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High efficient treatment of citric acid effluent by *Chlorella vulgaris* and potential biomass utilization

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HIGHLIGHTS

- *Chlorella vulgaris* C9-JN2010 with the highest growth rate was screened out.
- *Chlorella vulgaris* C9-JN2010 could efficiently remove nutrients in the CAE.
- Under the optimal conditions, the removal efficiencies of nutrients were more than 90.0%.
- Content of algal protein was high (around 500.0 mg g^{-1} of the assayed biomass).
- Proportions of PUFAs in the lipids and essential amino acids in algal protein were fairly high.

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ABSTRACT

The efficiency of treating citric acid effluent by green algae *Chlorella* was investigated. With the highest growth rate, *Chlorella vulgaris* C9-JN2010 that could efficiently remove nutrients in the citric acid effluent was selected for scale-up batch experiments under the optimal conditions, where its maximum biomass was 1.04 g l^{-1} and removal efficiencies of nutrients (nitrogen, phosphorus, total organic carbon, chemical oxygen demand and biochemical oxygen demand) were above 90.0%. Algal lipid and protein contents were around 340.0 and 500.0 mg·g^{-1} of the harvested biomass, respectively. Proportions of polyunsaturated fatty acids in the lipids and eight kinds of essential amino acids in algal protein were 74.0% and 40.0%, respectively. Three major fatty acids were hexadecanoic acid, eicosapentaenoic acid and docosadienoic acid. This specific effluent treatment process could be proposed as a dual-beneficial approach, which converts nutrients in the high strength citric acid effluent into profitable byproducts and reduces the contaminations.

1. Introduction

China produces approximately one million tons of a citric acid as an output of product fermentation (http:// www. hdcmr. com/ bgfree 32552.html) and a total citric acid effluent (CAE) of around 0.5–0.6 billion tons was registered in 2010 with each ton product of citric acid generating 50.0–60.0 tons of wastewater (Zhu et al., 2004). The CAE contains high concentration of organic complex pollutants without toxic matters but rather low levels of heavy metals in the CAE (Table 1), which its treatment is still a hard task to the industry (Chen et al., 2006; Zhi et al., 2010). Commonly, the CAE is treated by biochemical or physical chemistry methods. Relative decrease of chemical oxygen demand (COD_{Cr}) are 69.0–98.0% by physical or (and) chemistry methods (Fu et al., 2007; Shi et al., 2009; Cheng and Lin, 2008) and relative decrease of COD_{Cr} and biochemical oxygen demand (BOD_5) are 70.0–98.0% and 90.0–99.0% by biochemical methods (e.g. aerobic biological treatment or (and) anaerobic biological treatment), respectively (Luo, 1996; Zhu et al., 2007; Wang et al., 2006).

Although the efficiency of wastewater treatment is higher using these traditional methods, these processes are more complicated and lack of renewable resource cycles. *Chlorella* species, under auto/heterotrophic conditions, can assimilate inorganic or (and) organic matters (Toshiyuki et al., 2009; Tamarys et al., 2011). More "environmentally friendly" biological systems based on *Chlorella* (Chlorophyceae) have been developed (Van der et al., 1998). Each ton of micro-algae biomass produced is equivalent to about 1 ton of CO_2 abated (Piccolo, 2009). *Chlorella* species can efficiently

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