Dual Role of *Chlorella vulgaris* in Wastewater Treatment for Biodiesel Production: Growth Optimization and Nutrients Removal Study

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The environmental footprint for microalgae based biofuel can be reduced by coupling the microalgae cultivation with wastewater treatment. In the present study, the nutrients source for microalga *Chlorella vulgaris* was replaced by municipal wastewater from wastewater treatment plant located at USM Engineering Campus, Penang. All cultivation experiments were conducted in 5 L photobioreactors (PBRs) under indoor condition with illumination from artificial lights and compressed-air aeration. The growth performances of microalgae *C. vulgaris* and nutrients uptake from wastewater were monitored throughout a 13-day cultivation period. The nutrients removal efficiency (NRE) for total nitrogen (TN) and total phosphorus (TP) by microalgae are 72.1 wt% and 89.7 wt%, respectively under the optimum cultivation conditions. Subsequently, microalgae biomass was collected by flocculation method, followed by extraction of lipid and transesterified to biodiesel. It was found that the biomass collected under optimum cultivation conditions achieved a maximum biomass dry weight density (*N*) of 0.76 g/L (or an equivalent biomass daily productivity, *P* of 58.6 mg/(L・d)).

Key Word
Microalgae, Wastewater, Nutrients removal efficiency, Biomass, Biodiesel

1. Introduction

There are two major challenges confronting humanity at the moment, which are environmental sustainability and energy crises 1). The immense consumption of fossil fuel has resulted to huge emission of greenhouse gases (GHGs) into the atmosphere causing global warming phenomenon 2). Therefore, developing an alternative renewable energy resource has emerged as a priority to many researchers world-wide. One possible solution to this problem is the utilization of microalgae as a renewable energy resources.

The phytoplankton characteristics of microalgae include rapid growth rate and may contain high lipid composition. In addition, microalgae grow in water that do not compete land area with edible-crops and can sequestrate CO₂ and utilize wastewater during its cultivation 3) - 6). The use of biofuels synthesized from microalgae can have carbon neutrality characteristic as the carbon released during combustion is balance off by the carbon assimilated during cultivation. Although microalgae based biofuels have many advantages, it has its fair share of weaknesses. One of them is the use of inorganic fertilizer during its cultivation increases the cost of production as compared to growing terrestrial oil bearing crops 7).

In the present study, the main objective is to investigate the integration of biomass production with wastewater treatment via microalgae cultivation. The optimization of microalgae cultivation conditions was performed, and nutrients removal efficiency by microalgae was evaluated. Then, the qualitative analysis on microalgae-based biomass and biodiesel were carried out to justify its feasibility as transportation fuels.
2. Materials and Method

2.1 Microalga strain and wastewater

A wild-type microalgae *Chlorella vulgaris* was isolated from a local freshwater body located at Penang, Malaysia. Then, the microalgae seed culture was preserved in organic fertilizer medium (Table 1) with tap water under the optimum cultivation conditions, as reported in previous works. The municipal domestic wastewater was collected from tertiary pond of a local wastewater treatment plant located at USM Engineering Campus, Penang, Malaysia. The wastewater has a pale brown color but clear, stored at 4 °C in a cold storage room. The sampling time of wastewater was fixed in order to maintain its chemical composition. The characteristic of municipal wastewater is tabulated in Table 2.

2.2 Microalgae cultivation and biomass harvesting

2.2.1 Cultivation conditions

Microalga *C. vulgaris* was cultivated with wastewater in a 5 L photobioreactor (PBR), as illustrated in Fig. 1. The PBR was a cylindrical transparent vessel with a working volume of 5 L. The PBR was connected to an air pump (Tideway HB110) to provide aeration to the cultivation system through a gas sparger. The cultivation medium was continuously illuminated by a 70 μmol m⁻² s⁻¹ cool-white fluorescent light (Philip TL-D 36W/85). The cultivation was maintained at ambient temperature (29 ± 2 °C).

In the subsequent optimization study, the volume of inoculum, organic fertilizer nutrient and municipal wastewater loaded to the PBR, pH of the microalgae culture, aeration rate of the cultivation system were predetermined prior to the experiments, as per described in Section 2.3. The pH of culture medium was varied by the addition of 2 M NaOH and/or 2 M HCl solutions.

2.2.2 Microalgae growth

The growth of *C. vulgaris* were monitored by measuring the optical density at 540 nm using an UV-vis spectrometer, OD₅₄₀ (Shimadzu UV mini-1240). The microalgae biomass dry weight density, N, was determined by drying microalgae sample at 105 °C overnight in an oven (Memmert). Then, OD₅₄₀ was correlated with N with an empirical correlation as shown in Eq. (1):

\[
N = 0.4605 \text{OD}_{540} - 0.0350, \quad R^2 = 0.9913
\] (1)

The specific growth rate, \( \mu \), and microalgae biomass productivity, \( P \), were calculated by Eq. (2) and Eq. (3), respectively:

\[
\mu (\text{day}^{-1}) = \frac{\ln \left( \frac{N_2}{N_1} \right)}{t_2 - t_1}
\] (2)

\[
P (\text{mg/L/day}) = \frac{(N_2 - N_1) 	imes 1000}{t_2 - t_1}
\] (3)

where \( N_1 \) and \( N_2 \) denoted as the microalgae biomass dry weight density (g/L) at time \( t_1 \) and \( t_2 \) (d), respectively.

2.2.3 Harvesting of microalga

The microalga *C. vulgaris* were cultivated for 13 d to reach stationary growth phase. Then, the PBR aeration system was terminated and the culture medium was harvested by flocculation with alum, as reported in previous work. As soon as the microalga cells were coagulated, two layers were observed: the top layer is water while bottom is concentrated microalgae culture. The water layer was drained out, leaving behind the concentrated
microalgae biomass that was further dried overnight in an oven at 105 °C to remove moisture from the microalgae biomass.

2.3 Optimization of microalgae growth

One-factor-at-a-time (OFAT) method was employed for optimizing the growth of microalgae C. vulgaris in municipal wastewater. The variables were optimized following these sequences: (i) initial pH value (2 - 11), (ii) amount of inoculum (100 - 500 mL), (iii) compressed-air aeration flow rate (1.4 - 3 L/min), and (iv) nutrient concentration (0 - 100 mL). For the first experimental run, the microalgae cultivation system was maintained at 400 mL of inoculum, 3 L/min of aeration rate, and 100 mL of organic fertilizer nutrient was added into 4500 mL of municipal wastewater. The experimental data was repeated for each variable. The P-value was calculated from Friedman test using Minitab 16 Statistical Software, with P > 0.05 indicating that the medians for the sampling data are equal.

2.4 Measurement of nutrient removal efficiency

The performance of wastewater treatment by microalgae was indicated by nutrient removal efficiency (NRE) during initial and end of cultivation, which is the difference in concentrations of total nitrogen (TN) and total phosphorus (TP), as depicted in Eq. (4):

\[
\text{NRE} (%) = \left( \frac{C_{i,j} - C_{f,j}}{C_{i,j}} \right) \times 100\%
\]  

(4)

where \( C \) is the concentration, \( j \) refers to total nitrogen (TN) or total phosphate (TP), while \( i \) and \( j \) denote to the initial and final cultivation concentrations, respectively.

The adopted analytical methods were Persulfate Digestion Method (HACH 10071) and Acid Persulfate Digestion Method (HACH 8190). A HACH DR-2800 spectrometer was used to measure the concentrations of TN and TP, respectively.

2.5 Characterization of microalgae biomass

The proximate analysis of microalgae biomass was conducted by analytical methods as summarized in Table 3.

The proximate analysis of microalgae C. vulgaris was tabulated in Table 4.

Apart from that, the elemental analysis on carbon (C), hydrogen (H), nitrogen (N) and sulfur (S) was conducted via an Elemental Analyzer (Perkin Elmer 2400). The results for CHNS was reported in mass percentage (wt %) and the molar fraction is described in Eq. (5).

\[
\text{Molar fraction} = \frac{\text{Atomic weight of element } i}{\sum (\text{Atomic weight of element } i)}
\]

(5)

The remaining of sample mass balance was assumed to be oxygen atom (O). Table 5 shows the elemental results in normalized percentage values for weight and molar fractions.

Meanwhile, the higher heating value (HHV) was calculated by Dulong’s formula, as in Eq. (6):

\[
\text{HHV (MJ/kg)} = 0.338 \times \text{C} + 1.428 \times \left( \frac{\text{H} - \text{O}/8}{\text{C}} \right) + 0.095 \times \text{S}
\]

(6)

where C, H, O and S represent carbon, hydrogen, oxygen and sulphur in mass percentages (wt%), respectively.

2.6 Microalgae biodiesel production

Transesterification reaction was employed to convert the crude lipid extracted from microalgae biomass into biodiesel. The composition of biodiesel was then analyzed for FAMEs.

2.6.1 Extraction of crude lipid from microalgae biomass

Initially, 5 g of dried microalgae biomass was transferred to a 500 mL conical flask that contain 225 mL mixed methanol-chloroform solution with a volume ratio of 2:1. The conical flask was sealed and the mixture was stirred at 400 rpm for 24 h at ambient temperature. Then, the biomass residue was filtered using Whatman® Grade 1 filter paper and the filtrate was rinsed with 25 mL of chloroform. On the other hand, the filtrate solution was evaporated through a rotary evaporator, to remove excessive solvent mixture at 95 °C. At the end of the evaporation process, the crude lipid was collected and stored...
Helium gas was used as carrier gas for subsequent use.\(^{11,12}\)

### 2.6.2 Transesterification reaction

Transesterification reaction was conducted in a batch reactor under the optimized reaction conditions as described in previous work\(^{11}\). Initially, 0.2 g of crude lipid was dissolved in 180 mL of methanol and 100 µL of 35 wt% H\(_2\)SO\(_4\) (catalyst) were loaded into a reaction vial. Then, the reaction condition was held for 6 h at a temperature of 60 °C. At the end of the transesterification reaction, excess methanol was removed via rotary evaporator. The microalgae-based biodiesel in rotary flask was immediately quenched with n-hexane prior to gas chromatography (GC) analysis for fatty acid methyl esters (FAMEs) content.

### 2.7 Quantitative and qualitative analysis of microalgae biodiesel

The FAMEs content of the microalgae-based biodiesel analyte was analyzed by Perkin Elmer Clarus 500 gas chromatography equipped with flame ionization detector (GC-FID) using Nukol\(^{\text{TM}}\) column (15 m \(\times\) 0.53 mm ID \(\times\) 0.5 µm film thickness). Helium gas was used as carrier gas with an initial oven temperature of 110 °C (held for 0.5 min), and then programed to heat up to 220 °C with a rate of 10 °C/min (held for 8 min). The detector and injector were maintained at 220 and 250 °C, respectively. Later on, 1 µL of analyte that was diluted with n-hexane and methyl heptadecanoate (internal standard, IS), was injected into the GC-FID column. The analytical procedure had been described in detail in previous work\(^{11}\), and the FAMEs content can be calculated using Eq. (7).

\[
\text{FAME content, } \% = \frac{\sum A - A_{IS}}{A_{IS}} \times \frac{C_{IS} \times V_{IS}}{m} \times 100 \%
\]  

where \(\sum A\), \(A_{IS}\), \(C_{IS}\), \(V_{IS}\) and \(m\) represent the total peak area of C14:0 to C24:1, peak area of internal standard (methyl heptadecanoate), concentration of the internal standard solution (2 mg/L), volume of the internal standard solution used (0.5 mL), and mass of the analyte (mg), respectively.

### 2.8 Statistical analysis

All the experimental results were repeated at least twice and reported as the mean value.

### 3. Results and Discussion

#### 3.1 Optimization of microalgae growth in municipal wastewater

The effect of each parameter for optimizing the growth of microalga \(C. vulgaris\) in municipal wastewater is discussed in the following sections.

#### 3.1.1 Effect of pH control

Fig. 2(a) illustrates the growth performance of microalgae \(C. vulgaris\) in municipal wastewater with different initial pH of cultivation medium at 3 L/min aeration rate. 400 mL inoculum seeds and addition of 100 mL organic fertilizer. The results obtained illustrated a slower growth on extreme conditions, either acidic (pH 2) or alkaline (pH 9 and 11). However, under mild acidic (pH 3 and pH 5) and neutral (pH 7) cultivation conditions, the growth of \(C. vulgaris\) demonstrated a similar growth trend. A longer lag phase (2 days) is observed in neutral and alkaline cultures, while the microalgae growth remained stagnant at pH 11. As a result, the optimum initial pH for microalgae growth is pH 3, with a maximum biomass yield \(N_{\text{max}}\) of 0.7895 g/L. Evidently, it can be proved from Fig. 2(b) that the pH values in microalgae cultivation medium tend to converge to pH 3 at the end of cultivation period, especially for pH 5 and 7. According to Hansen\(^{13}\), pH of growth medium is a crucial factor in determining the survival of dominant species in a mixed culture, which involved multiple species of microorganism. Thus, pH adjustment was employed as an alternative strategy to control the growth of dominant microalgae, while terminated the growth of inhibitors such as bacteria, fungus, grazers, and etc. It was noted that most of the inhibitors are unable to survive under acidic condition. Furthermore, the influence of pH is in agreement with the findings reported by Borowitzka\(^ {14}\), particularly in alkaline cultivation medium (pH > 9). This is due to the formation of carbonate from the soluble inorganic carbon that created a carbon limitation environment and further inhibited the cells growth. In addition, the use of municipal wastewater for microalgae cultivation without sterilization is a good approach for cost reduction. Hence, the microalgae cultivation medium with pH 3 is chosen for the subsequent optimization study.

#### 3.1.2 Effect of inoculum volume

By varying inoculum volume under 3 mL/min aeration rate, addition of 100 mL of organic fertilizer and culture maintained at pH 3, the effects of inoculum volume on the growth of microalgae \(C. vulgaris\) in municipal wastewater is shown in Fig. 3. The optimum inoculum volume occurred at 400 mL, indicated a maximum microalgae biomass dry weight density, \(N_{\text{max}}\) of 0.71 g/L. Both inoculum microalgae seed with a volume of 300 and 500 mL reported the same biomass yield, \(N\) with 0.69 g/L, which is approximated to the optimum value. The minimum biomass yield \(N_{\text{max}}\) was observed at 100 mL inoculum. From Equation (2), it illustrates that higher initial concentration of microalgae inoculum would enhances the specific growth rate of microalgae. However, excessive volume of microalgae...
Fig. 2 The effect of initial pH of the microalga *Chlorella vulgaris* growth in municipal wastewater: (a) Microalgae growth performances under different initial pH values for culture medium, and (b) Changes in pH value of microalgal culture medium throughout a 13-day cultivation period. Cultivation conditions: 400 mL of inoculum culture seeds, 3 L/min of compressed-air aeration rate supplied, and 100 mL of organic fertilizer nutrients medium.

Fig. 3 The effect of inoculum volume towards the growth performance of microalga *Chlorella vulgaris* in municipal wastewater. Cultivation conditions: microalgae culture maintained at pH 3, 3 L/min of compressed-air aeration rate supplied, and 100 mL of organic fertilizer nutrients medium.

Inoculum would inhibit the biomass production due to the self-shading effect in microalgal cells culture \(^\text{15}\). Hence, excessive amount of inoculum after optimum volume would not increase the biomass dry weight density yield. Hereafter, 400 mL of the inoculum seed culture was chosen for the subsequent optimization study.

3.1.3 Effect of aeration rate

Fig. 4 illustrates the growth of microalga *Chlorella vulgaris* in municipal wastewater at various compressed-air aeration rate with addition of 100 mL organic fertilizer.
400 mL of inoculum seed and culture maintained at pH 3. The results obtained show that increasing compressed-air aeration flow rate significantly increases the microalgae biomass dry weight density yield to a maximum at 2.6 L/min. The aeration supplied to PBRs cultivation system provided a well-mixed environment for microalgae growth. In addition, higher compressed-air aeration also indicates a higher CO₂ concentration supplied to the microalgae culture system. Subsequently, the CO₂ dissolved in the culture medium was utilized for cells growth, as CO₂ played a vital role in photosynthesis process. Nonetheless, excessive concentration of CO₂ dissolved would not further increase the biomass density yield due to limited number of microalgae cells available in the cultivation system. Hence, a compressed air aeration rate of 2.6 L/min is chosen for the subsequent optimization study.

3.1.4 Effect of initial nutrients concentration

Fig. 5 illustrates the growth performance of *C. vulgaris* in municipal wastewater, in which increasing volume of initial organic fertilizer nutrients promoted the growth of microalgae (as an additional organic carbon source to enhance the biomass production). The *C. vulgaris* cells undergo asexual reproduction, where nitrogen, N as the major nutrients required, promoted the cells growth rate. Furthermore, microalgae culture that was cultivated in solely municipal wastewater was still able to grow, albeit at a slower rate, justifies its potential as a growth medium. However, with the addition of 25 mL of organic fertilizer nutrient could boost up the microalgae biomass production with an estimation of 50% increase (from 0.46 to 0.63 g/L), as compared with purely municipal wastewater cultivation. However, further nutrient increment into the microalgae culture is insignificant towards microalgae cell growth.
This is because biomass production maintained at 0.76 g/L for addition of both 75 and 100 mL of nutrients. This may be due to other limiting factors, such as light photons availability and CO2 concentration that dominate the cell growth rate. Hence, the optimum initial organic fertilizer nutrient solution was found to be 75 mL.

3.1.5 Optimization conditions

In summary, the optimum microalgae cultivation condition was found at: (i) culture maintained at pH 3, (ii) using 400 mL of microalgae inoculum seeds, (iii) PBR system aerated with compressed-air at a rate of 2.6 L/min, and (iv) addition of 75 mL of organic fertilizer nutrients.

3.2 Nutrient removal efficiency (NRE) versus microalgae biomass productivity

The performance of Chlorella vulgaris cultivation for dual functions; wastewater treatment and biomass production was measured by using NRE and microalgae biomass productivity respectively. The NRE performance will be significantly depend on the nutrient uptake by microalgae population. According to studies reported in literature, the major nutrient constituents needed for microalgae cell growth included nitrogen and phosphorus, which can be indicated by total nitrogen (TN) and total phosphorus (TP) amount in the cultivation medium. The reported experimental results depicted a removal efficiency of 11.9-74.3% and 22.5-94.8% for TN and TP, respectively, throughout all the cultivation conditions as stated in Section 3.1.

Simultaneously, the overall biomass productivity denoted a maximum of 58.6 mg/(L-d) and a minimum of 10.4 mg/(L-d). From the optimization study, the results indicated that the abiotic (pH and nutrients concentration) and biotic factors (inoculum volume) have greater influences towards the microalgae biomass productivity, as compared with the operational factor (compressed-air aeration rate). Meanwhile, the NRE demonstrates a similar trend for the effect of pH, while other factors showing inconsistence results in biomass productivity.

Fig. 6(a) illustrates the influence of pH control towards the NRE and microalgae biomass productivity. The maximum NRE are 73.3% for TN and 85.9% for TP, with reference to 58.3 mg/(L-d) of biomass at the optimum cultivation pH 3. The TN removal efficiency maintained at 72.5 ± 1.4% and a biomass productivity of 56.6 ± 2.6 mg/(L-d) throughout the entire range of pH from 3 to 7. However, a drastic decrease in NRE (reduction of 30% for TN) and biomass productivity (67% reduction) was observed...
for cultures in medium with pH 9. As the alkalinity of microalgae cultures increased to pH 11, the TP removal efficiency was decreased by 67%. The alkaline microalgae culture (pH 11) resulted to a minimum biomass productivity (10.4 mg/(L・d)) and NRE for both TN and TP at 11.9% and 22.5% respectively. These results are in good agreement as those reported in Section 3.1.1, in which lower biomass yield resulted to minimum NRE. According to Borowitzka 14, precipitation of phosphorus at higher pH environment (especially at pH > 9) contributed to the decrease in phosphorus concentration that is available for microalgae growth. Hence, the removal efficiency of TP was reduced significantly in alkaline growth environment. Additionally, higher cultivation pH also led to flocculation of microalgae and therefore reduced the nutrients uptake and cell growth.

The NRE and biomass productivity of Chlorella vulgaris with various volume addition of inoculum is illustrated in Fig. 6(b). The optimum inoculum volume (400 mL) gave the highest biomass productivity (547 mg/(L・d)), with a relatively low NRE (64.4% for TN and 66.7% for TP). The maximum and minimum removal efficiency for TN are 75.5% and 63.3%, whereas TP are 87.8% and 56.3%, respectively. The inconsistent biomass productivity with respective to their nutrients uptake indicated that amount of inoculum used have insignificant effect.

Fig. 6(c) demonstrates the effect of compressed-air aeration rate towards the nutrient uptake and biomass productivity. The results showed that biomass productivity is proportional to the TN uptake, while TP remained almost constant. The biomass productivity was found maximum (53.0 mg/(L・d)) at optimum conditions, with a TN and TP removal efficiency of 73.0% and 89.7%, respectively. Higher aeration rate promoted cell growth in the cultivation system, and hence increased the nutrient uptake, in accordance to the biomass productivity.

The feasibility of using solely municipal wastewater as the nutrient source was studied by culturing Chlorella vulgaris in solely municipal wastewater and with the addition of organic fertilizer nutrients, by holding other parameters at optimum conditions (Fig. 6(d)). The maximum biomass productivity was found at 58.6 mg/(L・d) with addition of 75 mL organic fertilizer nutrient. The NRE was also found to be the highest, at 72.1% and 89.7% for TN and TP, respectively. Whereas when using solely municipal wastewater, a reduction of 40% in biomass productivity (35.3 mg/(L・d)) was observed. However, the NRE maintained at 63.5% for TN and 37.8% for TP, which is higher than that with addition of 25 mL of organic fertilizer nutrients. The reduction of biomass productivity is due to the uncontrolled growth of bacteria or fungus that are competing for the same source of nutrient.

Therefore, it can be easily justified that the nutrients (TN & TP) removal efficiency corresponded positively to a higher yield of microalgae biomass productivity, with the maximum P (58.6 mg/(L・d)) corresponded to 72.1% and 89.7% for TN and TP removal efficiency, respectively.

### 3.3 Microalgae biomass characterization

The proximate analysis of microalgae biomass at optimum cultivation condition is tabulated in Table 4 (Section 2.5). The high ash content at almost 25 wt% is due to high total organic content (eg. sludge) in municipal wastewater (associated with the accumulation of other pollutants) 20. Apart from this, the presence of carbohydrate and lipid make it feasible to be converted into transportation biofuels such as bioethanol and biodiesel, whereas bio-based materials and chemical products (eg. additives, animal food, supplements and etc) can be produced from protein 21.

The elemental analysis result is shown in Table 5 (Section 2.5), with chemical formula denoted as C_{111}H_{254}O_{44}N_{5}. The high weightage of oxygen atom, O indicated that products produced from this biomass would be highly oxygenated compounds, which would degrade the quality of the biofuels produced. Besides that, the presence of nitrogen, N and sulphur, S will contribute to emission of undesired products such as pollutant gases (CO, CO_{2}, NO_{x}, SO_{x} and etc) during direct combustion 21.

The calculated HHV for microalgae biomass based on Dulong's equation is 18.75 MJ/kg, which is approximated to the HHV for cellulosic biomass (~18.6 MJ/kg), as reported by Sheng and Azevedo 24. This value supports the suitability of microalgae biomass for biofuel application.

### 3.4 Microalgae biodiesel production

#### 3.4.1 Crude lipid extraction

The yield of crude lipid extracted from the microalgae biomass was found to be 10.54 wt%, which will be used for the subsequent transesterification reaction.

#### 3.4.2 Transesterification reaction

Microalgae-based biodiesel is successfully produced from the crude lipid extracted. Under optimum transesterification reaction, 90 wt% of the FAME content was achieved, and was further quantified by GC-FID.

#### 3.4.3 Microalgae biodiesel characterization

The distribution of FAMEs profile is illustrated in Fig. 7. Fig. 7(a) elucidates the quantitative analysis of microalgae biodiesel, which consists of hydrocarbon with chain length from C14 to C24; dominated by C16 that accounted for a total of 83.55 wt% (by omitting the IS peak). The GC chromatograph (Fig. 7(b)) of the analyte illustrates
the predominance of long chains saturated fatty acids, SFAs (C14:0, C16:0, C20:0) and monounsaturated fatty acids, MUFAs (C18:1, C22:1, C24:1), which exhibited the characteristic to produce a good oxidative stability biodiesel.  

3.5 Future outlook

For future study improvement, the consideration of heterotrophic cultivation mode in extreme condition (higher alkalinity environment) can greatly reduce the biomass production cost. Since the quality of microalgae biomass produced is greatly affected by the wastewater quality, a more comprehensive analysis of wastewater (eg. TOC, turbidity, heavy metals compositions etc.) should be included to carefully evaluate the effectiveness in controlling the contaminations from wastewater in microalgae cultivation system.

4. Conclusions

The dual role of microalgae cultivation system is demonstrated by coupling the microalgae biomass production and wastewater treatment process. This has also resulted to higher microalgae biomass productivity with a higher nutrient removal efficiency (NRE). The maximum biomass production was found to be 0.76 g/L or equivalent to daily productivity of 58.6 mg/(L・d). In addition to that, it has also demonstrated a promising performance in nutrients removal efficiency for both TN and TP in municipal wastewater at 72.1% and 89.7% respectively under optimum cultivation condition.

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