Integrated campus sewage treatment and biomass production by *Scenedesmus quadricauda* SDEC-13

Lin Han\(^a\), Haiyan Pei\(^{a,b,*}\), Wenrong Hu\(^{a,b}\), Liqun Jiang\(^a\), Guixia Ma\(^a\), Shuo Zhang\(^a\), Fei Han\(^a\)

\(^a\)School of Environmental Science and Engineering, Shandong University, 27 Shanda Nan Road, Jinan 250100, China
\(^b\)Shandong Provincial Engineering Centre on Environmental Science and Technology, 17923 Jingshi Road, Jinan 250061, China

**Highlights**

- Campus sewage was recycled twice for *S. quadricauda* SDEC-13 cultivation.
- Nutrients were basically removed and sewage could be discharged on standard.
- Lipid content obtained in twice use of campus sewage were all higher 27%.
- Limited nutrients in campus sewage had no effect on the protein and lipid quality.
- Campus sewage without consuming pretreatment can be utilized directly.

**Abstract**

The notion of wastewater treatment combined with biomass production is potential and prospective. Campus sewage was utilized twice in procession to cultivate the newly isolated microalgae *Scenedesmus quadricauda* SDEC-13. Nutrients was efficiently removed with the phosphorus and nitrogen removal efficiency nearly 100% and more than 70% respectively in twice use of campus sewage. Ammonium was consumed rapidly within five days in 1st use. There was no significant difference in the lipid and protein content but distinct difference in their respective productivity which is ascribed to the lower biomass productivity caused by limited nutrients in 2nd use. The diverse nutrient concentration in twice use of campus sewage and BG-11 had effects on the composition of fatty acids and amino acids. SDEC-13 performed better biodiesel quality compared with BG-11 medium and produced high quality protein when cultivated in campus sewage. Finally, the campus sewage after twice use reached the corresponding discharge standard.

© 2014 Elsevier Ltd. All rights reserved.

**1. Introduction**

Using microalgae as feedstock for biomass production is widely popular because of their great potential and abundant advantages comparing with other feedstock. However, due to the high cost for microalgae cultivation, the goal of achieving large-scale commercial production has not been realized. The idea of applying the wastewater as medium for the cultivation of microalgae simultaneously for biomass production and wastewater treatment attracts widespread concern (Kothari et al., 2012). On one hand, wastewater as medium contains sufficient nutrients such as nitrogen and phosphorus that enough for sustaining the growth of microalgae (Yang et al., 2011; Kothari et al., 2012). Furthermore, Yang et al. (2011) pointed out that to produce 1 billion gallons of microalgae-based biodiesel per year the water demand amounted to more than 85% of the annual freshwater usage by US. So choosing the wastewater as substitute for microalgae cultivation greatly reduced the cost for providing the nutrients and water (Chang et al., 2013: Yang et al., 2011). On the other hand, compared with physicochemical treatment applying microalgae for wastewater biological treatment could be more eco-friendly and resource saving (Kothari et al., 2013). In all, cultivating microalgae in wastewater for biomass production is a win–win solution.

Campus sewage as a characteristic domestic wastewater is a vast wastewater source that should not be ignored. The water consumption in colleges and universities is increasing with the surge of staff, capitation water consumption of college students in China is 200–300 L/d which is approximately twice or three times than resident's water consumption according to the related statistical
data thus it puts stress on the treatment of campus wastewater. If this campus wastewater can be handled with a cost-effective method rather than directly discharging into gang of municipal sewage pipe it will be benefit for water regeneration. Campus wastewater is an integrated wastewater combined with sewage from toilets, bathrooms, dormitory, hospital and canteens which contains large numbers of nutrients (Li et al., 2012) and was suitable for biological treatment. The concentration range of typical pollutants in campus sewage are: COD$_{a}$ 120–320 mg/L, TP 2.3–1.5 g/L, K$_2$ 2.86 g/L, MnCl$_2$ 0.04 g/L, MgSO$_4$ was added into the recycled sewage with an initial concentration approximately similar to that in 1st use to meet the phosphorous requirements of algae growth. The experiment was set in triplicate and figures reported in this paper are averages.

2. Methods

2.1. Microalgae strain

The microalgae strain S. quadricauda SDEC-13 used was isolated from a local lake in Jinan Shandong province previously (Han et al., 2014), which displayed best performance during the cultivation in synthetic sewage. It was pre-cultured in BG-11 medium which pH was adjusted to around 7.1. The compositions are as follows:

| NaNO$_3$ | 1.5 g/L | K$_2$HPO$_4$ | 0.04 g/L | MgSO$_4$ | 7H$_2$O | 0.075 g/L | CaCl$_2$ | 2H$_2$O | 0.036 g/L | EDTA | Na$_2$ | 0.001 g/L | Na$_2$CO$_3$ | 0.02 g/L | A$_5$ (trace mental solution) | 1 ml/L | A$_5$ contains H$_2$BO$_3$ | 2.86 g/L | MnCl$_2$·4H$_2$O | 1.86 g/L | ZnSO$_4$ | 7H$_2$O | 0.22 g/L | Na$_2$MoO$_4$·2H$_2$O | 0.39 g/L | CuSO$_4$·5H$_2$O | 0.08 g/L | Co(NO$_3$)$_2$·6H$_2$O | 0.05 g/L |

2.2. Campus sewage

The campus sewage used was derived from the campus of Shandong University, which flowed through the septic-tank. The sewage collected was filtered only by six layers of gauze to remove those large, un-soluble suspended solids. Then the supernatant was put into use directly without other processing such as autoclaving and attenuation. The water quality indexes of campus sewage were measured according to the Chinese state standard testing methods (Administration, 2002) and were shown in Table 1.

2.3. Experimental design

S. quadricauda SDEC-13 kept in BG-11 medium was transferred to the vertical bubble-columns photo-bioreactor (PBR) designed by our laboratory (Patent No. 2012205920571) which containing the supernatant mentioned in Section 2.2 with the initial optical density 0.2 (approximately 0.12 g/L biomass concentration). All these PBRs with the height 30 cm, width 12 cm and 3 L capacity were placed in the artificial climate chamber with the following cultivation conditions: continuous illumination provided by fluorescent tubes (36 W, Philips), light intensity 4000 lux detected by an irradiance sensor (ZDS-10, Shanghai Cany Precision Instrument Ltd., China), temperature 25 ± 1 °C and continuous air aeration (600 mL/min) from the aerator at the bottom of PBRs.

During the cultivation, biomass concentration, NO$_2$–N, NH$_4$–N, TP and pH were determined every day. When the algae reached the decline phase, the strains were harvested by centrifugation. Then the pellets were used to analyze the lipid and protein content, fatty acids methyl ester (FAME) and amino acid (AA) compositions, while, the supernatant was put into reuse for next cultivation. But phosphorus in campus sewage was used up after once use thus excess K$_2$HPO$_4$ was added into the recycled sewage with an initial concentration approximately similar to that in 1st use to meet the phosphorous requirements of algae growth. The experiment was set in triplicate and figures reported in this paper are averages.

2.4. Analytical methods

2.4.1. Microalgae growth

Biomass concentration (dry weight, DW, g/L) was determined daily to indicate the growth properties of S. quadricauda SDEC-13 following the method (Song et al., 2013). The specific growth rate ($\mu$) was calculated by the biomass concentration in the logarithmic phase following the Eq. (1) (Ji et al., 2014):

$$\mu \ (\text{day}^{-1}) = \left(\frac{\text{Ln}N_2 - \text{Ln}N_1}{t_2 - t_1}\right)$$

(1)

where $N_1$ and $N_2$ represent the biomass concentration at $t_1$ and $t_2$ respectively, the biomass productivity ($P_b$) was calculated following the Eq. (2):

$$P_b \ (\text{mg/L/d}) = \left(\frac{X_2 - X_1}{t_2 - t_1}\right)$$

(2)

### Table 1

**Characteristics of the campus sewage used in this study.**

<table>
<thead>
<tr>
<th>Water quality index</th>
<th>COD$_{a}$</th>
<th>NO$_2$–N</th>
<th>NH$_4$–N</th>
<th>TP</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value (mg/L)</td>
<td>240.18</td>
<td>69.58</td>
<td>27.19</td>
<td>2.40</td>
<td>8.70</td>
</tr>
</tbody>
</table>

```
where \( X_2 \) and \( X_1 \) represent the biomass concentration at \( t_2 \) and \( t_1 \) respectively.

### 2.4.2. Nutrient removal

Every day 20 mL microalgae culture was decanted from PBRs then by centrifugation at 4000 rpm, 10 °C for 10 min and filtration by 0.45 μm membranes. After these preprocessing, the supernatant was used to monitor the concentration of \( \text{NO}_3^- - \text{N}, \text{NH}_4^- - \text{N} \) and TP following the Chinese state standard testing methods. The removal efficiency can be calculated following the Eq. (3):

\[
\text{Removal efficiency} = \left( \frac{C_i - C_f}{C_i} \right) \times 100\% \quad (3)
\]

where \( C_i \) represent the concentration at \( t_i \) and \( C_0 \) represent the initial concentration.

### 2.4.3. Lipid content

When the algae began to stop growing, they were harvested by centrifugation and then biomass pellets were obtained. The pellets, washed twice with 0.5 M of ammonium formate, were free-dried by freezing drier (FDU-1200, Shanghai Ailang Instruments Co., Ltd.). The lipids were extracted from the dried algae powder using the chloroform methanol method and quantified gravimetrically as described by Song et al. (2013).

### 2.4.4. Fatty acid methyl ester (FAME) analysis

FAME was extracted using the one-step trans-esterification method and then analyzed through the Trace GC Ultra and DSQMS (Thermo fisher, USA) equipped with an auto sampler (AS3000) and a VF-23 ms fused-silica capillary column (30 m × 0.25 mm × 0.25 um) using helium as carrier to determine the compounds just as Song et al. (2013) described.

### 2.4.5. Amino acid analysis

About 60 mg dried algal powder was prepared to determine the composition of amino acid by amino acid analyzer (L-8900, Hitachi, Japan). The essential amino acid score (EAAS) was calculated following the Eq. (4) (FAO/WHO, 1973):

\[
\text{EAAS} = \frac{\text{mg of essential amino acid/1g of test protein}}{\text{mg of essential amino acid/1g of reference protein}} \times 100 \quad (4)
\]

The essential amino acid index (EAAI) was computed as the following Eq. (5) (Feng et al., 1997):

\[
\text{EAAI} = \sqrt{\prod_{i=1}^{n} \frac{\text{aai}}{\text{AAI}}} \quad (5)
\]

The aai represents the percentage of certain essential amino acid to total essential amino acids in the test protein, AAi is the percentage of certain essential amino acid to total essential amino acids in the reference protein and \( n \) represents the kinds of essential amino acid.

### 3. Results and discussions

#### 3.1. Microalgae growth characteristics

The campus sewage could be recycled twice when cultivated S. quadricauda SDEC-13, and the growth curves of SDEC-13 indicated by biomass concentration are displayed in Fig. 1. The growth cycles of the 1st use and 2nd use of campus sewage were 16 days and 10 days respectively. The shorter growth cycle in the 2nd use may contribute to the limited nutrients in the recycled wastewater. During the first cultivation (16 days), SDEC-13 underwent the lag phase, exponential phase, stationary phase but without obviously visible decline phase (also called lysis phase). That is because the growth cycles is relatively shorter compared with researcher's finding that lysis phase of microalgae would appear after 18 days (Moazami et al., 2012). The not evident lag phase in the 1st use confirmed that newly isolated strains have better environment adaptabilities (Zhou et al., 2011). But the lag phase in the 2nd use about 6 days was longer. That was due to growth arrest caused by deficiency of phosphorus for the campus sewage after once use which contained only trace of phosphorus could not sustain the growth of SDEC-13 in the first three days in the 2nd use, with the adding of phosphorus algae began to survived slowly on the fourth day and entered the logarithm phase on the sixth day. The biomass concentration and logarithm phase of the 1st use were well above that in the 2nd use. Under identical cultivation conditions and with approximately similar inoculation, the notable distinctions of growth curves between twice use can be ascribed to the only difference – various nutrients concentration (shown in Fig. 4) in campus sewage used successively.

The growth characteristics of SDEC-13 cultivated in control medium BG-11 and twice use of campus sewage are summarized in Table 2. SDEC-13 obtained identical maximum biomass concentration when cultured in BG-11 medium and the first use of campus sewage, it was nearly three times than that obtained in 2nd use of campus sewage. The nitrogen and phosphorus concentrations in initial campus sewage were less than 1/3 compared with BG-11 medium. While the identical maximum biomass concentration is benefit from the organic carbon in campus sewage which may promote the biomass yields (Chang et al., 2013). The specific growth rate and doubling time in twice use of campus sewage were both higher than in BG-11. It proved that SDEC-13 propagated more rapidly in campus sewage. SDEC-13 achieved lower biomass productivity when grown on the 2nd use of sewage due to the nutrient depletion in 1st use. The residual nutrients after once consumption were insufficient to satisfy the nutritional requirements of microalgae growth. But the biomass productivities

![Fig. 1. Growth curves of S. quadricauda SDEC-13 in twice use of campus sewage.](image)

| Table 2: Growth characteristics of S. quadricauda SDEC-13 in BG-11 and twice use in campus sewage. |
|---------------------------------------------------------------|--------|--------|--------|
| Maximum biomass concentration (g/L) | 1.09 | 1.09 | 0.37 |
| Specific growth rate (μm d⁻¹) | 0.20 | 0.23 | 0.22 |
| Biomass productivity (mg/L/d) | 81.79 | 79.17 | 50.19 |
| Doubling time (d) | 3.54 | 3.02 | 3.14 |
| Lipid content (%) | 31.31 | 27.36 | 27.27 |
| Lipid productivity (mg/L/d) | 66.51 | 68.20 | 22.61 |
| Protein content (%) | 36.48 | 35.25 | 31.06 |
| Protein productivity (mg/L/d) | 78.87 | 87.88 | 25.76 |
achieved in this study were all higher than *Chlorella* sp. (34.6 mg/L/d) cultivated by centrate wastewater in pilot-scale photo-bioreactors (Min et al., 2011) and *Scenedesmus* SDEC-8 (41.06 mg/L/d) which overtop other five newly isolated microalgae strains in air aerated culture system (Song et al., 2014).

3.2. Nutrient removal properties

Changes of nutrients concentration during the cultivation period were determined. Figs. 2 and 3 illustrate the variations of NO₃⁻—N, NH₄⁺—N, pH and TP with time in the first use of campus sewage. From the curve of Fig. 2, drastic decrease of ammonium was witnessed within 5 days with the removal rate 89.73%. While SDEC-13 consumed comparatively less nitrate in these 5 days, furthermore the nitrate concentration had a sharp rise on day 5. This was in accordance with ideas found by Wang and Lan (2011), who deduced that ammonium could be easier utilized than nitrate. Nevertheless, the abundant ammonium removal was partly due to volatilization because the pH reached up to 9.86 on day 5 and 600 mL/min aeration was given during the cultivation period. It is well acknowledged that stripping effect on aqueous ammonia could be promoted by aeration especially in alkaline environment (Park et al., 2010). The reason why nitrate concentration increase on day 5 may attribute to the nitrification was facilitated in the case of aerobic condition which provided by aeration so that some of ammonium was oxidized to nitrate. From then on nitrate was consumed rapidly as the prime nitrogen source to satisfy the requirements of nitrogen for the growth of SDEC-13, the biomass concentration increased more rapidly correspondingly during the exponential phase (as shown in Fig. 1). TP was expeditiously removed just in a few days, the removal rates reached up to 92.98% on the fourth day. Photosynthesis of microalgae led to a gradual increasing pH from an initial value 8.70 to 9.86 on day 5. The increase pH may contribute to the precipitation of phosphorus and phosphate adsorption on microalgal cells, the phosphorous level decreased consequently (Zhu et al., 2013).

From the Fig. 4, the initial and final concentration together with corresponding removal efficiency of NO₃⁻—N, NH₄⁺—N, TP could be clearly known. SDEC-13 obtained higher nitrate removal efficiency in the twice use of campus sewage than BG-11 (50.74%, data not shown). The removal efficiencies of TP nearly close to 100% among three groups were all a little higher than 96.5% that obtained by *Spirulina platensis* in synthetic human urine (Chang et al., 2013). The initial concentration of TP was relative low and consumed rapidly within few days, however, the growth of microalgae did not stop immediately along with the consumption of phosphorus.

3.3. Lipid production and FAME analysis

Lipid content obtained during the 1st use and 2nd use of campus sewage by SDEC-13 was 27.36% and 27.27% (Table 2) respectively higher than the average value 20% reported (Song et al., 2014).
266  
L. Han et al. / Bioresource Technology 175 (2015) 262–268

2013). Seemingly, limited nutrients in 2nd use had no adverse impact on the lipid production. In this respect, applying the wastewater into another use until achieving the discharge standard is feasible. Lipid productivity (22.61 mg/L/d) obtained in 2nd use was only one third compared with in 1st use (68.20 mg/L/d), which was attributed to the low biomass productivity caused by nutrient insufficiency. But it was still superior to the value achieved by Scenedesmus sp. which was cultivated under approximately similar nutrient concentration (Li et al., 2010). What is more, lipid productivity in the twice use of campus sewage were all comparable with other corresponding algae or condition. In Han et al. (2014) study, lipid productivity obtained by SDEC-13 when cultivated in artificial wastewater (18.08 mg/L/d) was less than one third compared with the value in 1st use and also was lower than the value in 2nd use. While, the highest lipid productivity obtained by Scenedesmus SDEC-8 in three wastewater samples was 53.84 mg/L/d (Song et al., 2014) lower than 68.20 mg/L/d in the 1st use of campus sewage.

The content and composition of fatty acid methyl ester (FAME) were analyzed and exhibited in Table 3. There was no significant difference in the composition of FAME but some difference in the amount during the cultivation of BG-11 medium and twice use of campus sewage, which may contribute to the variation in nutrient content. C16-C18 with the percentage above 99.99% almost made up the whole FAME without long-chain hydrocarbons no matter in BG-11 medium or twice use of campus sewage. This was in favor of biodiesel conversion (Li et al., 2011). Palmitic acid (C16:0) as the predominant constituents in all groups accounting for a percentage 64.41%, 54.20% and 57.07% respectively. This was in conformity with the finding that both Nannochloropsis oculata and Chlorella vulgaris showed high value (around 60%) of palmitic acid even though under different nitrogen concentration (Converti et al., 2009). It was different in study of Zhu et al. (2013), Chlorella zofingiensis only contains 23.87% of palmitic acid but more stearic acid (C18:0) as it shown in Table 3. This may be attributed to the difference of algae species for Scenedesmus SDEC-8 performed similar fatty acids composition (Song et al., 2014) compared with S. quadricauda SDEC-13 in this study. Moreover, the content of palmitic acid in Chlorella sp. was also lower accounting for 16.10% (Li et al., 2011). Oleic acid (C18:1) as the second majority component was regarded as one of the optimal ingredients for the oxidative stability and low-temperature property (Wu et al., 2012). So campus sewage may be better substrate for biodiesel production for the percentage of oleic acid in the twice use was almost twice the amount (17.33%) in BG-11. In addition, the content of saturated fatty acids (SFA) and unsaturated fatty acids (UFA) was nearly equivalent in the twice use of campus sewage which was good to maintain the oxidative stability and low-temperature property (Wu et al., 2012). The content of linoleic acid (C18:2) and linolenic acid (C18:3) decreased with the nutrient concentration decreased, which match the finding that as the concentration of nitrogen and phosphorous increased, the content of C18:2 and C18:3 also increased (Song et al., 2014; Lin and Lin (2011)) also concluded that C18:3 decreased when in the nitrogen starvation period. The quantity of C18:3 obtained in twice use of campus sewage was lower than in BG-11 and they were all far less than 12% restricted by European standards (EN, 2008). By this token limited nutrients not only did not impose restrictions on the lipid content but also promote the biodiesel quality.

### 3.4. Protein content and amino acid compositions

As we know, proteins are composed of different amino acids so protein content obtained in this research referred to the refined protein content expressed by the sum of amino acids content. The protein content shown in Table 2 of SDEC-13 was all above 30% no matter cultivated in BG-11 medium or campus sewage. The small difference in protein content among three groups with an order BG-11 > 1st use > 2nd use contributed to the nutrient concentrations especially nitrogen concentration in culture medium. This was in conformity with Ji et al. (2014) who had reported that the protein content of C. vulgaris increased with the increasing nutrients in monosodium glutamate industrial wastewater within certain limits. The protein content of S. quadricauda SDEC-13 was lower than C. vulgaris but higher than that in several common vegetable feed proteins such as soybean meal, peanut meal and so on (Li et al., 2013) also more than Leptotyphlops filiformis (Gressler et al., 2010) a kind of red algae and Dunaliella tertiolecta as well as Nannochloropsis sp. (Welladsen et al., 2014) as shown in Table 4. Moreover, protein productivity was far above C. vulgaris (Ji et al., 2014) profited from higher biomass productivity. SDEC-13 obtained the maximum protein productivity (87.88 mg/L/d) in the 1st use of campus sewage. So, it is potential for S. quadricauda SDEC-13 to make use of campus sewage for the protein synthesis.

The composition, proportion and availability in amino acids basically determine the nutritional quality of the protein. Qualitative and quantitative analysis of the amino acid (AA) composition about SDEC-13 in three groups were conducted and displayed in Table 4 together with comparisons with common feed protein and other microalgae studied. The protein obtained in this study consisted of 18 kinds of amino acid which including 8 kinds of essential amino acids (EAA) while tryptophan was missed in Nannochloropsis sp. and D. tertiolecta (Welladsen et al., 2014). Comparatively, 6 kinds of the EAA were all higher than the standard regulated by FAO/WHO, 1973. The distinction of various amino acids among three groups was irregular. It seems as if the composition of amino acid was insusceptible to the difference in nutritional composition of culture medium. The portion of EAA to total amino acids (TAA) was similar to 42.7% reported by de J Raposo et al. (2010). Chemical score (CS) is the lowest value of EAA, it was obtained by methionine (Met) in three groups which is agreed with first limited amino acid was methionine in all batch

---

**Table 3**

FAME profiles of the S. quadricauda SDEC-13 in BG-11 and twice use of campus sewage.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SFA (% of total FAME)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C16:0</td>
<td>64.41</td>
<td>54.20</td>
<td>57.07</td>
<td>16.10</td>
<td>56.21</td>
<td>61.1</td>
<td>23.87</td>
</tr>
<tr>
<td>C18:0</td>
<td>1.37</td>
<td>0.91</td>
<td>4.35</td>
<td>1.55</td>
<td></td>
<td>6.7</td>
<td>33.81</td>
</tr>
<tr>
<td>Subtotal</td>
<td>65.78</td>
<td>55.57</td>
<td>57.98</td>
<td>21.45</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MUFA (% of total FAME)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C16:1</td>
<td>4.03</td>
<td>3.03</td>
<td>1.19</td>
<td>10.88</td>
<td>2.67</td>
<td>6.2</td>
<td>8.73</td>
</tr>
<tr>
<td>C18:1</td>
<td>17.33</td>
<td>32.88</td>
<td>34.02</td>
<td>8.45</td>
<td>33.18</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Subtotal</td>
<td>21.36</td>
<td>35.91</td>
<td>35.21</td>
<td>19.33</td>
<td>35.85</td>
<td>6.2</td>
<td>24.46</td>
</tr>
<tr>
<td>PUFA (% of total FAME)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C18:2</td>
<td>6.15</td>
<td>3.69</td>
<td>3.00</td>
<td>14.36</td>
<td>5.32</td>
<td>–</td>
<td>10.22</td>
</tr>
<tr>
<td>C18:3</td>
<td>8.07</td>
<td>4.83</td>
<td>3.82</td>
<td>18.79</td>
<td>1.07</td>
<td>21.1</td>
<td>3.67</td>
</tr>
<tr>
<td>Subtotal</td>
<td>14.22</td>
<td>8.52</td>
<td>6.82</td>
<td>42.94</td>
<td>6.39</td>
<td>21.1</td>
<td>17.85</td>
</tr>
<tr>
<td>C16-C18 (% of total FAME)</td>
<td>99.99</td>
<td>99.99</td>
<td>100</td>
<td>82.71</td>
<td>98.69</td>
<td>95.1</td>
<td>80.31</td>
</tr>
</tbody>
</table>

SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids. –: not detected.
experiments (Ji et al., 2014). CS achieved in this study (ranged from 61.20% to 77.51%) was higher than the value of Ji et al. (2014) reported. According to the evaluation criteria proposed by Feng et al. (1997), protein obtained with high quality when the value of EAAI is greater than 0.95, so protein produced in this study could be called high quality protein with EAAI all higher than 1.00. It also means nutritional deficiency in campus sewage especially in the 2nd use made no difference on the protein quality.

3.5. Large-scale applications for future

It was known that high cost is the bottleneck to hold back the large scale production of biodiesel. The microalgae SDEC-13 used in this study was isolated from local environment in Jinan which has better environmental adaptability. It can take advantage of the sunlight and absorb carbon dioxide to produce high value products including biodiesel, protein, carbohydrate, pharmaceuticals and cosmetics. Campus sewage used in this study was filtered only through 6-layers gauze without any other pretreatment. Experiment results showed that there was no detrimental effect on the quality of lipid and protein, rather, lipid quality was better than that obtained in BG-11. Campus sewage used was filtered by gauze only without consuming pretreatment which is economic and convenient, so it is feasible to put it in large scale practical use in the future.

4. Conclusions

Campus sewage was recycled twice for the S. quadricauda SDEC-13 cultivation and could be discharged on standard eventually. Lipid content achieved in it were all above 27%, though protein content was slightly lower in the 2nd use because nutrient insufficiency but still higher than 30%. Limited nutrients had no detrimental effect on the quality of lipid and protein, rather, lipid quality was better than that obtained in BG-11. Campus sewage used was filtered by gauze only without consuming pretreatment which is economic and convenient, so it is feasible to put it in large scale practical use in the future.

Acknowledgements

This research was funded by National Science Fund for Excellent Young Scholars (51322811), Science and Technology Development Planning of Shandong Province (2012GGE27027), the Program for New Century Excellent Talents in University of Ministry of Education of China (Grant No. NCET-12-0341).

References


