSTRACT

Photosynthetic bacteria (PSB) are considered ideal for high COD wastewater treatment and resource recovery. This work is the first continuous-mode long-term (440 days) pilot study (240 L) by using PSB-membrane (PSB-MBR) system for such purpose. Results showed that the system started-up in 27 days for brewery wastewater and then stably operated under various temperature, initial COD and pH conditions, which showed fast start-up and strong robustness. Comparing with small-batch PSB-MBR system, the capacity of pollutants treatment degradation rate in the pilot-continuous PSB-MBR system was promoted. The operation parameters for pilot-continuous PSB-MBR system were determined as follows: light-micro aerobic, 72 h hydraulic retention time, 1200 mg L^{-1} inoculum size and 1.0 g L^{-1} d^{-1} organic loading rate, 2.5 F/M. Under these conditions, the COD and NH_4^+ in effluent were below 80 and 15 mg L^{-1}, respectively. The PSB cell production reached 483.5 mg L^{-1} d^{-1} with protein, polysaccharides, carotenoid, bacteriochlorophyll, and coenzyme Q10 of 420.9, 177.6, 2.53, 10.75, 38.6 mg g^{-1}, respectively, showing great potential of resource recovery from organic wastewater. In addition, the collected biomass had no acute toxicity to crucian carps. This work provides a base for the scale-up of this novel technology.

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1. Introduction

Each year, over 10 billion tons of wastewater, mostly consisting of organic wastewater, are generated globally. Biological wastewater treatment technologies, which have been developed over more than a century, are the main methods of purifying organic wastewater (Davis and Masten, 2004). However, the energy requirements for maintaining aeration for microorganisms activities and for further purification of wastewater are high. In addition, large amounts of residual sludge are generated, causing severe secondary pollution. In recent decades, environmental pollution (Wang et al., 2015), energy crises, and resource shortages (Hao et al., 2017) have caused increasing problems, and so the integration of water purification and resource and energy recovery have become a new trend in sewage treatment (McCarty et al., 2011). For example, McCarty et al. (2011) proposed using domestic wastewater as a net energy producer. With the aid of an anaerobic fluidized membrane bioreactor, energy can be generated from wastewater, which further reduces the energy costs of membrane operation (Kim et al., 2011). Batstone and Virdis (2014) outlined wastewater treatment and nutrient recovery, focusing on the generation of value-added chemicals through mixed culture biotechnology using anaerobic digestion technology. Some wastewater treatment plants successfully explored technologies for phosphorous recovery (https://www.mwrd.org/irj/portal/anonymous/stickney) and water regeneration (https://www.pub.gov.sg/watersupply/fournationaltaps/newater).

Photosynthetic bacteria (PSB) are a group of prokaryotes with the original photo synthetic and multiple metabolic systems that enable flexible survival and allow versatile substances utilization (Imhoff and Trüper, 1989). For sewage treatment, PSB utilize carbon (C), nitrogen (N) and phosphorus (P) from wastewater and for proliferation. The PSB cells contain significant amounts of high value-added products, including single cell proteins (SCP), carotenoids, 5-aminolevulinic acid (5-ALA), coenzyme Q, and other physiological activators that can be utilized in agriculture, and in the cosmetic and medical industries (Sasaki et al., 2016). Using PSB to treat wastewater is a technique that has been developed since 1970s (Kobayashi and Tchan, 1973), and over the past 50 years, most studies have emphasized wastewater purification. To date, PSB have been successfully used in the treatment of many types of wastewater, including soybean (Wu et al., 2012), fermented starch (Prachanurak et al., 2014), azo dye (Wang et al., 2015), domestic (Hülsen et al., 2016a, 2016b), critic acid (Zhou et al., 2016) and digested swine (Wen et al., 2016) wastewater treatment. Results showed that high-quality effluent can be achieved using PSB technology.

In recent years, owing to the increasing popularity of the bioeconomy concept, as described above, researchers have begun consider the generation of biomass and high value-added products (bio-resources production from N and P present in wastewater) as being equally important as wastewater treatment efficiency in recent years (Wu et al., 2012; Chitapornpan et al., 2013; Batstone and Virdis, 2014; Idi et al., 2015). For example, Wu et al. (2012) improved biomass production through the addition of trace elements to wastewater. Zhou et al. (2015) improved carotenoid production through optimizing light conditions. Liu et al. (2016) optimized carotenoid production by adjusting the hydraulic retention time (HRT) and organic loading rate (OLR). Qin et al. (2017) improved pollutants removal and biomass production by using a novel pendulum type oscillation hollow fiber module. All the studies were based on short-term batch or semi-batch mode operation. In addition, a few studies exist that used continuous mode PSB wastewater treatment. Chitapornpan et al. (2013) and Prachanurak et al. (2014) used a PSB-anaerobic membrane bioreactor (AnMBR) and a pipe overflow PSB-MBR to treat food processing wastewater and fermented starch wastewater. Hülsen et al. (2016a, 2016b) obtained high-quality effluent using a PSB-AnMBRs to treat domestic wastewater. However, these systems only operated at small scale. Although Kaewsuk et al. (2010) operated a 600 L PSB-MBR, the system was operated in batch mode. To realize large-scale applications, the plant should be scaled up and operated long-term in continuous mode. Furthermore, the safety of the produced biomass should be evaluated for resource utilization.

A PSB-MBR system is an ideal candidate for a scaled-up study. In this system, pollutants were removed by the combined effects of biochemical degradation of PSB and membrane filtration (González et al., 2017). In addition, the membrane can intercept the biomass, which is beneficial for biomass harvesting. For example, Gao et al. (2015, 2016) combined microalgae and membrane to realize wastewater treatment and microalgae biomass production. Lu et al. (2013) harvested 99.5% of PSB biomass using a separated PSB-MBR setup, and the effluent met the national standard. Chitapornpan et al.'s (2013) study also showed that, without a membrane, 64.5% of the total biomass was washed out of the system. In addition, improved membrane fouling control has been achieved, allowing continuous operation to be realized (González et al., 2017; Qin et al., 2017).

To take full advantage of the harvested PSB, the wastewater treated by the PSB should be non-toxic, and preferable a high chemical oxygen demand (COD), so that more cells can be produced. Potential candidates include dairy (Kaewsuk et al., 2010), soybean (Wu et al., 2012), brewery (Lu et al., 2013), starch (Prachanurak et al., 2014), citric acid (Zhou et al., 2016), sugar (Meng et al., 2017) and other food processing wastewater (Chitapornpan et al., 2013).

Therefore, in this study, long-term pilot-scale PSB-MBR treatment of brewery wastewater were carried out in continuous mode. A 240 L PSB-MBR was constructed and operated for 440 d. The stability, pollutants removal efficiency and PSB cell growth potential of the system were evaluated. In addition, the safety of the PSB generated from the brewery wastewater was also investigated. This work is the first pilot-scale, continuously, and long-term demonstration of this technology designed to simultaneously realize wastewater purification and resource recovery.

2. Materials and methods

2.1. PSB

The inoculated PSB were purchased from the Beijingyujing Biotechnology Limited Liability Company, where PSB are sold as fish feed. The main PSB strains were *Ectothiorhodospira*, *Rhodobacter sphaeroides* and *Rhodopseudomonas capsulate*. The PSB were incubated in a thermostat shaker (120 rpm, 26–30 °C) with an RCVBN medium (Yang et al., 2017) for 48 h before use.

2.2. The brewery wastewater

The wastewater was obtained from a local manufacturer and allowed to settle for 1 h to remove the suspended solid. The COD, NH_4^+, TP, SS and pH levels after sedimentation were 2200–3200, 50.0–70.0, 5.0–8.0, 20.0–40.0 mg L^{-1} and 8.0–9.0, respectively. Because of the lack of actual brewery wastewater for some period, artificial brewery wastewater was used as a supplement. Artificial brewery wastewater was created by diluting beer to an initial COD level of 2500–4800 mg L^{-1}. Ammonium chloride and mono potassium phosphate were added to the raw and artificial brewery wastewater so that the initial NH_4^+ and TP levels were approximately about 125.0–240.0 and 25.0–40.0 mg L^{-1}, respectively, providing favorable conditions for PSB growth.

2.3. The PSB-MBR system

The PSB-MBR system is shown in Fig. 1. The reactor was made of transparent plexiglass. The system was 160 cm in length, 30 cm in width, and 50 cm in height. The total volume of the system was 240 L, with a working volume of 200 L. Five flat sheet membranes were submerged in the plexiglass tank in parallel. The interval between each