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THESIS

OPTIMAL CONDITION FOR NUTRIENT REMOVAL AND
MICROALGAE BIOMASS PRODUCTION IN WASTEWATER
FROM INSTANT NOODLE FACTORY USING MICROALGAE
CULTIVATED IN PHOTOBIOREACTOR

The logo of Kasetsart University is a large, light green circular emblem. It features a central figure of a deity or guardian spirit, possibly a Ganesha-like figure, holding a sword and a mace. The figure is surrounded by a decorative border with floral and geometric patterns. The text 'KASETSART UNIVERSITY' is written in a semi-circle above the figure, and '1943' is written below it. There are also two small floral symbols on either side of the central figure.

WORAWIT WHANGCHENCHOM

A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
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Worawit Whangchenchom 2014: Optimal Condition for Nutrient Removal and Microalgae Biomass Production in Wastewater from Instant Noodle Factory using Microalgae Cultivated in Photobioreactor. Master of Engineering (Advanced and Sustainable Environmental Engineering), Major Field: Advanced and Sustainable Environmental Engineering, Faculty of Engineering. Thesis Advisor: Associate Professor Wilai Chiemchaisri, D.Tech.Sc. 179 pages.

Cultivation of microalgae using wastewater exhibits several advantages such as nutrient removal and the production of high valuable products such as lipid and pigments. With this study, two types of wastewater from instant noodle factory; mixed liquor suspended solids (MLSS) and effluent after sedimentation tank were investigated for green microalga *Scenedesmus* sp. cultivation under laboratory condition. MLSS and effluent without dilution showed the highest specific growth in preliminary testing. There was no significant ($p < 0.05$) difference on growth and biomass of wastewater from instant noodle factory and control (BG11) using Duran bottle as culture vessel under laboratory condition. Ammonia from ammonification and nitrate were nitrogen source for microalgae cultivated in MLSS and effluent, respectively. Phosphate addition could promote higher maximum algal biomass especially from MLSS. MLSS was therefore used as the culture medium for outdoor algal culture in 6 L vertical column photobioreactor. It was found that aeration with 2% CO_2 supplement during daytime provided the highest productivity of *Scenedesmus* under batch culture in outdoor condition. Outdoor continuous culture of *Scenedesmus* was also performed with MLSS. At steady stage (day 21 – 38) with $0.46 \pm 0.03 \text{ day}^{-1}$ dilution rate, microalgal productivity was $167.43 \pm 13.02 \text{ mg/L/day}$. Moreover, cultivation of *Scenedesmus* could reduce total COD, soluble COD, total nitrogen and total phosphorus in wastewater from instant noodle factory.

Student's signature

Thesis Advisor's signature

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LIST OF ABBREVIATIONS

ADP	=	adenosine diphosphate
ATP	=	adenosine triphosphate
NADP ⁺	=	nicotinamide adenine dinucleotide phosphate
NADPH	=	nicotinamide adenine dinucleotide phosphate
CO ₂	=	carbon dioxide
COD	=	chemical oxygen demand
DO	=	dissolved oxygen
mg/L	=	milligram per liter
mg/L/day	=	milligram per liter per day
mg/m ² /Day	=	milligram per square meter per day
mg N/L	=	milligram nitrogen per liter
mg P/L	=	milligram phosphorus per liter
MLSS	=	mixed liquor suspended solids
mV	=	mili volt
N	=	nitrogen
ORP	=	oxidation reduction potential
P	=	phosphorus
TAN	=	total ammonia nitrogen
Temp.	=	temperature
TN	=	total nitrogen
TP	=	total phosphorus
TSN	=	total soluble nitrogen
TSP	=	total soluble phosphorus
TSS	=	total suspended solids
μ	=	micron
	=	specific growth rate
μg/L	=	microgram per liter

OPTIMAL CONDITION FOR NUTRIENT REMOVAL AND MICROALGAE BIOMASS PRODUCTION IN WASTEWATER FROM INSTANT NOODLE FACTORY USING MICROALGAE CULTIVATED IN PHOTOBIOREACTOR

INTRODUCTION

Discharge of wastewater from human activities is a cause of high nutrient loading into aquatic environments, which may lead to eutrophication and algal blooms (Abdel-Raouf *et al.*, 2011; Cai *et al.*, 2012). This appears to be a major problem in several parts of the world due to the lack of infrastructure for wastewater treatment. Moreover, conventional secondary treatment on domestic, agricultural and industrial water is not sufficient to treat nutrients from wastewater (Olgun, 2003; Rawat, 2011). Another environmental problem that has received much attention is global warming from greenhouse gases emission in the atmosphere. With recent industrial treatments, high nutrients wastewater and carbon dioxide gas emission are separately treated. However, using microalgae to treat wastewater has several benefits such as reducing nutrient loading, CO₂ fixation, removal of heavy metal, low cost maintenance, production of high-value bio-chemicals (algal metabolites), creating smaller carbon footprint in comparison with cultivation in clean water, no secondary pollution, and so on (Munoz and Guieysse, 2006; Park *et al.*, 2011; Rawat *et al.*, 2011; Sudhakar and Premalatha, 2012; Fathi *et al.*, 2013).

The word “phycoremediation” has been mentioned in many articles (Olgun, 2003; Rawat *et al.*, 2011; Sengar *et al.*, 2011). Phycoremediation refers to the use of algae for pollutant removal or biotransformation from wastewater especially high organic containing wastewater to prevent eutrophication. Microalgae are not only enhancing the nutrients removal but they also eliminate heavy metals and pathogens from wastewater.

The widely used microalgae for nutrient removal are *Chlorella* (Aslan and Kapdan, 2006; Langley *et al.*, 2012; Su *et al.*, 2012) and *Scenedesmus* (Su *et al.*, 2012; Pegallapati and Nirmalakhandan, 2013). However several studies showed that consortium of local algal strains had high efficiency for wastewater treatment (Chinnasamy *et al.*, 2010; Zhou *et al.*, 2012).

Further improvements of microalgal culture still depend on the improvement of culture techniques especially the use of photobioreactors for microalgal culture and the optimization of culture conditions. Therefore, the future of microalgal biotechnology appears promising, and innovative processes and products are expected to emerge over the next few years (Xu *et al.*, 2009). With this study, wastewater from instant noodle factory containing high residual nutrients was chosen as a new potential media for the cultivation of microalgae.

The aim of this study was to investigate optimal conditions for nutrient removal and microalgae biomass production in wastewater from instant noodle factory using microalgae cultivated in photobioreactor.

OBJECTIVES

The objectives of this study were:

1. To evaluate the possibility of wastewater from instant noodle factory as a source of nutrients for microalgal growth.
2. To study optimal conditions for cultivation of microalgae in wastewater under laboratory and outdoor conditions.

Scopes of work

Scopes of work in this study:

1. The experiments used wastewater from instant noodle factory for cultivation of microalgae in photobioreactor under laboratory and outdoor conditions.
2. Microalga was the nonindigenous strain, *Scenedesmus* sp.
3. Two types of wastewater used in this study were mixed liquor suspended solids (MLSS) collected from aeration tank of activated sludge wastewater treatment and effluent which was collected from final sedimentation tank.

LITERATURE REVIEW

Microalgae

Algae are generally found in aquatic environments. They are referred as simple organisms without cell differentiation into roots, stems, and leaves. Majority of algae are autotrophic, which generate their biomass from solar energy and inorganic source, however some are heterotrophic, which obtain their biomass from organic source. Algae are divided into microalgae, which are microscopic size, and macroalgae, which are large enough to be seen by eyes. Moreover, algae can be classified by using their biochemical and cytological characteristics into 10 phyla namely; Cyanophyta, Chlorophyta, Euglenophyta, Xanthophyta, Dinophyta, Crptophyta, Chrysophyta, Bacillariophyta, Rhodophyta, and Phaeophyta (Graham *et al.*, 2009; Bellinger and Sige, 2010).

Microalgae are referred as photosynthetic microorganisms which exploit solar energy for their growth. However, large amount of fertilizers can be used as their nutrient (Markou and Georgakakis, 2011). Several researches have been conducted by using microalgae to recover nutrients from waste or wastewater to reduce operation cost, solving environmental problems, and to generate valuable products from microalgae.

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Microalgae Culture Systems

Culture system for microalgae production is generally divided into open pond system and closed system.

1. Open system

Open pond system has widely been used for a cultivation of microalgae (Xu *et al.*, 2009). Open pond is a simple expansion of algal pond with a mechanism to deliver CO₂ and nutrients and paddle wheels to circulate algal medium (Sudhakar and Premalatha, 2012). Microalgal biomass production can be enhanced by bioengineering and biotechnology.

High rate algal ponds (HRAPs), a famous type of open algal pond, are usually 0.2–1 meters in depth allowing light penetration. Mixing is normally provided by a paddlewheel to give a mean horizontal water velocity of approximately 0.15–0.3 m/s. A single loop or multiple loops around central dividing walls is used in raceway configuration. According to the soil properties and local regulation, bottom of the pond may either be lined or unlined. CO₂ is also added into a sump which is 1.5 meters in depth (Figure 1). Using HRAPs in wastewater treatment prove to be an economically viable choice in a production of algal biomass for biofuels conversion with low environmental impact (Park *et al.*, 2011).

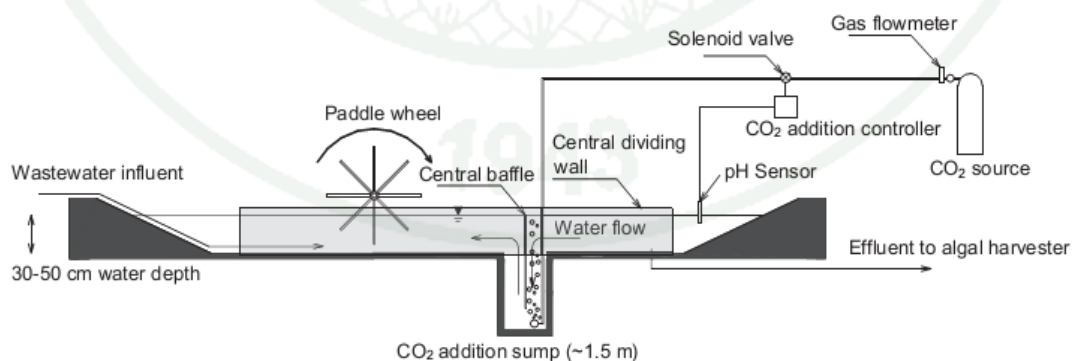


Figure 1 Side elevation of a high rate algal pond with CO₂ addition.

Source: Park *et al.* (2011)

2. Closed system

Closed photobioreactors are referred as a broad category of reactor such as tubular (Figure 2) or flat plate photobioreactors. They are generally enclosed which allow more precise control over growth conditions and resource management. They are a promising application in large scale microalgal cultivation for bioenergy but it is difficult in scaling up as relative volumes of light and dark zone change when the diameter tube or the thickness plate increased. In addition, large area of land is required (Xu *et al.*, 2009; Sudhakar and Premalatha, 2012). Table 1 shows a comparison between open and closed algal culture systems.



Figure 2 Schematic photobioreactor design, as follows a horizontal tubes.

Source: Abdel-Raouf *et al.* (2012)

Table 1 Comparison of open system and closed system for microalgal cultivation.

Parameter	Open system	Closed system
Scale-up	Easy	Difficult
Usage	Commercial	Not commercial
Light utilization	Poor	Very high
CO ₂ loss in to atmosphere	High	Low
Typical biomass yield (g/m ² day)	Low (10-60)	High (60-100)
Area requirement	Large	Small
Contamination risk	High	Low
Evaporative losses	High	Low
Area/volume ratio	Low	High
Process control	Difficult	Easy
Investment cost	Low	High
Operation cost	Low	High
Harvesting cost	High	Relative low
Typical cost of biodiesel	Low 2.0-2.5 USD/L	High 5-6 USD/L

Source: Xu *et al.* (2009); Sudhakar and Premalatha (2012)

Cultivation Factors Effecting Microalgal Growth

Typically, there are various parameters effecting microalgal growth. Those parameters are summarized below.

1. Carbon source

Fifty percent of algal biomass is made up from carbon, so carbon supply is vital for successful cultivation. Carbon can be supplied as inorganic substrate in gaseous form of CO₂ for photoautotroph. Sugar or acetate is supplied as organic carbon for heterotroph. For instance, *Chlorella* sp. can growth in heterotrophic condition by using appropriate organic carbon source such as acetate (Perez-Garcia *et al.*, 2011).

Photosynthesis of algae always requires CO₂ supply. However, concentration of CO₂ in normal air (0.03%) is not sufficient to sustain optimal growth and high productivity. To overcome this obstacle, CO₂ enriched air is provided. Normally, CO₂ in water might present in the following form:

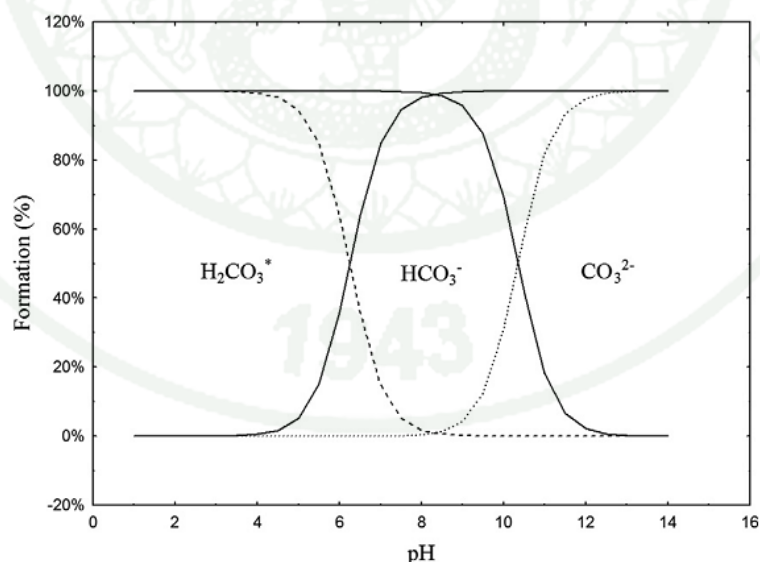


Figure 3 Formation of inorganic carbon species as a function of pH.

Source: Markou and Georgakakis (2011)

Additional CO₂ supply to microalgae unclearly shows on increasing productivity. Several studies exhibited moderate CO₂ supplement could promote algal growth (Kong *et al.*, 2010; Li *et al.*, 2011; Putt *et al.*, 2011; Hu *et al.*, 2012). On the other hand, CO₂ did not enhance microalgal productivity in some researches (Min *et al.*, 2011).

2. Nitrogen

Besides the carbon, nitrogen is the most significant element for algal growth as 10% of their biomass consists of nitrogen. Naturally, main source of nitrogen from water body in form of nitrate, is stream and river discharged (Graham *et al.*, 2009). In term of economical algae cultivation, urea, ammonia or nitrate fertilizer can be used as nitrogen source. Moreover, cyanobacteria can fix nitrogen from atmosphere. Form of ammonia depends on pH (Figure 4), nitrogen loss as NH₃ can be occurred by this phenomenon (Becker, 1993).

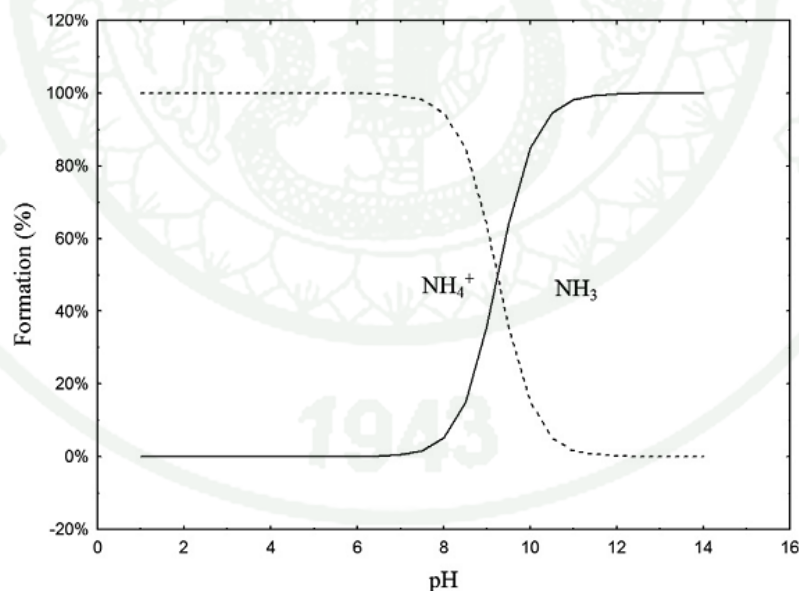


Figure 4 Formation of ammonia/ammonium species as a function of pH.

Source: Markou and Georgakakis (2011)

3. Phosphorus

Phosphorus is essential for algal cellular process such as biosynthesis of nucleic acids. Phosphorus concentration is often growth limiting factor in natural habitat (Becker, 1993). The form of phosphorus, which is utilized by microalgae, is the orthophosphate form (PO_4^{3-}). Figure 5 shows a formation of phosphate species as a function of pH. The available organic phosphorus is hydrolyzed to PO_4^{3-} by extracellular enzymes (Markou and Georgakakis, 2011).

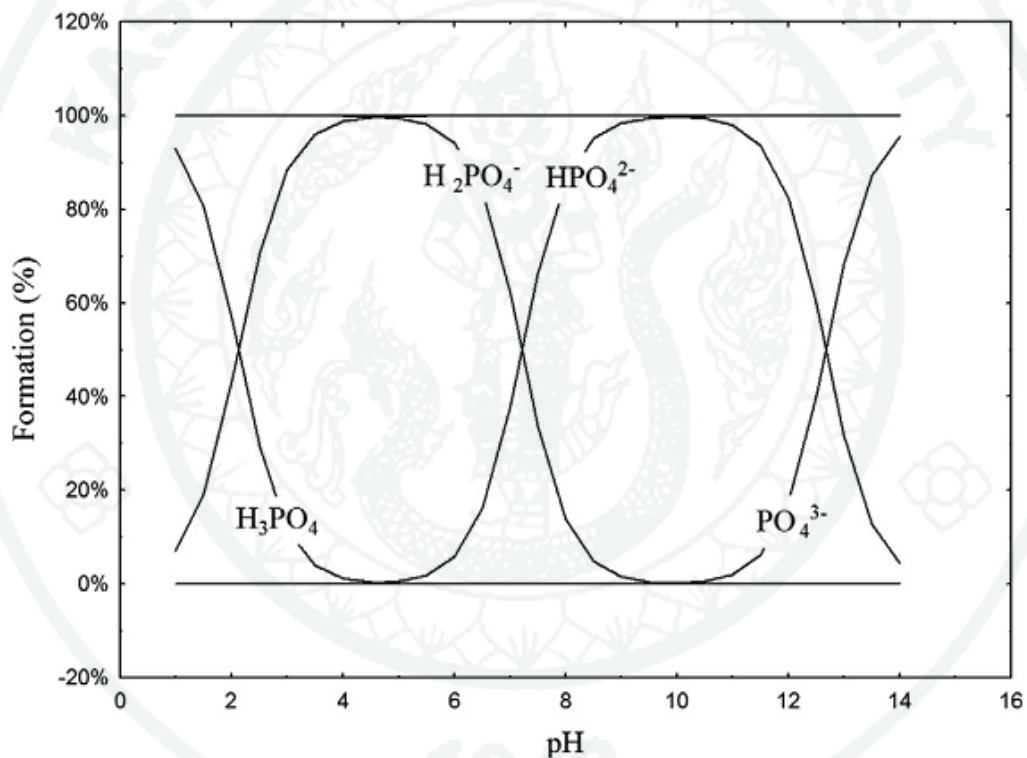


Figure 5 Formation of phosphate species as a function of pH.

Source: Markou and Georgakakis (2011)

4. Other nutrients

Besides carbon, nitrogen, and phosphorus, other essential for algal growth nutrients are required. Table 2 briefly shows function of chemical nutrients for algae.

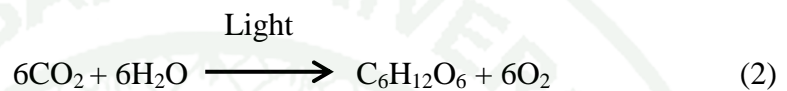
Table 2 Nutrients commonly required by algae.

Element	Example of function/ location in algal cells
N	Amino acids, nucleotides, chlorophyll, phycobilins
P	ATP, DNA, phospholipids
Cl	Oxygen production in photosynthesis, trichloroethylene, perchloroethylene,
S	Some amino acids, nitrogenase, thylakoild lipids, CoA, carrageenan, agar, DMSP, biotin
Si	Diatom frustules, silicoflagellate skeletons, synurophyte scales and stomatocyst walls, walls of the ulvophyte <i>Cladophora</i>
Na	Nitrate reductase
Ca	Alginates, calcium carbonate, calmodulin
Mg	Chlorophyll
Fe	Ferredoxin, cytochromes, nitrogenase, nitrate and nitrite reductase, catalase, glutamate synthetase, superoxide dismutase cofactor
K	Agar and carrageenan, osmotic regulation (ionic form), cofactor for many enzymes
Mo	Nitrate reductase, nitrogenase
Mn	Oxygen-evolving complex of photosystem II, wall-like lorica of some euglenoids and the chlorophyte <i>Dysmorphococcus</i> , superoxide dismutase
Zn	Carbonic anhydrase, alcohol dehydrogenase, glutamic dehydrogenase
Cu	Plastocyanin, cytochrome oxidase
Co	Vitamin B ₁₂
V	Bromoperoxidase, some nitrogenases
Br, I	Halogenated compounds with antimicrobial, anti-herbivore, or alleopathic functions

Source: Graham *et al.*, (2009)

5. Light

Light is the most important energy source for algal photosynthesis. Photosynthesis is the biochemical process by using light energy to transform inorganic molecules to organic matter. Light energy is used to strip protons and electrons from molecules with the result to produce oxygen. The process of photosynthesis can be summarized by an equation (2) below (Graham *et al.*, 2009):



Due to a reduction of CO_2 to organic carbon, this process is known as carbon fixation. This process can be divided into light dependent reaction and light independent reaction as following;

(a) Light reaction:



(b) Light-independent reaction:



High light intensity can promote microalgae biomass accumulation, lipid production, as well as the removal of chemical oxygen demand and nitrogen (Li *et al.*, 2011). Therefore, light penetration is a significant factor which depends on depth of water to support photosynthesis (Chinnasamy *et al.*, 2011).

6. pH

A concentration of nutrients is affected by pH. Changing pH can alter the solubility of ammonium or phosphates present in medium. Alkaline water shows in ammonia stripping or phosphate precipitation. The pH values between 9 and 11 induced the precipitation of phosphorus in the form of calcium phosphate (Laliberte *et al.*, 1997).

Chinnasamy *et al.* (2010) reported that pH was the most important factor on biomass productivity. Even algal growth is affected by pH, it is difficult to determine on optimum pH, though it increases as algae growth due to carbon dioxide consumption. Therefore, pH can be used as a good indicator for algal productivity.

7. Temperature

By increasing temperature to optimum range, algal productivity can be enhanced since algal respiration and photorespiration increase. The optimal temperature is measured under conditions of maximum algal growth rate (sufficient nutrient and light conditions). A range of optimal temperature is between 28 to 35 °C. Moreover, temperature also increases the pond water ionic equilibrium, pH, and gas (oxygen and CO₂) solubility (Park *et al.*, 2011; Cai *et al.*, 2013).

8. Predators

Microalgal growth is consumed by many herbivorous protozoa and zooplankton (e.g. rotifers and cladocerans) which can reduce algal concentration and production to low level within a few days especially in outdoor cultivation (Park *et al.*, 2011; Cai *et al.*, 2013).

Wastewater

Wastewater is water containing various impurities into the water until it is not needed and contemptuous for common people. It is no longer suitable for use. It can damage receiving natural water by being released without treatment (Pollution Control Department [PCD], 2013). The typical characteristics of wastewater are showed in Figure 6.

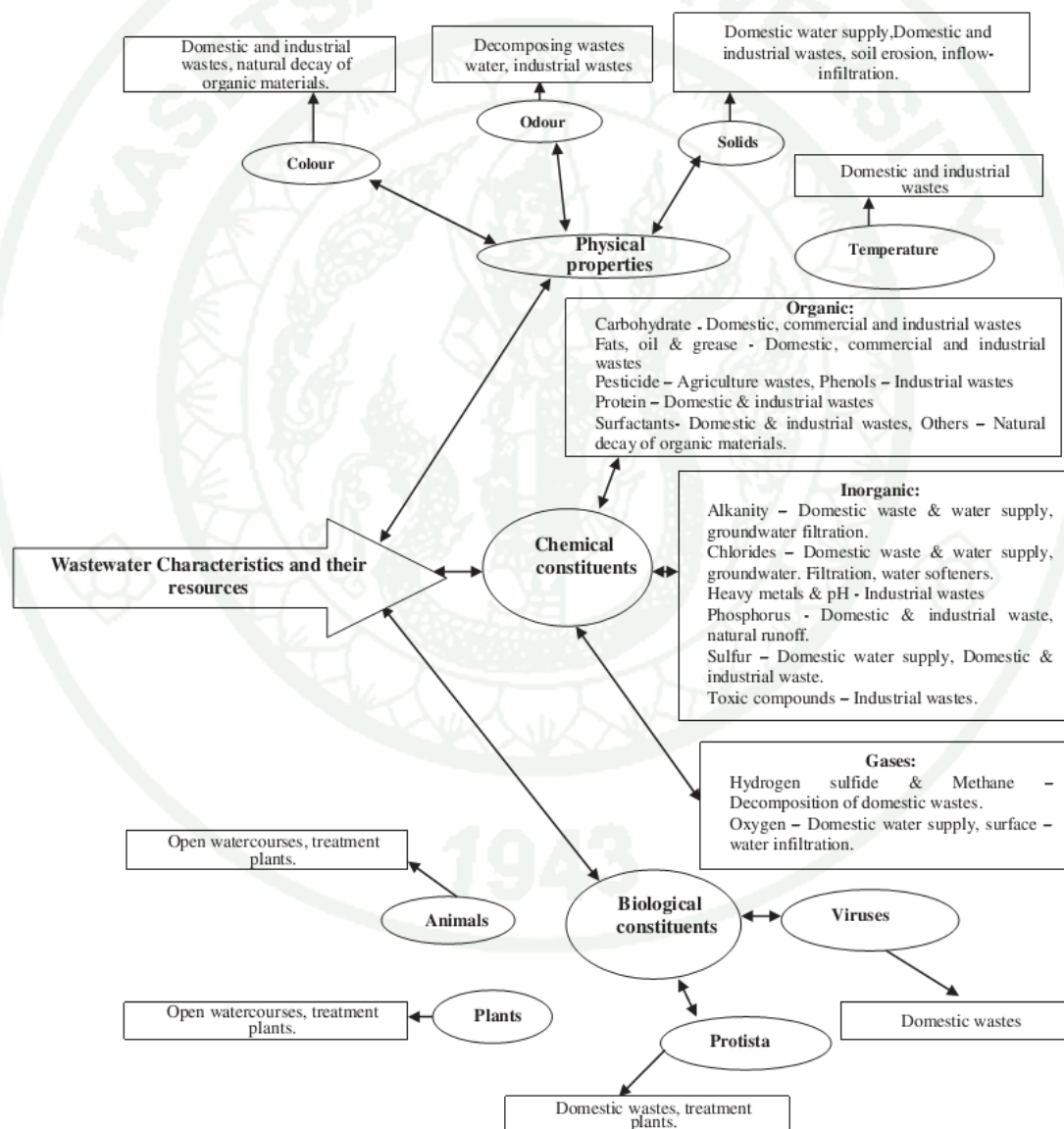


Figure 6 The characteristics of wastewater and their resources.

Source: Metcalf and Eddy (1991)

Eutrophication

In 1998, Lawrence and Jackson defined that eutrophication is the enrichment of bodies of fresh water by inorganic plant nutrients such as nitrate, and phosphate. It might occur naturally but is also the result of human activities (cultural eutrophication from fertilizer runoff and sewage discharge) and is particularly evident in slow-moving rivers and shallow lakes.

Wastewater from human activities is a cause of high nutrient loading into aquatic environment, which may lead to eutrophication and thus algae blooms (Cai *et al.*, 2012). In several parts of the world, this problem occurs due to the lack of infrastructure for wastewater treatment. Furthermore, where infrastructure is built, preference is given to municipal wastewater and other high-strength organic wastewater is left untreated. This is often the case of animal waste (Olgun, 2003).

A result of high eutrophication may create one or more environmental problems including high levels of chlorophyll a, low dissolved oxygen, algae blooms, and overgrowth of submerged aquatic vegetation (Southern California Coastal Water Research Project, 2010). Algal bloom can be harmful by releasing toxin to marine mammals, fish, domesticated animals, and human.

Microalgae and Wastewater Treatment

Typically, wastewater treatment plant consists of several stages to remove pollutant in wastewater released by domestic, agricultural, industrial water activities. Microalgal cultivation can be used as tertiary treatment in wastewater treatment plant as it uses inorganic nutrients such as nitrogen and phosphorus for growth. Algae do not only remove nutrient but they also reduce heavy metal and organic compound without releasing secondary pollutants (Abdel-Raouf *et al.*, 2012). Tam and Wong (1989), however, attempted to use high inoculum size of microalgae as a secondary treatment.

The word “phycoremediation” has been mentioned in many articles (Olgun, 2003; Rawat *et al.*, 2011; Sengar *et al.*, 2011). It refers to the use of algae for pollutant removal or biotransformation from wastewater especially high organic containing wastewater to prevent eutrophication. Microalga is not only enhancing the removal of nutrients but they also eliminate heavy metals and pathogens from wastewater. The end of treatment by using algae furnishes an interesting raw material for the production of high-value chemicals (algae metabolites) or biogas (Munoz and Guieysse, 2006). Carbon fixation usually occurs when algae fix carbon dioxide from atmosphere, therefore this method can be used for greenhouse gas mitigation.

Generally, a relation between photosynthesis microalgae and heterotroph is a key component in BOD removal process (Figure 7). Microalgae furnish oxygen automatically by photosynthesis, with the use of CO₂ released from bacterial respiration.

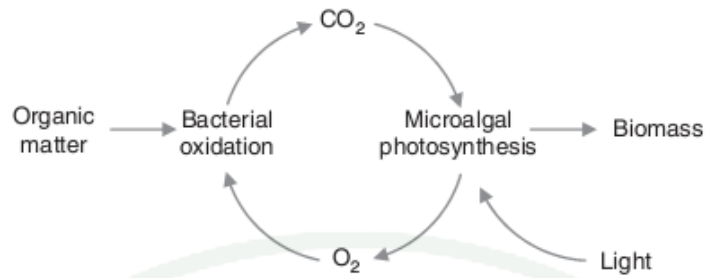


Figure 7 Principle of photosynthetic oxygenation in BOD removal processes.

Source: Munoz and Guieysse (2006)

The removal of nutrients from wastewater is by biomass assimilation (Su *et al.*, 2012). For nitrogen removal, algal organic nitrogen is derived from inorganic sources including nitrate, nitrite, nitric acid (HNO_3), ammonium (NH_4^+), ammonia (NH_3), and nitrogen gas (N_2). Microalgae play a key role in converting inorganic nitrogen to organic form through a process called assimilation. Moreover, cyanobacteria have ability to convert atmospheric nitrogen into ammonia by nitrogen fixation. Assimilation, which is performed by all eukaryotic algae, requires inorganic nitrogen only in forms of nitrate, nitrite, and ammonium as shown in Figure 8. Ammonium is not only removed by cell metabolism, but also by ammonia stripping, where significant amounts of ammonia can be volatile at increased pH and temperature. (Garcia *et al.*, 2000)

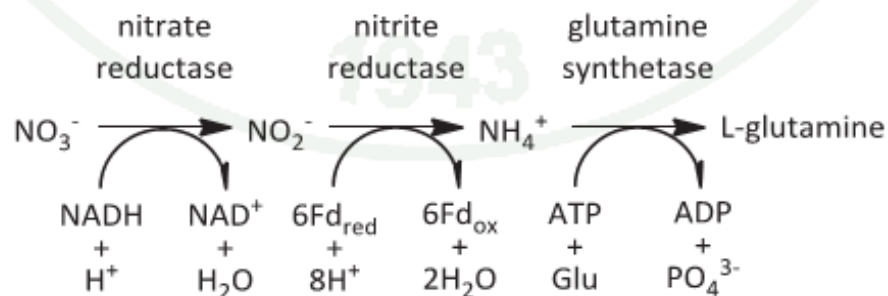


Figure 8 Simplified schematic of the assimilation of inorganic nitrogen.

Source: Cai *et al.* (2013)

Phosphorus, a component in energy transfer system, their removal is similar to the removal of nitrogen. Phosphorus removal from wastewater does not only occur by an uptake into the cell, but also by external conditions such as pH and dissolved oxygen. Phosphate will precipitate from the medium as a result of elevated pH to basic condition (Cai *et al.*, 2013). Li *et al.* (2011) reported lower exogenous CO₂ concentration promote phosphorus removal due to the high pH.

Algal production in wastewater is limited by several inhibitory parameters including: environmental factors (light and temperature); operational parameters (pH, dissolved CO₂, DO and nutrients), and biological contaminants (zooplankton grazing, and pathogens such as fungal and viral infection). So conditions including supply CO₂ from flue gas, enhancing light penetration may improve this process (Park *et al.*, 2011).

The widely used microalgae cultures for nutrient removal are species of *Chlorella* (Aslan and Kapdan, 2006; Langley *et al.*, 2012; Su *et al.*, 2012), and *Scenedesmus* (Su *et al.*, 2012; Pegallapati and Nirmalakhandan, 2013). However several studies showed consortium of local strain had high efficiency to treat wastewater (Chinnasamy *et al.*, 2010; Zhou *et al.*, 2012). Table 3 shows the use of different microalgae strains on nutrient removal.

Table 3 Nitrogen and phosphorus removal by various genera of microalgae and cyanobacteria in the axenic batch processes of different waste streams.

Category	Genus and species	Waste stream	Process type	Removal time (day)	Nutrients removal efficiency (%)		Reference(s)
					Total nitrogen (TN)	Total phosphorus (TP)	
Chlorophyte	<i>Chlorella</i> sp.	Digested manure	Batch	21	76–83	63–75	Wang et al. (2010)
	<i>C. pyrenoidosa</i>	Industrial wastewater	Fed-batch	5	87–89	70	Hongyang et al. (2011)
	<i>C. vulgaris</i>	Municipal wastewater	Batch	2–10	55–88	12–100	Ruiz-Marin et al. (2010)
	<i>Scenedesmus</i> sp.	Artificial medium	Batch	0.2–4.5	30–100	30–100	Zhang et al. (2008)
	<i>S. dimorphus</i>	Industrial wastewater	Batch	9	-	20–55	Gonzalez et al. (1997)
Cyanobacteria	<i>Oscillatoria</i> sp.	Municipal wastewater	Continuous	14	100	100	Craggs et al. (1997)
Diatom	<i>P. tricornutum</i>	Municipal wastewater	Continuous	14	80-100	50-100	Craggs et al. (1995)

Source: Cai et al. (2013)

***Scenedesmus* sp.**

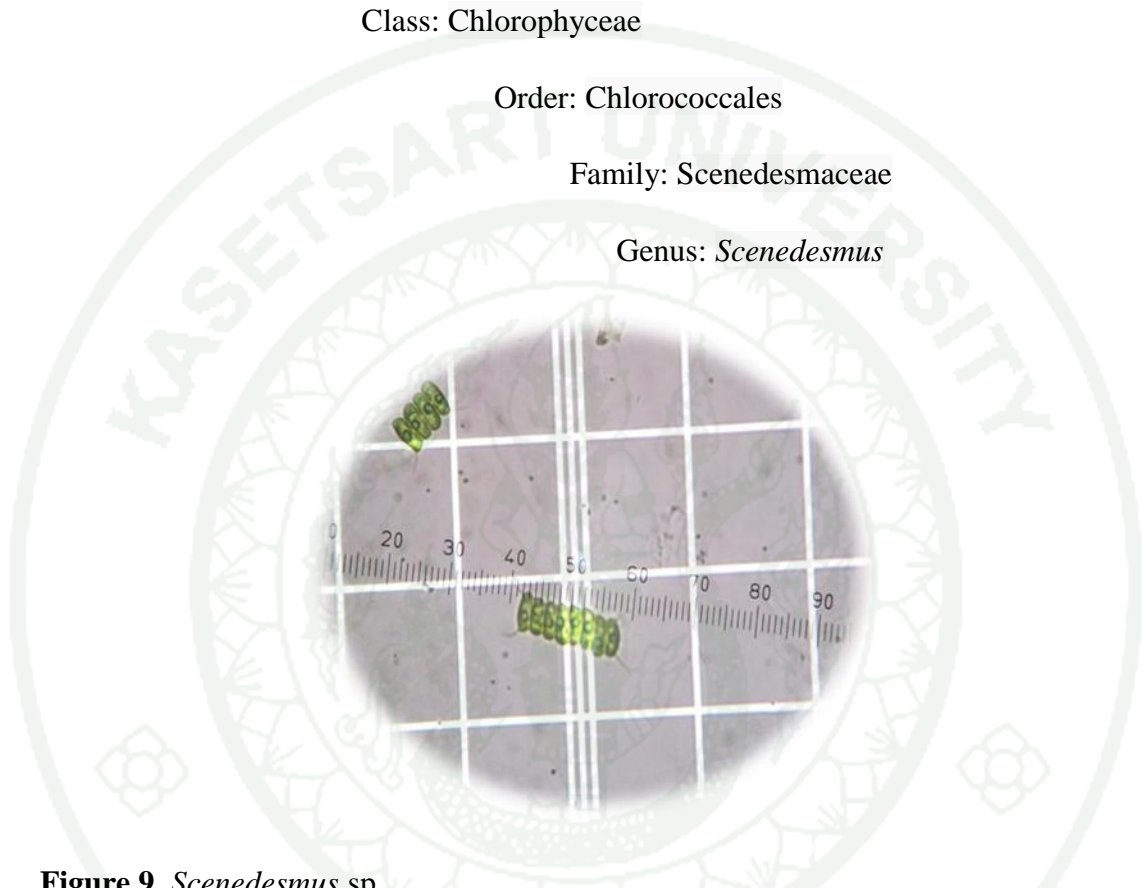
Kingdom: Plantae

Phylum: Chlorophyta

Class: Chlorophyceae

Order: Chlorococcales

Family: Scenedesmaceae

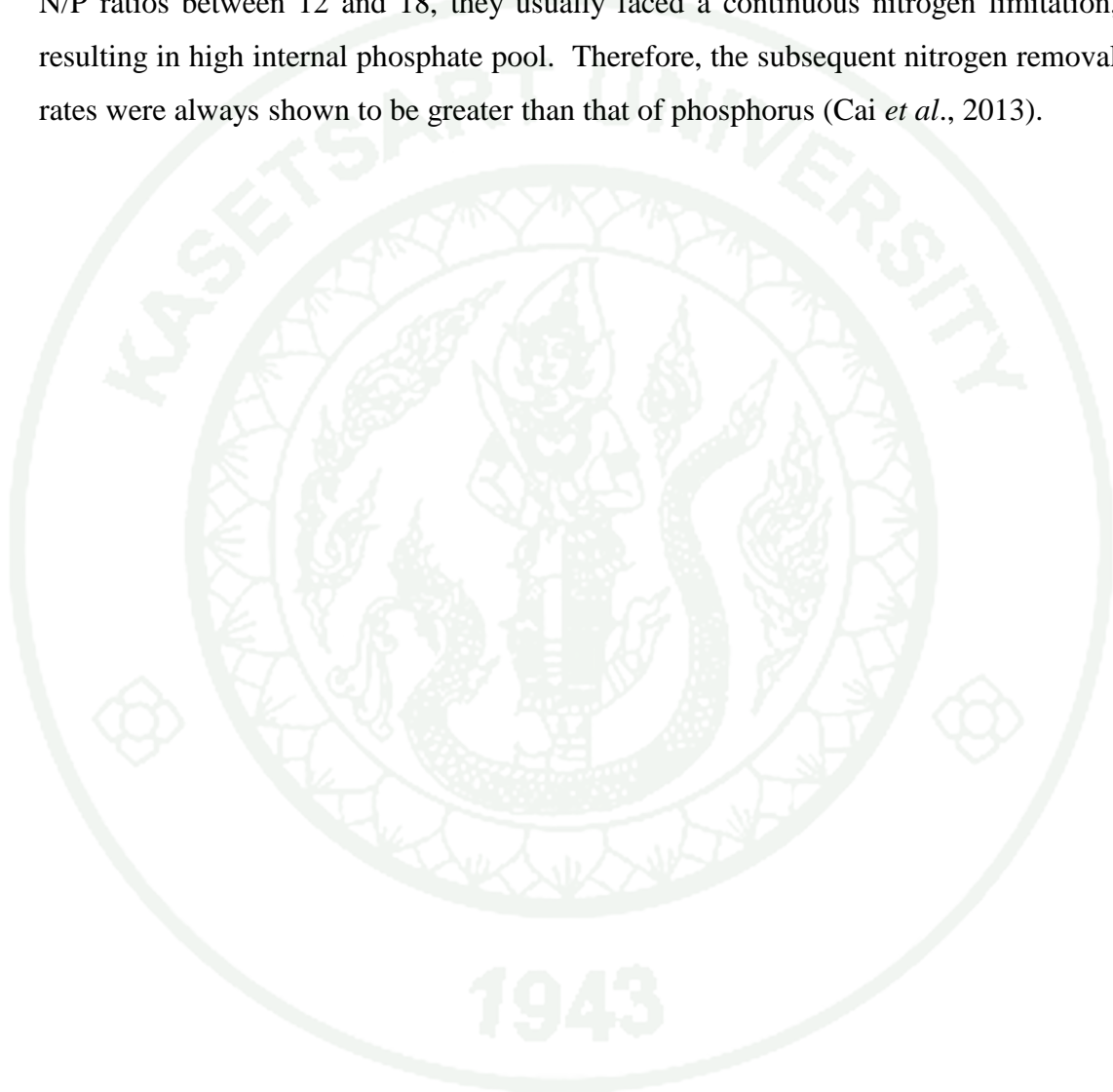
Genus: *Scenedesmus***Figure 9** *Scenedesmus* sp.

Scenedesmus sp. is classified as Chlorophyte. They are flat colonies of 2, 4 or 8 cell arranged in a row, though there might be a single rows of 12 cells. Cells are 5-30 mm long. Most species have spines at the corners of the colonies. Cells are equipped with spines and bristles, which make colonies more buoyant and allow increased light and nutrient uptake while deterring predation in water. A method of reproduction is asexual. There are numerous species and verity of this genus (Morgan, 2005; Cai *et al.*, 2013).

Scenedesmus sp. is widely used for nutrient removal. Table 3 shows that the nitrogen and phosphorus removal efficiencies of *Scenedesmus* spp. were 30–100%. Its nutrient uptake was not significantly different from that of some *Chlorella* species, as

shown by a comparison of *Scenedesmus dimorphus* and *C. vulgaris* (Gonzalez *et al.*, 1997)

It was reported that *Scenedesmus* sp. needed the N/P ratio of approximately 30 to grow without limitation by either nutrients. Being grown in an environment with N/P ratios between 12 and 18, they usually faced a continuous nitrogen limitation, resulting in high internal phosphate pool. Therefore, the subsequent nitrogen removal rates were always shown to be greater than that of phosphorus (Cai *et al.*, 2013).



Microalgae Utilization

Human utilize algae in many ways. Nutrient-rich algae are grown as aquaculture crops for direct use as human food. Normally, algae are primary producer in ecosystem that provide sufficient oxygen for another living organisms. In recent years, there has been renewed interest in algal bioenergy. Several algae can be used as non-food crops for biofuel's raw material and they can fix carbon dioxide from atmosphere (Graham *et al.*, 2009; Langley *et al.*, 2012). Table 4 summarizes microalgae utilization.

Table 4 Applications of algae.

Application	Detail
Food	Protein supplement/ fortification in diets for malnourished children and adult
Feed	Protein/ vitamin supplement in feeds for poultry, pig, fish, and bivalves
Therapeutics	<ul style="list-style-type: none"> - β-carotene as possible anti-skin-cancer treatment - Algal antibiotics as wound treatment, enzymatic, hydrolyzates to promote skin metabolism - Regulation of cholesterol synthesis - Isotopic compound in medical research
Pigment	<ul style="list-style-type: none"> - β-carotene as food color and food supplement (provitamin A) - Xanthophylls in chicken and fish feeds - Phycobilins as food color, in diagnostics, cosmetic, and analytical reagents
Source of fine chemical	<ul style="list-style-type: none"> - Glycerol used in foods, beverage, cosmetics, and pharmaceuticals - Fatty acid, lipids, waxes, sterols, hydrocarbon, amino acid, enzymes, vitamin C and E - Polysaccharides as gums, viscosifiers, and ion exchangers
Fuel	<ul style="list-style-type: none"> - Long chain hydrocarbons and esterified lipids as combustible oil - Hydrogen and biogas
Hormones	Auxins, gibberellins, and cytokines
Others	Biofertilizer, soil conditioner, waste treatment

Source: Becker (1993)

Algae Harvesting by Cross Flow Filtration

Cross flow filtration is one of the microfiltration techniques. Microfiltration is a type of physical filtration process where a contaminated fluid is passed through a special pore-sized membrane to separate microorganisms and suspended particles from process liquid. According to the direction of fluid flow, microfiltration is normally divided into dead end filtration and cross flow filtration (Baker, 2012).

With dead-end filtration, all particles larger than the pore sizes of the membrane are retained at the membrane surface. All of the feed water is treated at once, resulting in packed or compressed solids formation. This process is mostly used for batch or semi continuous filtration of low concentrated solutions.

Cross-flow filtration process is passed through tangentially with respect to the membrane. Part of the feed stream containing the treated liquid is collected below the filter while parts of the water are passed through the membrane untreated. Cross flow filtration is understood to be a unit operation rather than a process.

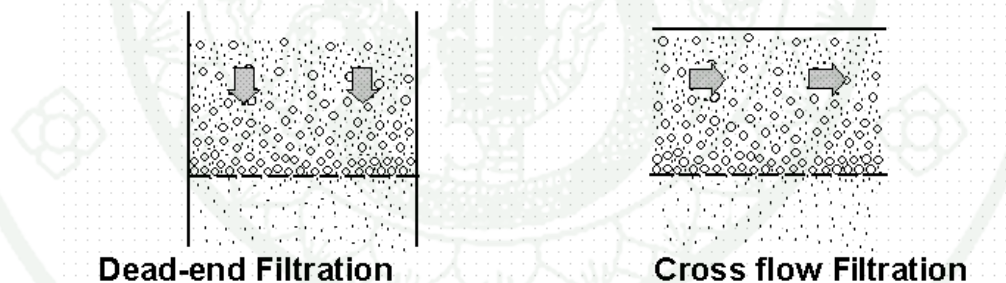


Figure 10 Dead-end filtration and cross flow filtration.

Source: Poirier (2001)

As microalgal cells cannot be easily separated from water by simple filtration, Chutivisut (2009) applied the cross flow filtration to separate natural microalgae and particulate matter from shrimp tank. It was found that cross flow filtration can remove the microalgae and particulate matters for more than 60% and can separate algal cells that smaller than pore size of the filter. This technique is therefore very useful for the large scale microalgae harvesting.

MATERIALS AND METHODS

Materials

1. 6 L vertical column photobioreactor (Figure 16)
2. 2000 mL Duran bottles (Figure 14)
3. Centrifuge
4. Spectrophotometer (Biotex Power wave x52)
5. Vortex mixer (Scientific Industries model G560E)
6. Micropipette
7. COD reactor
8. Air pump
9. GF/C filter WHATMAN NO.47
10. Fluorescence lamp
11. Desiccator
12. Thermometer
13. DO meter
14. pH meter
15. Autoclave (Hirayama HICLAVE HVE 50)
16. Liquid CO₂ storage tank
17. Solenoid valve
18. Refrigerator
19. Dosing pump
20. Submerge aquarium pump
21. Check valve
22. Auto recording light intensity and temperature
23. Cross flow filtration system (Figure 17)
23. Scientific glassware

Methods

This research was conducted under laboratory conditions. Wastewater was collected from wastewater treatment plant of instant noodle factory (Wan Thai Foods Industry Co., Ltd) in Bangkok. The green microalga *Scenedesmus* sp. was used as a nonindigenous robust strains for investigating nutrient removal and microalgae biomass production. For batch culture experiments, effects of wastewater types, phosphate addition, and external CO₂ supplement were evaluated using 2000 ml Duran bottle as the culture vessel under laboratory condition. Outdoor semi continuous experiment was also conducted for determining optimal condition under natural environment. Outdoor continuous culture was operated in 6 L vertical column photobioreactor using optimal condition obtained from batch operations. The overall experiment flowchart is illustrated in Figure 11.

1. Source of Microalgae and Culture Medium

Scenedesmus sp. was obtained from culture collection of the Center of Excellence for Marine Biotechnology, Chulalongkorn University. *Scenedesmus* sp. was incubated under continuous light (5000 lux) at 25± 1 ° C in BG-11 medium containing (g/L): K₂HPO₄·3H₂O, 0.04; MgSO₄·7H₂O, 0.075; CaCl₂·2H₂O, 0.036; citric acid, 0.006; ferric ammonium citrate, 0.006; EDTA, 0.001; NaNO₃, 1.5; Na₂CO₃, 0.02; trace metal mix A5, 1.0 ml which consisted of (g/L) H₃BO₃, 2.86; MnCl₂·4H₂O, 1.81; ZnSO₄·7H₂O, 0.222; NaMoO₄·2H₂O, 0.39; CuSO₄·5H₂O, 0.079; and CoCl₂·6H₂O, 0.05 (Zhou *et al.*, 2012).

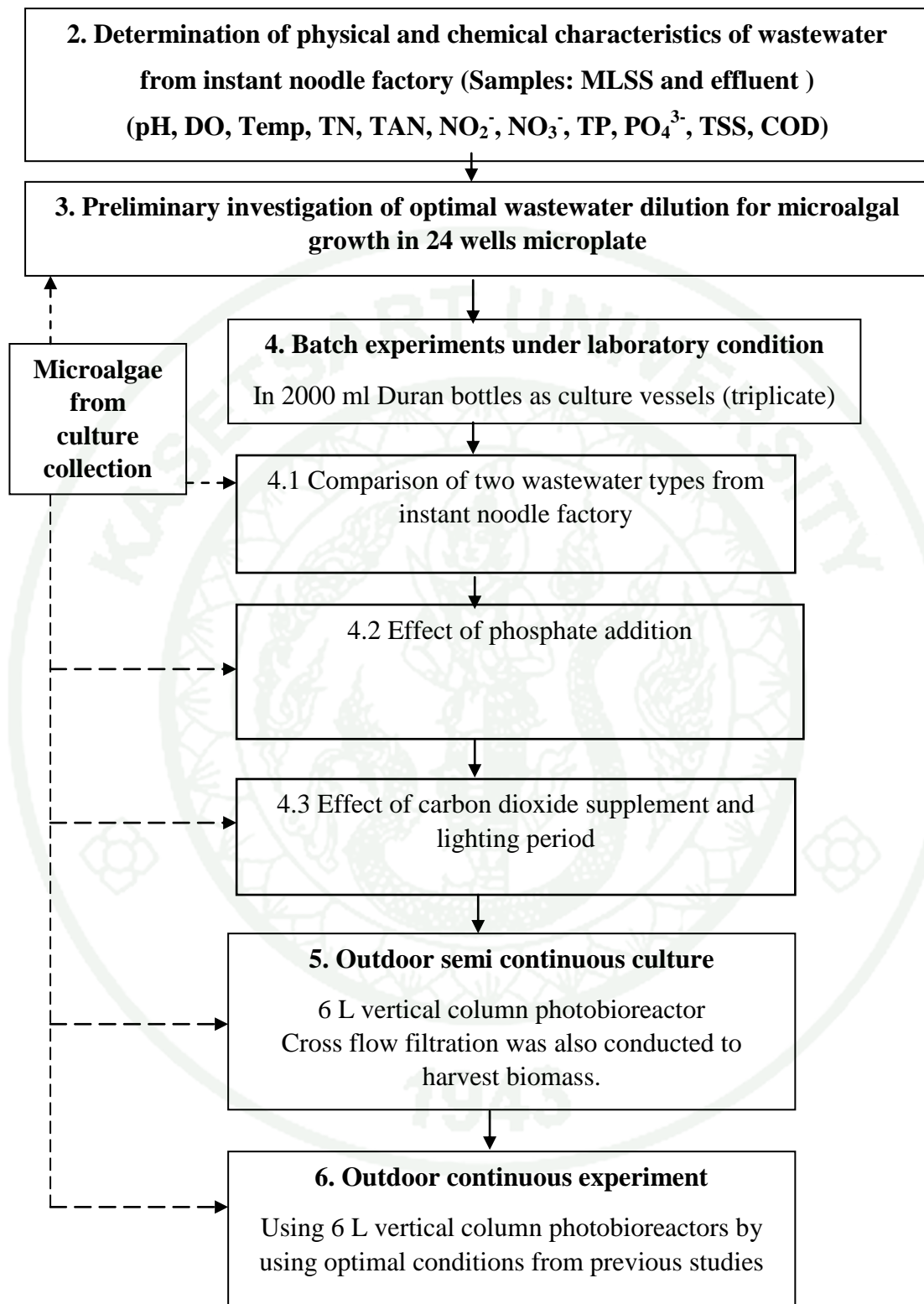


Figure 11 Schematic diagram of the experiments.

2. Wastewater Collection and Analysis

Wastewater was taken from the different stages of the activated sludge wastewater treatment plant of Wan Thai Foods Industry Co., Ltd, which is an instant noodle factory, in Bangkok. The mixed liquor suspended solids (MLSS) collected from an aeration tank and effluent collected from a final sedimentation tank (Figure 12) were chosen for this study. The wastewater samples were transported to the laboratory and kept frozen at -20°C prior to analysis (Zhou *et al.*, 2012). Dissolved oxygen (DO), temperature, and pH were measured immediately during water sampling. Wastewater parameters including total nitrogen (TN), total ammonia nitrogen (TAN), nitrate (NO_3^-), nitrite (NO_2^-), total phosphorus (TP), phosphate (PO_4^{3-}), total suspended solids (TSS) and chemical oxygen demand (COD) were determined according to standard methods for wastewater analysis (APHA, 2005). The analytical methods for each parameter were shown in Table 5. Analytical procedures, chemical reagents, and standard curve for nutrient analysis were shown in appendix A.

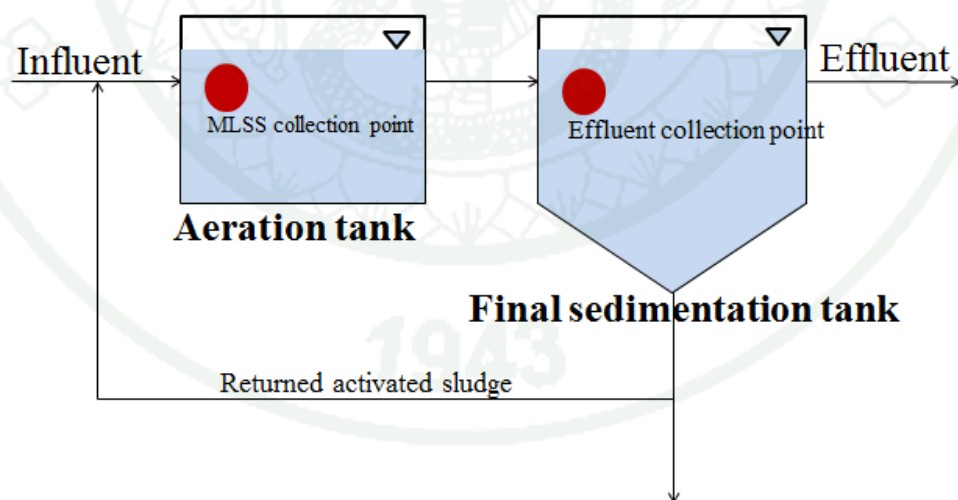


Figure 12 Diagram of Activated sludge wastewater treatment process of Wan Thai Foods Industry Co., Ltd. Wastewater samples i.e. MLSS and effluent were collected from aeration tank and sedimentation tank, respectively.

Table 5 Analytical method for each parameter of wastewater.

Parameter	Method	References
pH	pH meter	
Dissolve oxygen (DO)	DO meter	
Temperature	Thermometer	
Total nitrogen (TN)	Oxidizing and nitrate analysis by Spectrometric	Grasshoff (1999)
Total ammonia nitrogen (TAN)	Salicylate-Hypochlorite method	Bower and Hansen (1980)
Nitrate	Ultraviolet Spectrometric screening method	APHA (2005)
Nitrite	Spectrometric	Srickland and Parsons (1972)
Total phosphorus	Oxidizing and phosphate analysis by Spectrometric	Grasshoff (1999)
Phosphate	Spectrometric	Srickland and Parsons (1972)
Total suspended solids (TSS)	Gravimetric method	APHA (2005)
Chemical oxygen demand (COD)	Close reflux, Titrimetric method	APHA (2005)

3. Preliminary Investigation of Optimal Wastewater Dilution for Microalgal Growth

Each MLSS (5500 ± 244.34 mg ss/L) and effluent sample was filtered and diluted with deionized water into four concentrations i.e. 100%, 75%, 50%, and 25% in order to investigate the effect of various nutrients concentration that able to support microalgal growth. BG11 medium was assigned as control. The screening experiment was performed using 24 wells microplate (tissue culture plate) (Figure 12) filled with 1800 microliters of wastewater and then inoculated with 200 microliters (10% inoculation) of *Scenedesmus* sp. stock culture. The experiment was conducted with four replicates (four wells) for each concentration. Growth of the microalgae was determined by measuring OD₆₈₀ nm daily using microplate spectrophotometer (Power Wave XS2) within 10 days in order to estimate microalgae growth.



Figure 13 The 24 wells microplates for preliminary investigation of optimal wastewater dilution for microalgae growth.

4. Batch Culture Experiments under Laboratory Condition

Ten days-batch culture experiments were conducted to determine optimal condition for microalgae growth and nutrient removal. All batch cultivations were carried out in triplicate in 2000 mL Duran bottles as the culture vessel. Duran bottles were filled with 1800 ml of wastewater and 200 ml of inoculants and cultivated at 33.2 ± 0.7 °C under continuous artificial light at approximately 5000 lux. The diagram of reactor was illustrated in Figure 13.

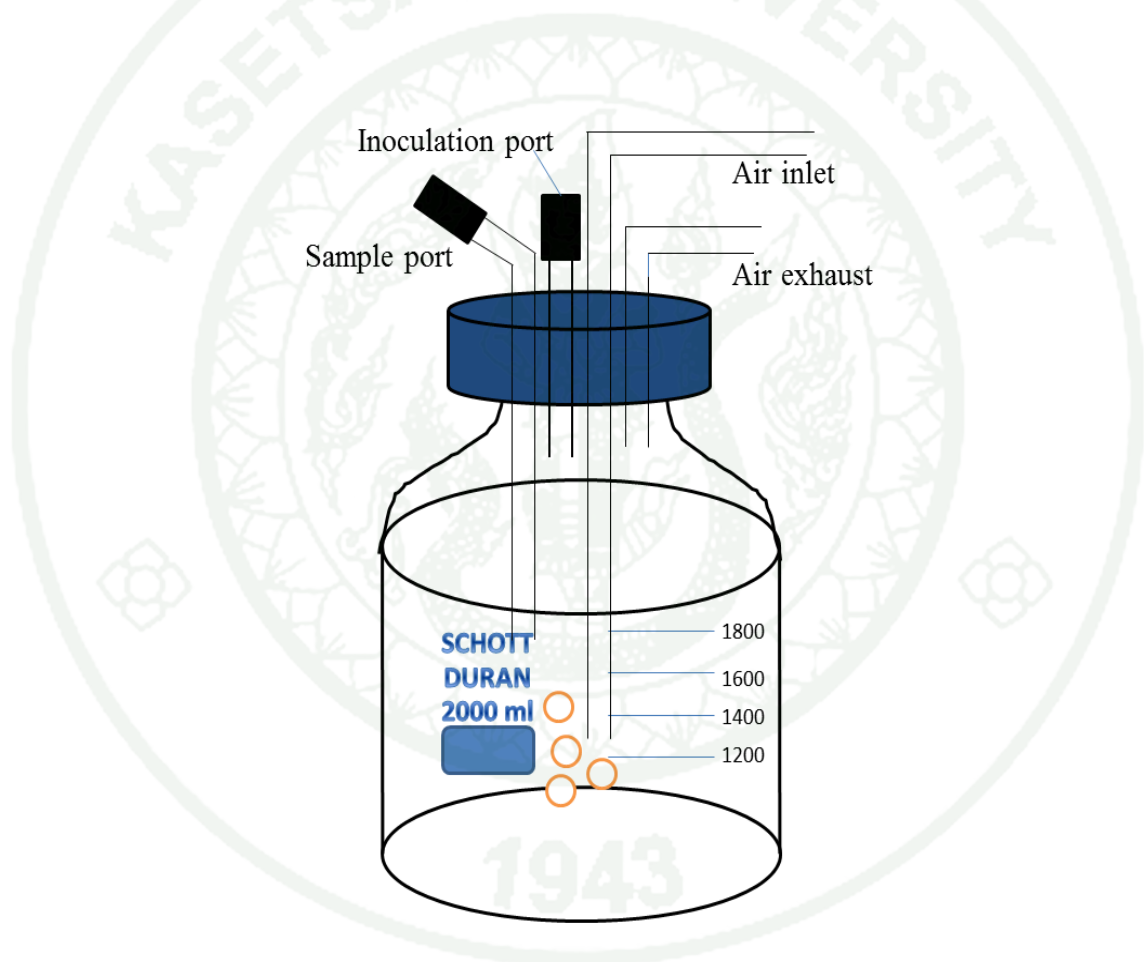


Figure 14 A 2000 ml Duran bottle used as the culture vessel for microalgae growth under batch experiment.

4.1 Use of undiluted wastewater from instant noodle factory for microalgae growth

MLSS and effluent from wastewater treatment plant without dilution (100%) (optimal dilution from section 3) were used as the culture medium for *Scenedesmus* sp. cultivation. BG-11 medium was assigned as a control. Continuous aeration was supplied to all reactors by air pump and continuous artificial light at approximately 5000 lux was provided by cool white fluorescence lamps. Ten milliliters of wastewater was collected daily during ten days cultivation in order to determine microalgal growth (cell count with haemocytometer) and nutrient removal.

4.2 Effect of phosphate addition to enhance microalgae growth in wastewater from instant noodle factory

In general, phosphate concentration in the water is the limiting factor for microalgal growth (Graham *et al.*, 2009). MLSS and effluent without dilution were used as the culture medium. Continuous aeration was supplied to all reactors by air pump and continuous artificial light at approximately 5000 lux was provided by cool white fluorescence lamps. The experiment consisted of T1 (MLSS), T2 (MLSS with phosphate addition), T3 (effluent), and T4 (effluent with phosphate addition). K_2HPO_4 was added in the 4th day to compensate phosphate depletion during cultivation. Ten milliliters of wastewater was collected daily during ten days cultivation in order to determine microalgal growth (cell count with haemocytometer) and nutrient removal.

4.3 Effect of lighting period and external carbon dioxide supplement on growth of microalgae cultivated in wastewater

According to previous results from section 4.1 and section 4.2, MLSS was selected for *Scenedesmus* sp. cultivation. Two percent carbon dioxide mixed with air (volume/volume) derived from a liquid carbon dioxide storage tank (Figure 14) was supplied to culture vessels while 100% air supplement were assigned as a control. The experiment consisted of T1 (control; continuous light and continuous aeration), T2 (carbon dioxide supplement under continuous light), T3 (12:12h

light:dark cycle with continuous aeration), and T4 (12:12h light:dark cycle with carbon dioxide supplement). Light source used in this study was cool white fluorescence lamps providing approximately 5000 lux light intensity. Ten milliliters of wastewater was collected daily during ten days cultivation in order to determine microalgal growth (cell count with haemocytometer) and nutrient removal.

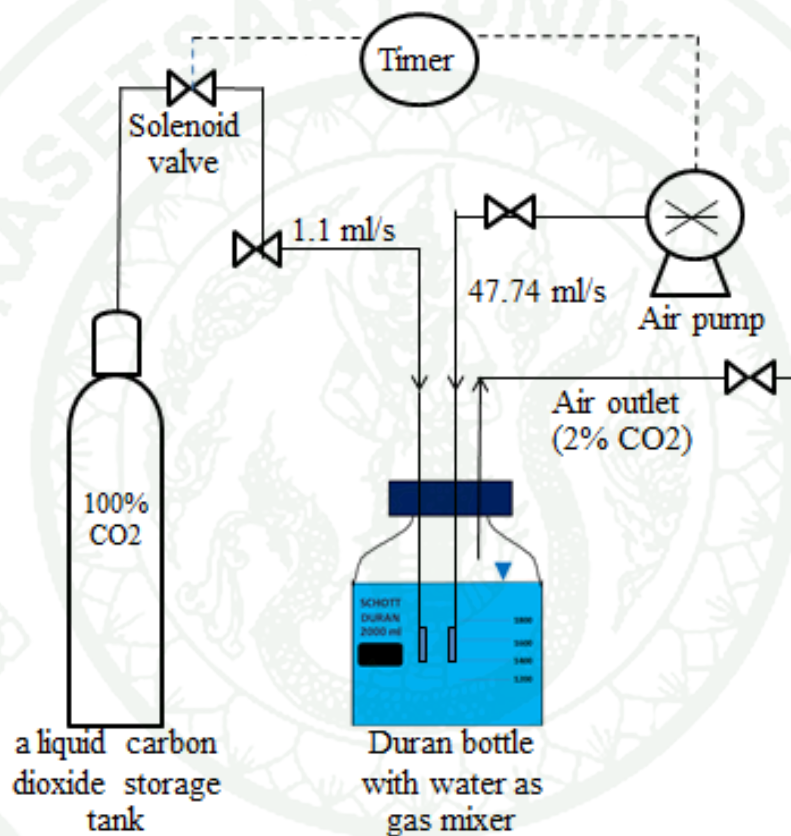


Figure 15 Diagram of external CO₂ mixing device in this experiment.

5. Outdoor Semi Continuous Culture Experiments

Effects of aeration and external CO₂ supplement on growth of *Scenedesmus* sp. under outdoor condition were investigated in 6 L vertical column photobioreactors. Vertical column photobioreactor was made from transparent acrylic with the thickness of 2 mm. The photobioreactor was 100 cm in height and 10 cm in diameter (Figure 15). There were 3 trials for outdoor semi continuous experiments as shown in Table 6. The optimal condition obtained from trial 1 and 2 was repeated in trial 3 in order to confirm optimal condition to be used in further experiment.

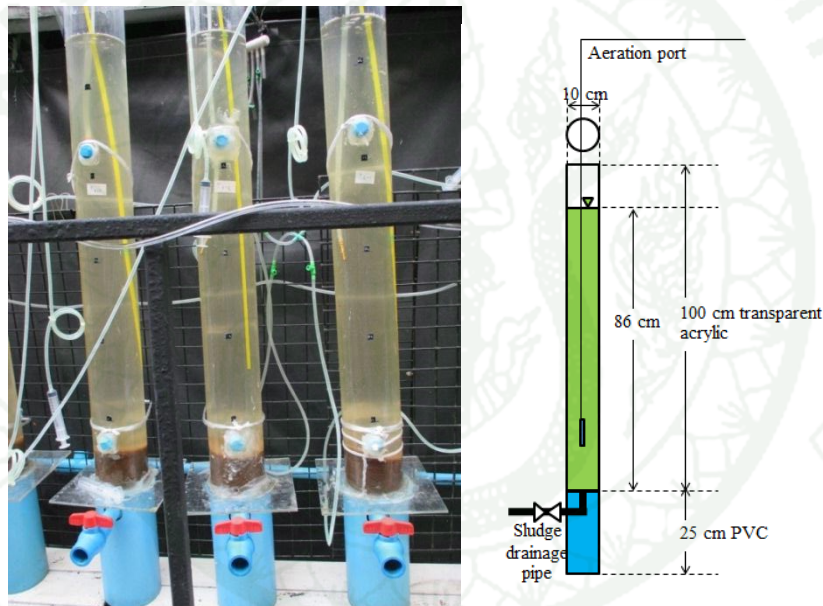


Figure 16 6 L Vertical column photobioreactor for semi continuous culture experiments.

Table 6 Trials for outdoor semi continuous culture experiments.

Trial	Treatment	Duration	Algal harvesting (times)
1	T1-1 (Continuous aeration)	12 days	3
	T1-2 (Continuous external CO ₂ supplement)	(18 December 2013 - 30 December 2013)	
2	T2-1 (Aeration during daytime)	24 days	4
	T2-2 (External CO ₂ supplement during daytime)	(11 February 2014 - 7 March 2014)	
3	T3-1 (Continuous aeration)	17 days	4
	T3-2 (External CO ₂ supplement during daytime)	(12 March 2014 - 29 March 2014)	

Photobioreactor was filled with 5400 mL of MLSS and leave for 30 minutes to settle down solid particle in MLSS. Thereafter, 600 mL of *Scenedesmus* sp. inoculum in BG11 medium was added into reactor. All treatments were conducted in triplicates. Aeration was provided by air pump and external CO₂ was mixed to the air as shown in section 4.3 (Figure 14). For trial 2 and trial 3, air pump and CO₂ supplement were controlled by electronic timer to provide aeration or CO₂ supplement during 6 am to 6 pm which related to daylight period. Natural light intensity and temperature was measured automatically every 15 minutes and data was recorded with data logger (HOBO Part#UA-002-64). Ten milliliters of wastewater was collected daily during microalgae cultivation in order to observe microalgal growth (cell count with haemocytometer) and nutrient removal. Frequency of parameter analysis was shown in Table 7.

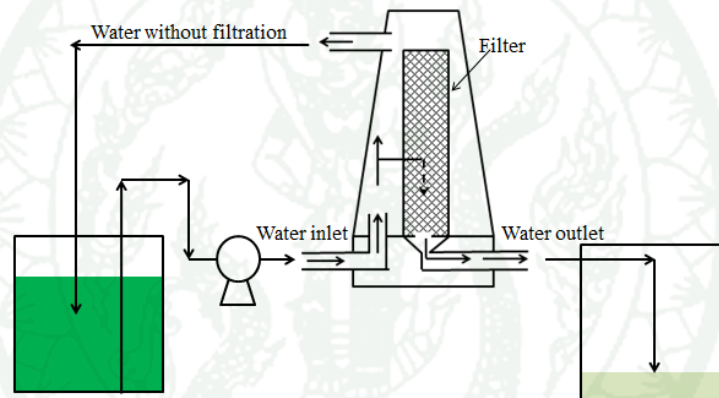
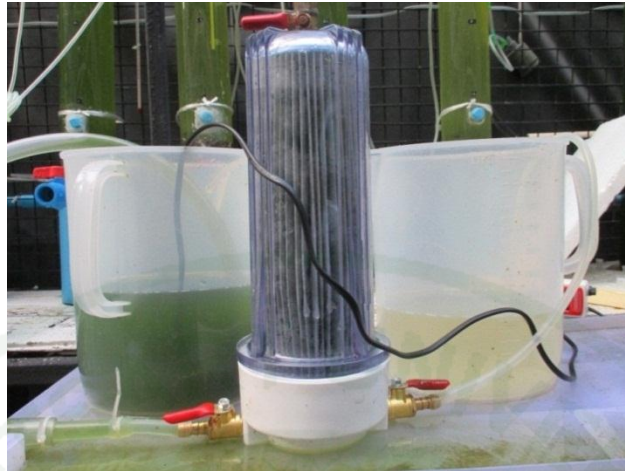


Figure 17 Diagram of the cross flow filtration device for *Scenedesmus* sp. harvesting from photobioreactor.

During algal culture experiment, when microalgal cells reached the end of exponential growth phase, algal harvesting was performed using cross flow filtration system (Figure 16). Five micron polyester cartridge filter was used as filter in a cross flow filtration device. At each harvesting batch, approximately 4000 mL of algae culture on the top of the reactor column was withdrawn for cross flow filtration. After filtration, 500 mL of concentrated algal cells was removed, and 3500 mL of filtrate with low algal density was recycled into the photobioreactor. Finally, 500 mL of wastewater was added into the photobioreactor to compensate the removed cultures.

6. Outdoor Continuous Culture Experiments

Vertical column photobioreactors as described in section 5 were used in this study. Addition of wastewater pump and effluent removal port were installed as the continuous culture system (Figure 17). CO₂ supplement (2 %) was only provided during daylight period (optimal condition from section 5). Before continuous operation, *Scenedesmus* sp. was cultivated 7 days under batch culture mode until it reached the end of exponential phase. MLSS collected from instant noodle factory was kept at 4°C in refrigerator. The experiment was performed in triplicate. MLSS was continuously fed to the photobioreactor by a dosing pump at 3 L/day and 6 L/day. Dilution rate was varied at 0.5 day⁻¹ and 1.0 day⁻¹ to investigating optimal dilution rate. Dilution rate was calculated according to the equation:

$$\text{Dilution rate (day}^{-1}\text{)} = \frac{\text{Flowrate } \left(\frac{\text{L}}{\text{day}}\right)}{\text{Volume of reactor (L)}} \quad (5)$$

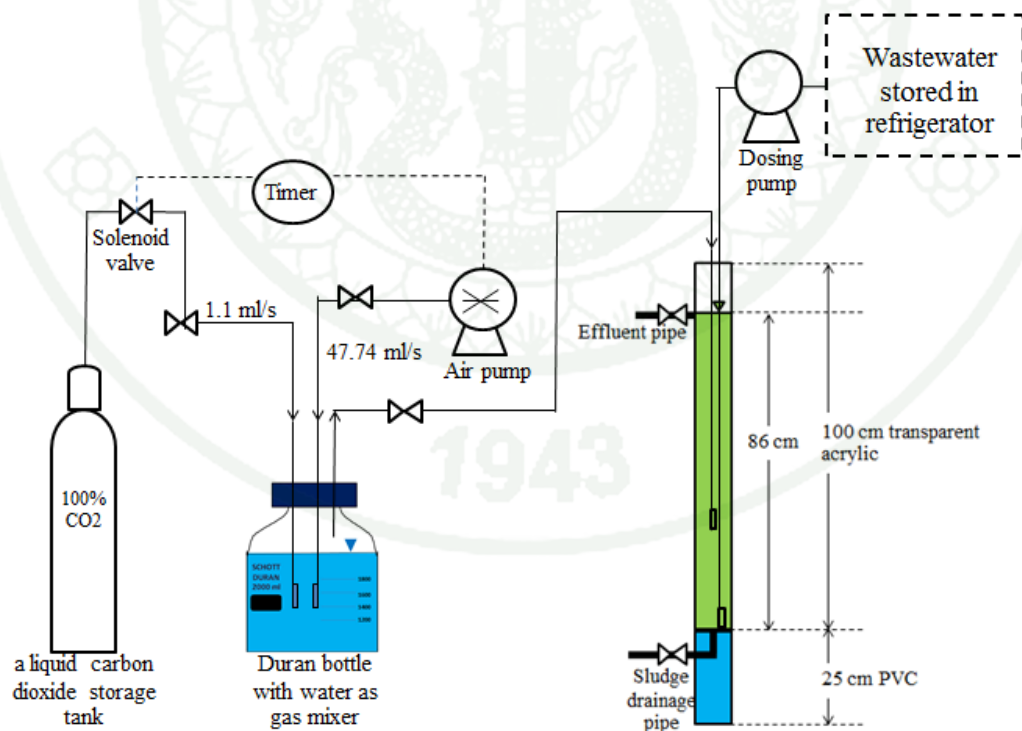


Figure 18 Diagram of continuous microalgal photobioreactor in wastewater from instant noodle factory.

CO₂ supplement was controlled by electronic timer allowing CO₂ supplement only with daylight period (from 6 am to 6 pm). Natural light intensity and temperature was measured automatically every 15 minutes and data was record in data logger (HOBO Part#UA-002-64). Twenty milliliters of wastewater was collected daily during cultivation in order to observe microalgae growth (cell count with haemocytometer) and nutrient removal. Frequency of parameter analysis was shown in Table 7.

6.1 Total lipid analysis

Scenedesmus sp. cells harvested from photobioreactor under outdoor continuous cultured was analyzed according to Bligh and Dyer method (1959) to determine total lipid content. Procedure for total lipid extraction was following:

- 1) Each 0.2 ml of algae sample with known biomass dry weight was added with 3.75 ml 1: 2 (v/v) CHCl₃: methanol and vortex well.
- 2) Add 1.25 mL CHCl₃ and vortex well.
- 3) Add 1.25 mL dH₂O and vortex well.
- 4) Centrifuge at 1000 rpm for 5 minutes at room temperature to separate the extract in two-phases (aqueous top, organic bottom).
- 5) Finally, recover the bottom phase, dried at 50 °C for 48 hrs. and weight with 4 decimal balance.
- 6) Calculate % total lipid.

6.2 C H N component in algae and wastewater sludge

Microalgae biomass, initial wastewater sludge in MLSS, and final wastewater sludge after microalgae cultivation were dried at 50 °C and homogenized. Carbon, hydrogen and nitrogen contents were analyzed using CHNS/O analyzer (Thermo Scientific™ FLASH 2000) at the Scientific and Technological Research Equipment Centre, Chulalongkorn University. With CHNS/O analyzer, gaseous products after pyrolysis in high purity oxygen were separated by chromatography and detected with thermal conductivity detector.

7. Analytical methods

Analytical methods for wastewater are shown in Table 5 and frequency of sampling was shown in Table 7.

7.1 Wastewater analysis

Ten milliliters of water samples for nutrient analysis were collected with daily basis. Water sample was filtered with GF/C filter (Whatman) and kept frozen. Analysis method of wastewater parameter was shown in Table 5. Relative removal efficiency in percent were calculated by dividing the difference between the first day and final day concentrations by the first day concentration, then multiply by 100.

7.2 Measurement of microalgal growth

The microalgal cell density was counted daily under microscope observation using a haemocytometer. Biomass (dry weight) was calculated using linear relationship between dry weight biomass and cell density counted with haemocytometer (Appendix B) according to the equation:

$$\text{Dry weight (mg/L)} = (\text{Cell density (} 10^4 \text{cell/ mL)} + 7.2328) / 0.2945 \quad (6)$$

A growth curve was plotted between biomass or cell concentration and time. Specific growth rate (μ) of the cells during exponential phase was calculated with the following equation (Zhou *et al.*, 2012):

$$\mu = \frac{\ln N_2 - \ln N_1}{T_2 - T_1} \quad (7)$$

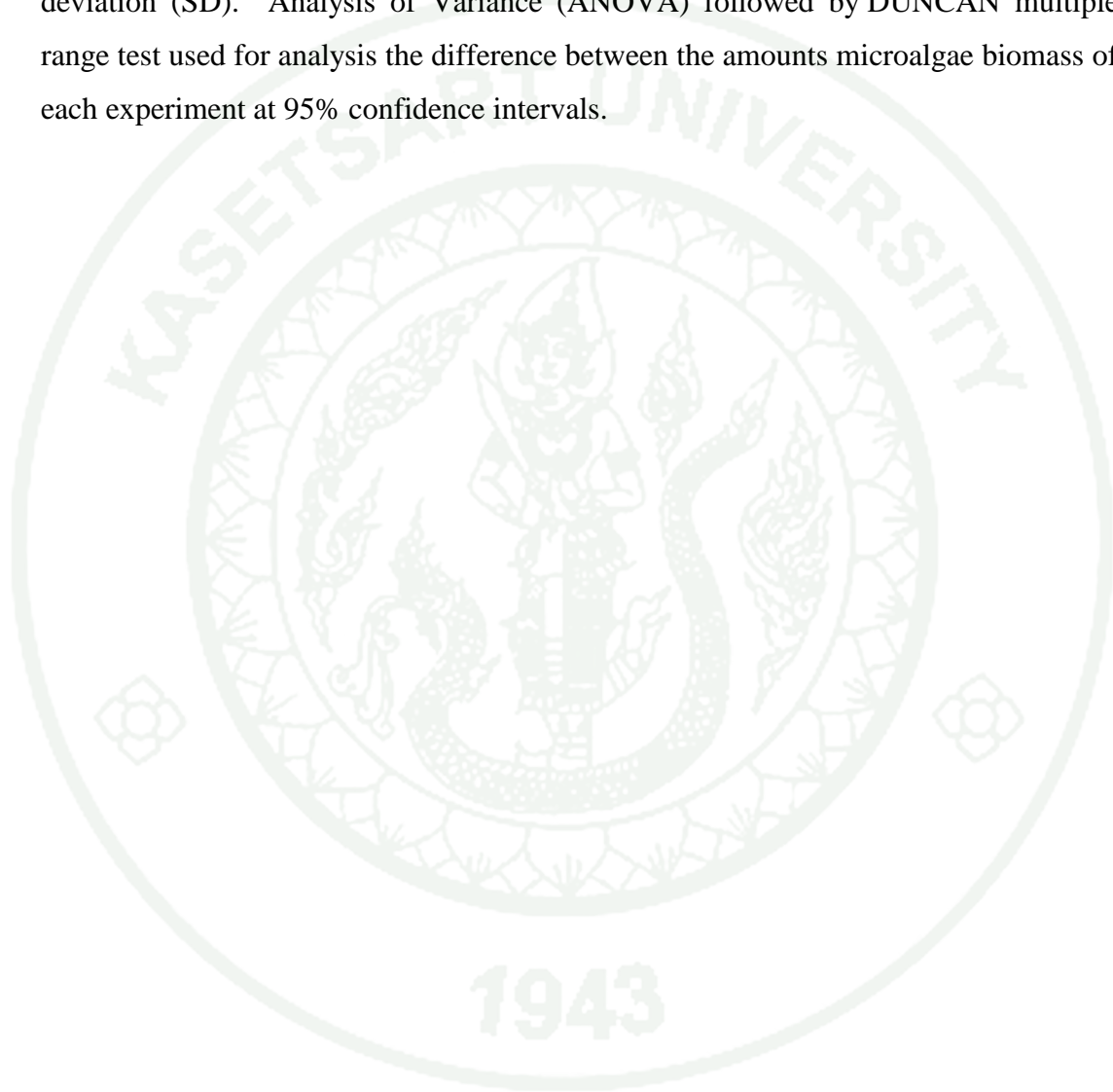
Where N_1 and N_2 are cell densities at times T_1 and T_2 respectively.

Table 7 Frequency of wastewater parameter analysis and microalgal growth.

Parameter	Analysis frequency		
	Batch experiment	Semi continuous experiment	Continuous experiment
pH and DO	-	Sometimes	Sometimes
Temperature	-	Daily	Daily
Total nitrogen	-	Initial and final	Daily
Soluble total nitrogen	-	Initial and final	Daily
Total ammonia nitrogen	Daily	Daily	Daily
Nitrite	Daily	Daily	Daily
Nitrate	Daily	Daily	Daily
Total phosphorus	-	Initial and final	Daily
Soluble total phosphorus	-	Initial and final	Daily
Phosphate	Daily	Daily	Daily
Chemical oxygen demand (COD)	Initial and final	Initial and final	Daily
Oxidation reduction potential (ORP)	-	-	Sometimes
Microalgae cell concentration	Daily	Daily	Daily
Calculation of microalgae biomass	Daily	Daily	Daily

8. Statistical Analysis

All experiments were done at least in triplicates. Wastewater effluent quality and microalgae growth were statistically analyzed using mean (\bar{x}) and standard deviation (SD). Analysis of Variance (ANOVA) followed by DUNCAN multiple range test used for analysis the difference between the amounts microalgae biomass of each experiment at 95% confidence intervals.



RESULTS AND DISSCUSSION

1. Characteristics of Wastewater from Instant Noodle Factory

Wastewater from instant noodle factory (Wan Thai Foods Industry Co., Ltd., Bangkok, Thailand) was collected from two stages of activated sludge treatment process; mixed liquor suspended solids (MLSS) and effluent from an aeration tank and sedimentation tank, respectively. Their characteristics were shown in Table 8.

Table 8 Physical and chemical characteristics of wastewater from instant noodle factory.

Parameter (Unit)	Wastewater	
	MLSS	Effluent
	Average \pm SD (min - max)	Average
pH	7.17 \pm 0.06 (6.98 – 8.23)	7.43
Total nitrogen (mg N/L)	189.87 \pm 14.80 (68.44 – 211.15)	68.74
Soluble total nitrogen (mg N/L)	32.09 \pm 7.43 (28.56 – 63.22)	45.07
Total ammonia nitrogen (mg N/L)	1.32 \pm 0.15 (nd. – 24.23)	1.24
Nitrite (mg N/L)	0.04 \pm 0.00 (nd. – 2.65)	nd.
Nitrate (mg N/L)	44.81 \pm 3.63 (6.33 – 63.29)	46.28
Total phosphorus (mg P/L)	5.93 \pm 0.37 (4.21 – 30.28)	3.13
Soluble total phosphorus (mg P/L)	0.40 \pm 0.07 (0.35 – 20.16)	1.33
Phosphate (mg P/L)	1.82 \pm 0.38 (0.23 – 18.22)	1.10
Total suspended solids (mg/L)	5500.00 \pm 244.34 (3408.25 – 9023.55)	126.67
Chemical oxygen demand (mg/L)	3366.00 \pm 200.92 (2908.11 – 11005.00)	198.00
Soluble chemical oxygen demand (mg/L)	367.16 \pm 8.08 (290.43 – 657.17)	148.88

Remark MLSS was collected seven times during 2013 and 2014 while effluent was collected only once in 2013.

Table 8 shows that MLSS from instant noodle factory contained high suspended solids and high COD. Due to the high TSS (5500.00 ± 244.34 mg/L) in MLSS, nitrogen and phosphorus were mostly deposited in insoluble organic particle. Ammonia, nitrite, and nitrate in MLSS were found in low concentrations (1.32 ± 0.15 mg N/L, 0.04 ± 0.00 mg N/L and 44.81 ± 3.63 mg N/L, respectively). In general, decomposition of organic compounds could release high amount of ammonia into the water due to ammonification process. This ammonia is the nitrogen source that enhanced growth of the microalgae. Effluent, on the other hand, had lower TSS (126.67 ± 5.77 mg/L) so it could be stated that almost nutrient in effluent was soluble form.

Noted that the major source of nitrogen in wastewater from instant noodle factory was probably from protein in wheat flour because the instant noodle uses wheat flour (85 – 94%) or rice flour as the main ingredient with lesser amount other ingredients (Food and Agriculture Organization of the United Nations, 2002; United State Agency International Development, n.d.). Typically, several proteins could be found in wheat starch such as albumins, globulins, gliadins and glutenins (Faculty of food land and food system, n.d.). These protein residues were therefore the nitrogen source in wastewater.

2. Preliminary Investigation of Optimal Wastewater Dilution for Microalgal Growth

Growth curves of *Scenedesmus* sp. in various percentages of wastewater were shown in Figure 19. The results indicated that both wastewaters without dilution provided the highest growth rate of *Scenedesmus* sp. Specific growth rate during the second day of algal cultivation with 100% MLSS and 100% effluent were 1.63 ± 0.11 day⁻¹ and 1.57 ± 0.16 day⁻¹, respectively. Both specific growth rates were significantly ($p < 0.05$) higher than BG11 medium (1.08 ± 0.14 day⁻¹) (Table 9). Min *et al.* (2011) also demonstrated that high concentration of nutrients in wastewater can support the highest growth performance of the microalga *Chlorella* sp. Therefore wastewater from instant noodle factory without dilution was selected for further study.

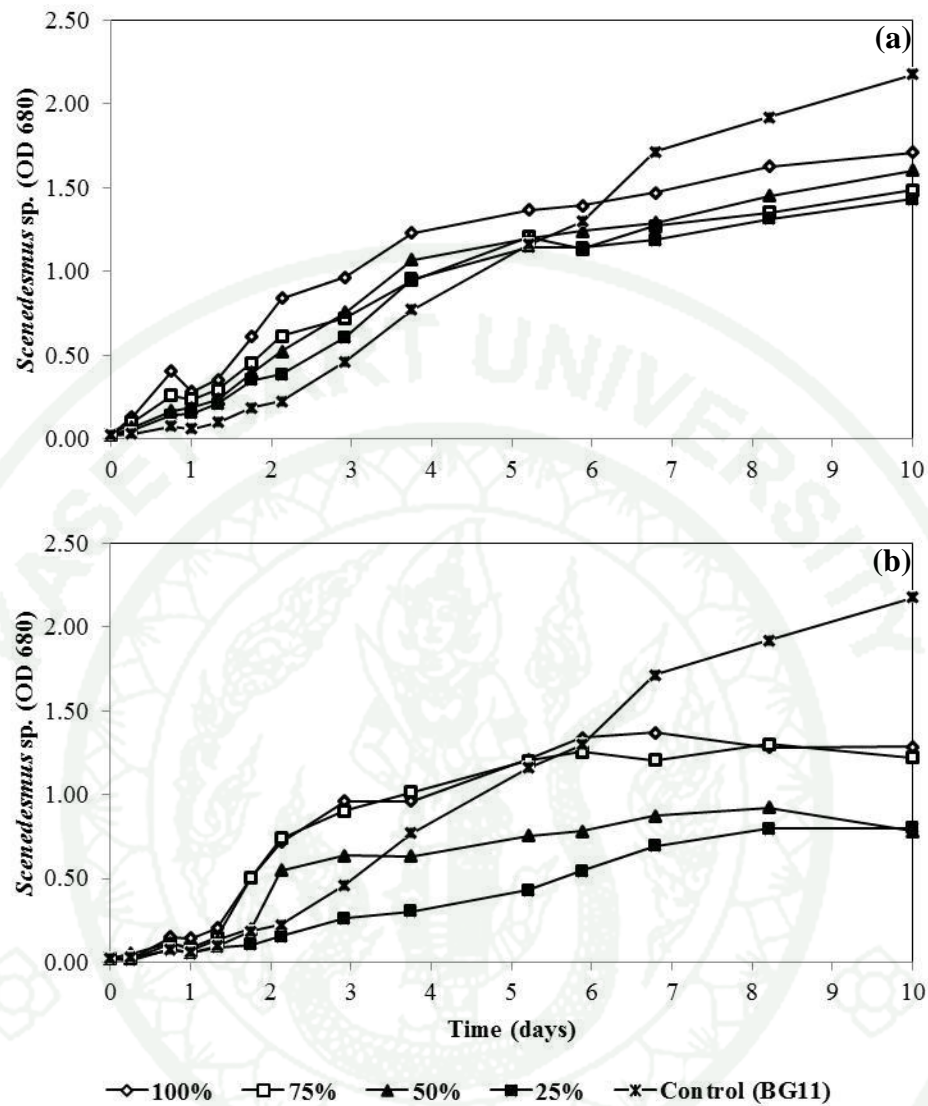


Figure 19 Growth curve of *Scenedesmus* sp. using various percentage of wastewater from instant noodle factory as a medium in 24 wells microplate under laboratory condition. (a) MLSS (b) effluent.

Table 9 Growth performance of *Scenedesmus* sp. in different medium in 24 wells microplate.

Medium	Initial optical density	Maximum optical density	Duration to reach stationary phase (day)	Specific growth rate (Day ⁻¹)
100% MLSS	0.03 ± 0.00 ^a	0.84 ± 0.13 ^a	2	1.63 ± 0.11 ^a
100% Effluent	0.03 ± 0.01 ^a	0.72 ± 0.11 ^a	2	1.57 ± 0.16 ^a
BG11 (Control)	0.03 ± 0.01 ^a	0.23 ± 0.02 ^b	2	1.08 ± 0.14 ^b

Remark Data with different letter superscript in the same column for each treatment were a significantly difference ($p < 0.05$).

3. Batch Culture Experiments under Laboratory Condition

3.1 Microalgae growth in undiluted wastewater from instant noodle factory under indoor batch cultivation

Figure 20 illustrated that MLSS and effluent without dilution could be successfully used as the culture medium for *Scenedesmus* sp. At the 4th day of the experiment, microalgae in all media reached the maximum biomass of 545.22 ± 193.92 mg/L and 741.88 ± 65.89 mg/L for MLSS and effluent, respectively. The data obtained in this experiment was slightly higher than previous report (McGinn *et al.*, 2012) which was 356 ± 15.4 mg/L of *Scenedesmus* sp. AMDD cultivated in municipal wastewater. Summary of growth performance was shown in Table 10. Since there was no significant ($p < 0.05$) difference on growth and biomass of all treatments and control, it could be stated that both wastewater types had a potential to be used as sole nutrients supplement for microalgal cultivation.

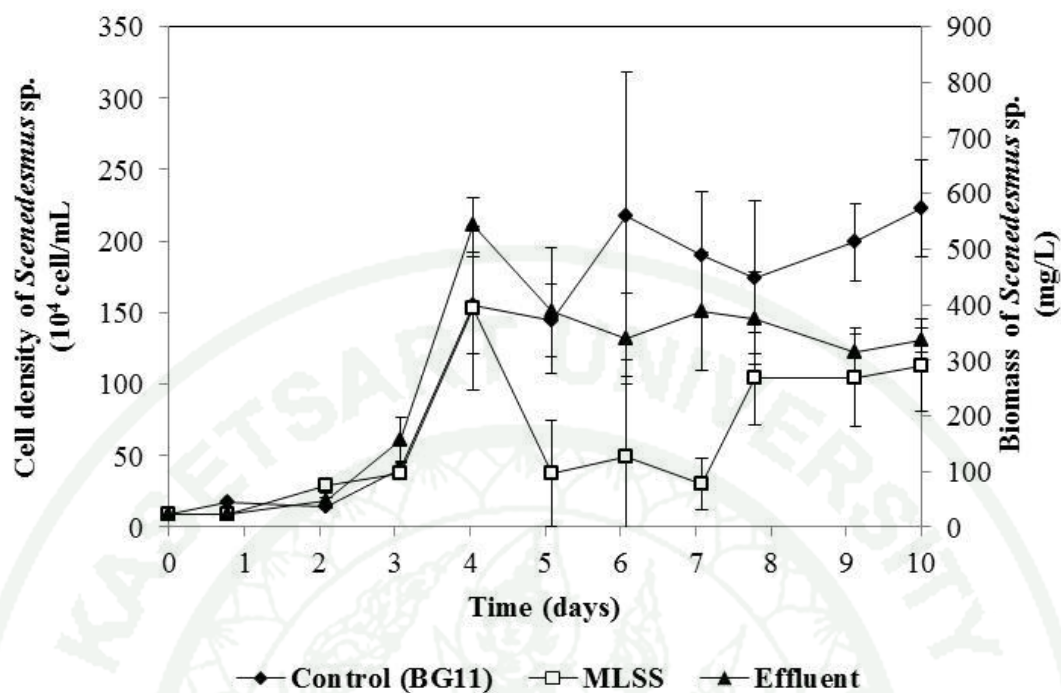


Figure 20 Growth curve of *Scenedesmus* sp. using wastewater from instant noodle factory as a medium under continuous light and aeration.

Table 10 Growth performance of *Scenedesmus* sp. using wastewater as a medium under continuous light and aeration.

Medium	Initial biomass (mg/L)	maximum biomass (mg/L)	Duration to reach stationary phase(day)	Specific growth rate (day ⁻¹)
MLSS	54.30 ± 0.33 ^a	545.22 ± 193.92 ^a	4	1.08 ± 0.11 ^a
Effluent	54.56 ± 0.48 ^a	741.88 ± 65.89 ^a	4	1.09 ± 0.08 ^a
Control (BG11)	54.76 ± 0.75 ^a	550.98 ± 115.82 ^a	4	1.08 ± 0.16 ^a

Remark Data with different letter superscript in the same column for each treatment were a significantly difference ($p < 0.05$).

Concentrations of inorganic nutrients during algal cultivation were shown in Figure 21. Total ammonia nitrogen was high in MLSS cultivation because of organic nitrogen breakdown (ammonification) which released ammonia into the medium. Park *et al.* (2010) reported that ammonium up to 100 ppm $\text{NH}_4\text{-N}$ did not inhibit growth of *Scenedesmus* sp., so ammonia concentration in this experiment was within the safety range for the alga. Accumulation of nitrite in control culture was due to the lack of nitrite oxidizing bacteria and anaerobic denitrification process could not occur in high oxygen condition in algal cultures. According to low concentration of phosphate in both wastewaters in at day 4, phosphates in MLSS and effluent was almost depleted (Figure 21 d). High ammonia concentration was found in MLSS and high nitrate was in effluent during cultivation. This finding leads to the assumption that ammonia was the nitrogen source for algae growth in MLSS while growth of algae in effluent was due to nitrate utilization. The uptake of ammonium and nitrate both removed nitrogen from wastewater but most of the microalgae prefer ammonia instead of nitrate as the nitrogen source for cell growth (Park *et al.*, 2010).

Moreover, cultivation of *Scenedesmus* sp. had been capable to reduce total chemical oxygen demand (COD) by 71.85 % and 39.89 % for MLSS and effluent respectively. On the other hand, reduction of soluble COD was 67.49% and 73.37 % for MLSS and effluent respectively (Figure 22). COD reduction is generally the results from bacterial decomposition in wastewater treatment. With this study, wastewater from instant noodle factory without sterilization contained natural bacteria so COD removal was related to both algal and bacterial activities. Min *et al.* (2011) also reported that *Chlorella* sp. cultivation in a pilot-scale photobioreactor could reduce COD by 86.3% in concentrate wastewater. They opined that COD reduction was due to algal and bacterial activities. However, COD removal by bacterial had minor contribution because COD removal was also found in autoclaved wastewater in batch cultivation.

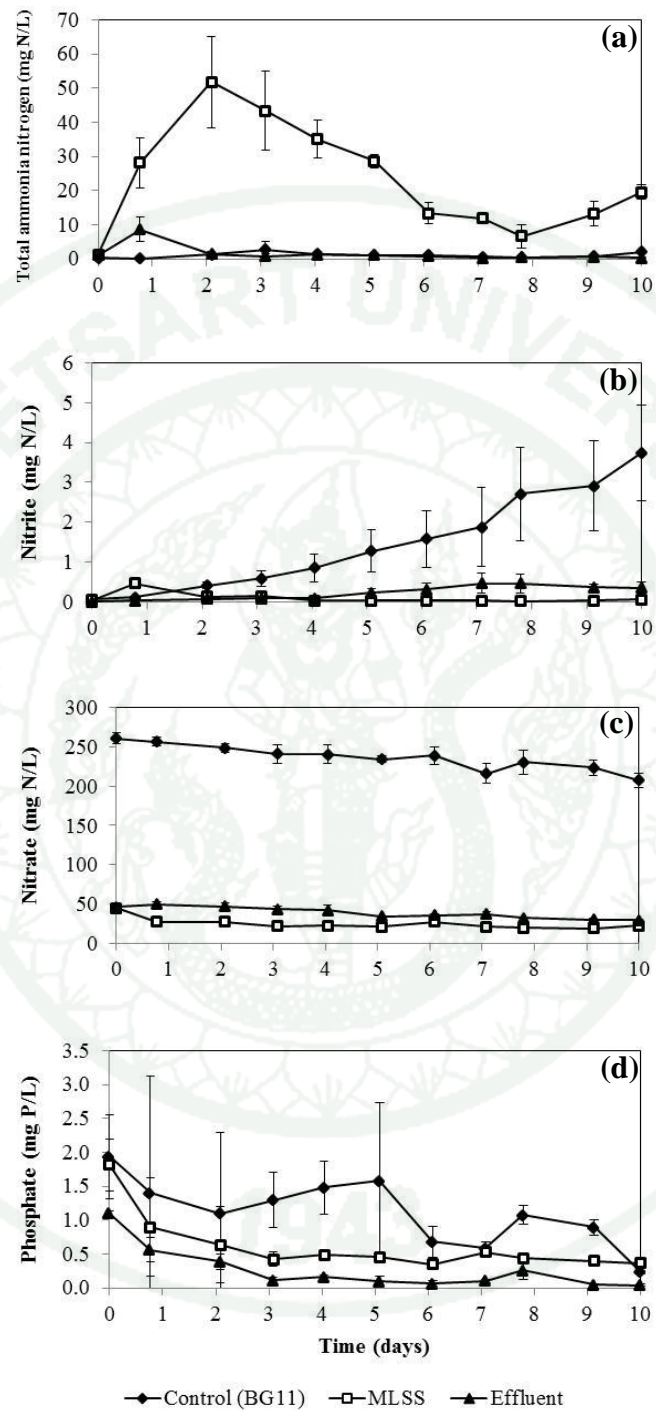


Figure 21 Inorganic nitrogen and inorganic phosphorus profile during *Scenedesmus* sp. cultivation under continuous light and aeration. (a) total ammonia nitrogen (b) nitrite (c) nitrate and (d) phosphate.

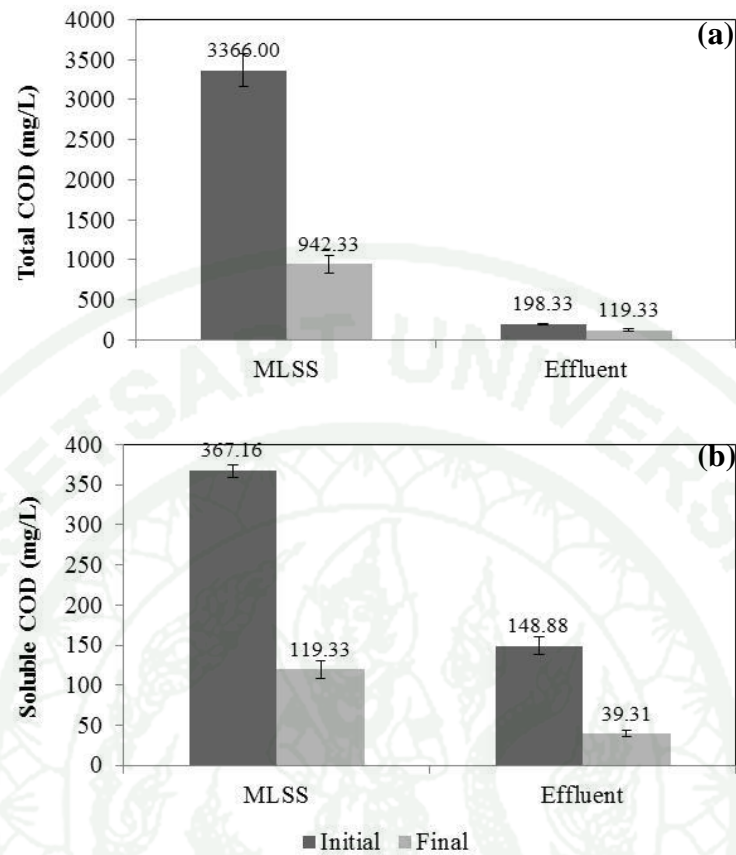


Figure 22 Chemical oxygen demand (COD) during initial and final day of microalgae cultivation in wastewater from instant noodle factory under continuous light and aeration. (a) total COD (b) soluble COD.

3.2 Effect of phosphate addition to enhance microalgae growth in wastewater from instant noodle factory

Growth of *Scenedesmus* sp. in wastewater from instant noodle factory was shown in figure 23 and Table 11. Changes of inorganic nutrients concentration including total ammonia nitrogen, nitrite, nitrate, and phosphate were shown in Figure 24. It was found that total ammonia in MLSS treatments (T1 and T2) was significantly higher than effluent. This was due to solid decomposition with ammonia as the end product. Phosphate in all four treatments, on the other hand, depleted from the culture medium within four days of algal culture (Figure 24 d). Therefore, K_2HPO_4 was added as phosphate supplement for T2 and T4 to investigate effect of phosphate addition for microalgae growth. After phosphate adding, T2 and T4 exhibited higher growth and biomass than T1 and T3. This result suggested that phosphate addition can enhance growth of microalgae cultivated in wastewater from instant noodle factory. Noted that, productivity of microalgal grew in MLSS wastewater was higher than that in effluent. MLSS wastewater was therefore chosen for further investigation.

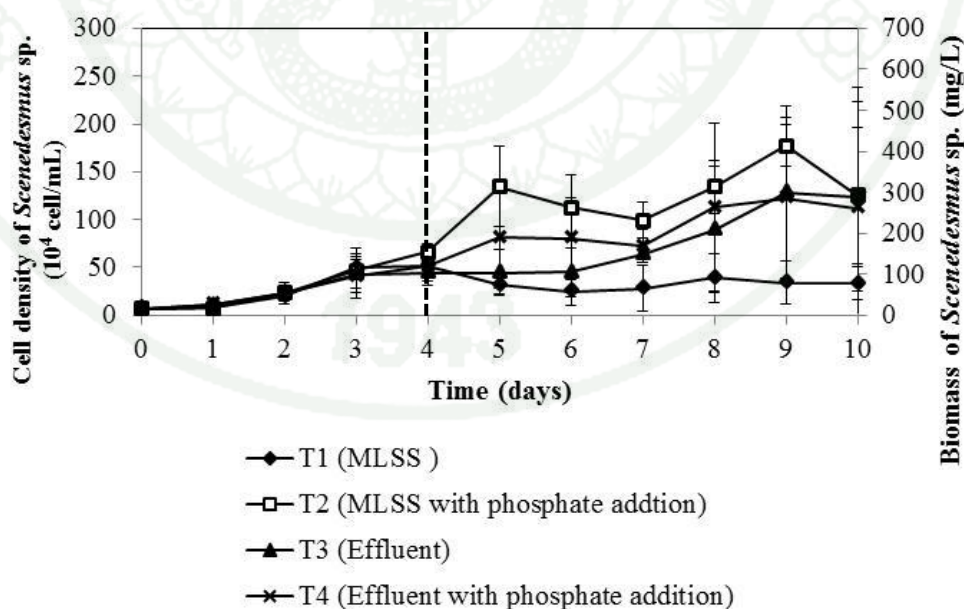


Figure 23 Growth curve of *Scenedesmus* sp. cultivation in MLSS or effluent. Dash line indicates phosphate adding in T2 and T4.

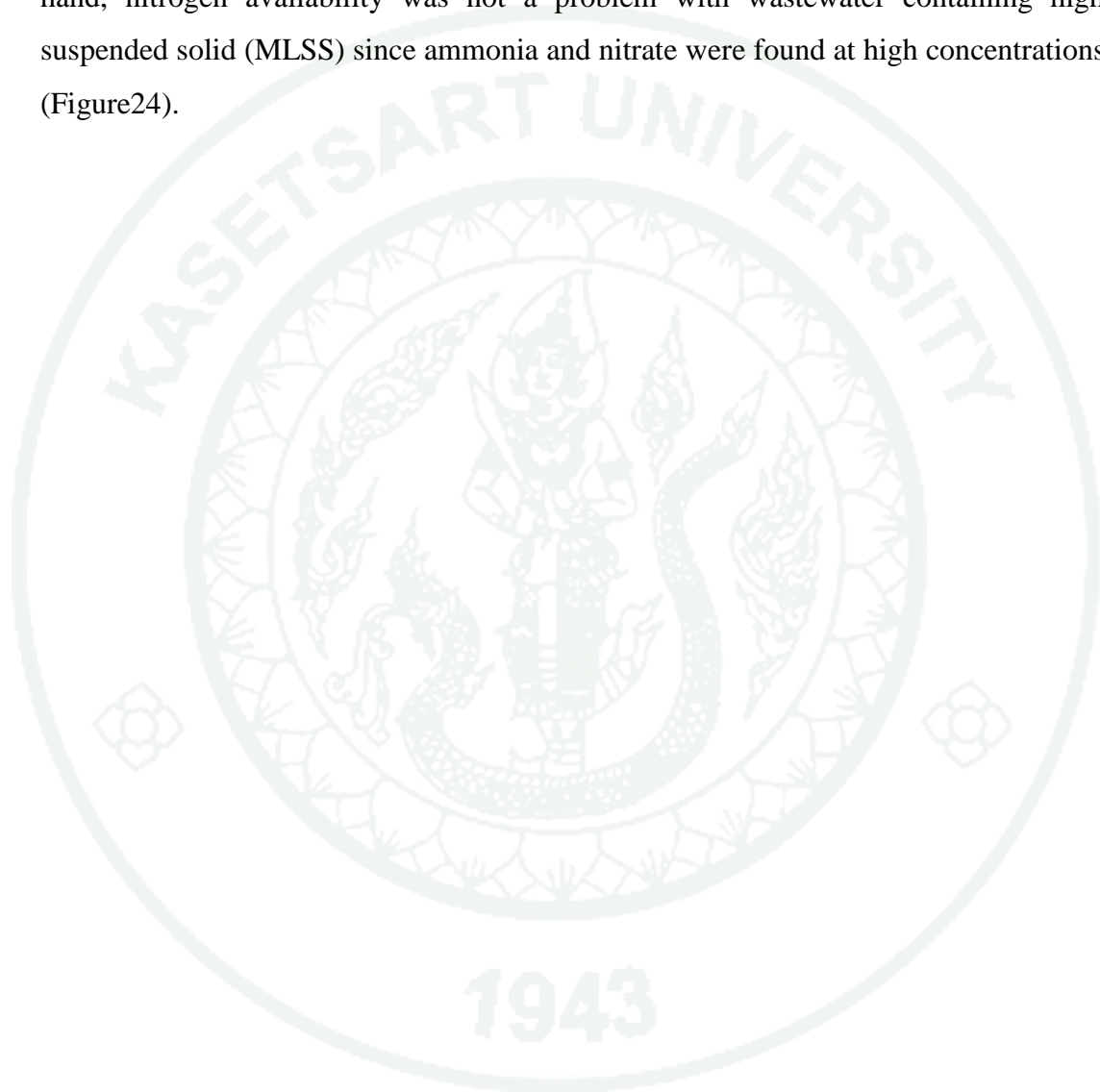
Table 11 Growth performance of *Scenedesmus* sp. cultivation in in MLSS or effluent.

Treatment	Initial biomass (mg/L)	Maximum biomass (mg/L)	Duration to reach maximum biomass (day)	Specific growth rate (day ⁻¹)
T1 (MLSS)	47.57 ± 2.13 ^a	200.19 ± 20.13 ^a	4	0.94 ± 0.50 ^a
T2 (MLSS with phosphate addtion)	48.33 ± 2.04 ^a	482.02 ± 144.46 ^b	5	1.12 ± 0.15 ^a
T3 (Effluent)	48.71 ± 1.18 ^a	174.15 ± 45.08 ^a	4	0.79 ± 0.20 ^a
T4 (Effluent with phosphate addtion)	46.13 ± 0.71 ^a	300.73 ± 182.35 ^{ab}	5	0.71 ± 0.37 ^a

Remark Data with different letter superscript in the same column for each treatment were a significantly difference ($p < 0.05$)

Phosphorus is the essential nutrient for plant as it incorporates in the cellular component and biosynthesis of nucleic acids. Reactive form of phosphorus for microalgal utilization is orthophosphate form (PO_4^{3-}). In general, phosphorus concentration in the water is the limiting factor for microalgal growth. Concentration of phosphate in BG11 medium is substantially high (30 – 40 mg/L KH_2PO_4) when compare with natural waters as it often limiting the algae growth (Ernst *et al.*, 2005). It was reported that *Scenedesmus* sp. required the N/P ratio of approximately 30 to grow (Cai *et al.*, 2013). N/P ratio (e.g. nitrate/ phosphate) in BG11 was 7 as it is an enrichment medium with excess of nutrients. In contrast, wastewater from instant noodle factory contained low phosphate (N/P ratio was approximately 40), it might be insufficient for microalgae growth so supplement of phosphate was therefore needed.

With this experiment, the results showed that low phosphate concentration in wastewater is the limiting factor for *Scenedesmus* sp. growth. The results after phosphate addition, as shown in Figure 23, indicated the significant of phosphate supplement for microalgal wastewater treatment process. On the other hand, nitrogen availability was not a problem with wastewater containing high suspended solid (MLSS) since ammonia and nitrate were found at high concentrations (Figure24).



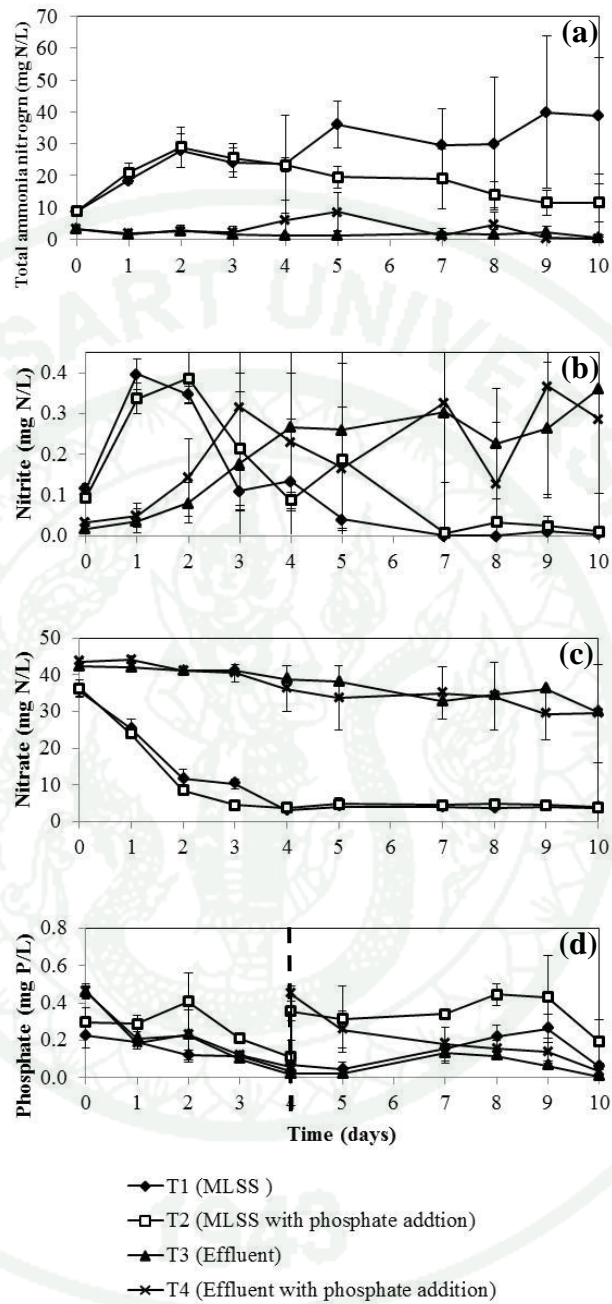


Figure 24 Inorganic nitrogen and inorganic phosphorus profile during *Scenedesmus* sp. cultivation in MLSS or effluent. (a) total ammonia nitrogen (b) nitrite (c) nitrate and (d) phosphate. Dash line indicates phosphate addition in T2 and T4.

With this experiment, phosphate addition was not significantly reduced COD removal as the reduction of COD in T1 and T2 was 85%, 89%, and in T3 and T4 was 23% and 32%, respectively. On the other hand, reduction of soluble COD was 89%, 36%, 25% and 31% for T1, T2, T3 and T4, respectively (Figure 25).

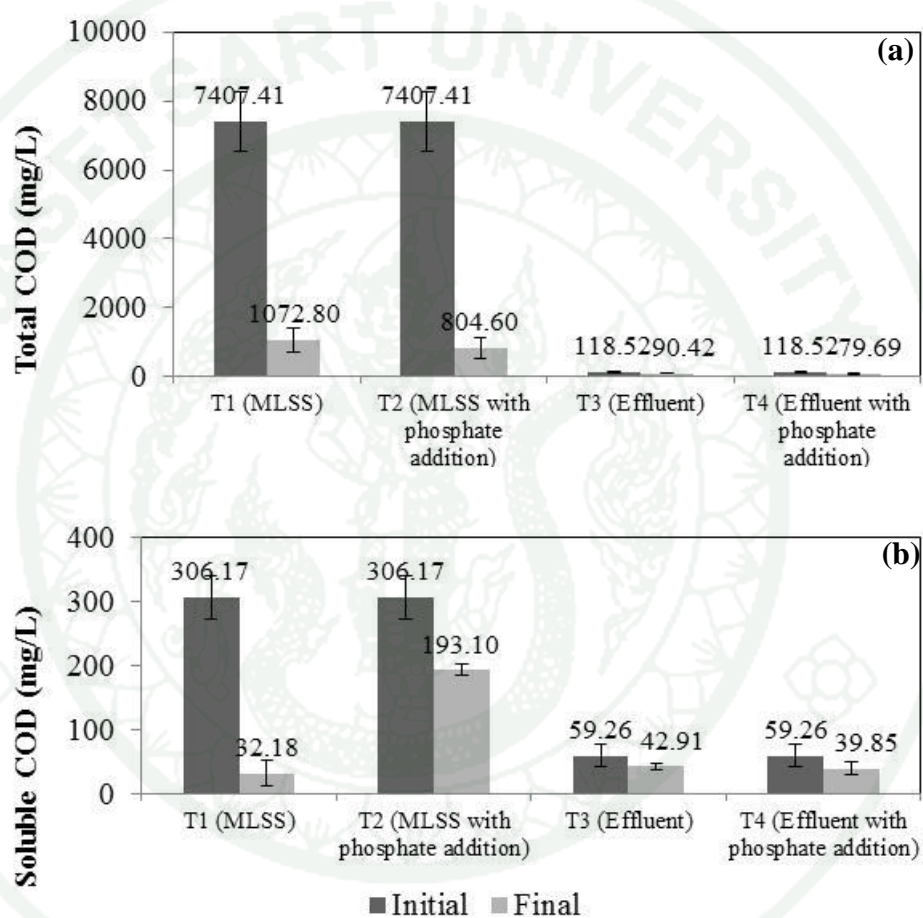


Figure 25 Chemical oxygen demand (COD) during initial and final day of microalgae cultivation in MLSS or effluent. (a) total COD (b) soluble COD.

3.3 Effect of lighting period and external carbon dioxide supplement on growth of microalgae cultivated in wastewater

According to previous experiment, MLSS was selected as the wastewater in this study. Figure 26 shows growth of *Scenedesmus* sp. with 2% carbon dioxide supplement. The growth analysis results indicated that, under laboratory condition, external carbon dioxide supplement did not clearly enhance growth of microalga *Scenedesmus* sp. in all treatments using MLSS wastewater from instant noodle factory. In addition, light period either continuous light or 12:12 light: dark cycle also provided similar growth of *Scenedesmus* sp..

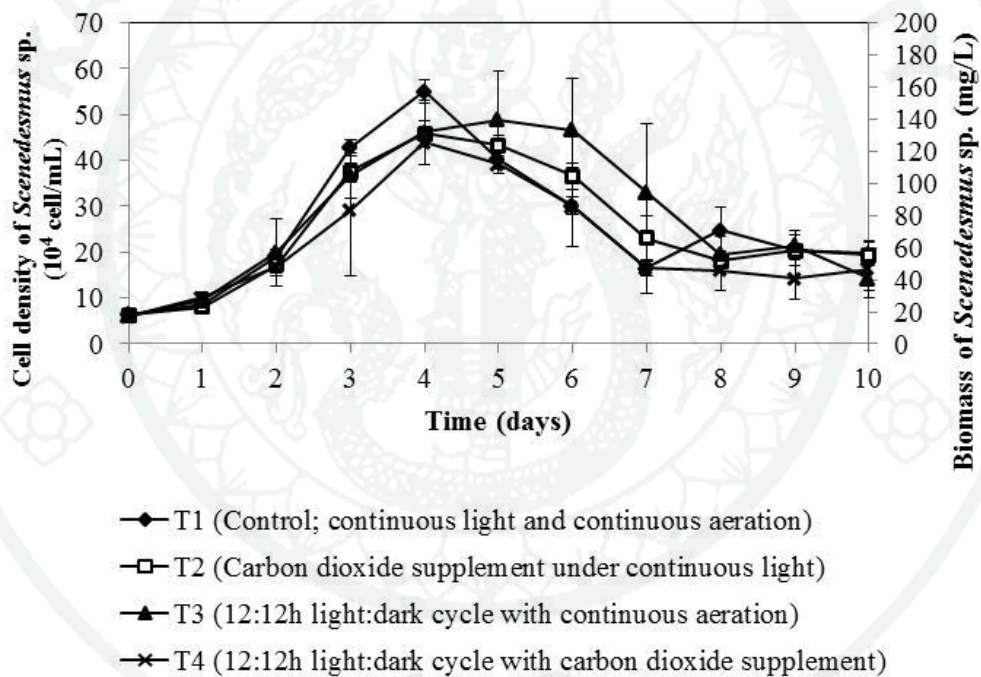


Figure 26 Growth curve of *Scenedesmus* sp. using MLSS wastewater from instant noodle factory as a medium with aeration or external carbon dioxide supplement under continuous illumination or 12:12 h light: dark cycle.

In general, fifty percent of algal biomass is carbon which derived from carbon dioxide fixation through photosynthesis. Carbon supplement plays a vital role for the success of algal cultivation. Many studies showed that carbon dioxide can enhance growth of microalgae (Xu *et al.*, 2009; Kong *et al.*, 2010, Pegallapati *et al.*, 2013). However, the results illustrated that external carbon dioxide supplement in this study did not clearly affect algal growth. Apart of photoautotrophic growth, sugar or acetate can be supplied as organic carbon for some heterotrophic or mixotrophic algae. For instance, *Chlorella* sp. can grow in heterotrophic condition using appropriate organic carbon source such as acetate (Perez-Garcia *et al.*, 2011). Since there were several reports on mixotrophic or even heterotrophic cultivation of *Scenedesmus* spp. (Shamala *et al.*, 1982; Mostafa *et al.*, 2012; Zhang *et al.*, 2013), use of organic carbon under mixotrophic condition could be occurred along with inorganic carbon uptake by photosynthesis. It was likely that mixotrophic growth of *Scenedesmus* sp. occurred in this experiment so the alga could consume both carbon dioxide from air bubbling and organic carbon from wastewater.

Decomposition of MLSS supplied high total ammonia nitrogen for *Scenedesmus* sp. growth in wastewater (Figure 27) while nitrate was remained in high concentration throughout the cultivation. Hence, it can summarize that total ammonia nitrogen was major nitrogen source for *Scenedesmus* growth using MLSS as the culture medium. Peak of nitrite was found only at the early days of culture as a result of nitrification process. Due to the low phosphate concentration, phosphate seems to be the limiting factor for batch cultivation with MLSS.

Reduction of COD was also found in this experiment. Total COD was reduced by 73%, 55%, 71% and 57% for T1, T2, T3 and T4, respectively. On the other hand, reduction of soluble COD was 84%, 73%, 83% and 73% for T1, T2, T3 and T4, respectively (Figure 28).

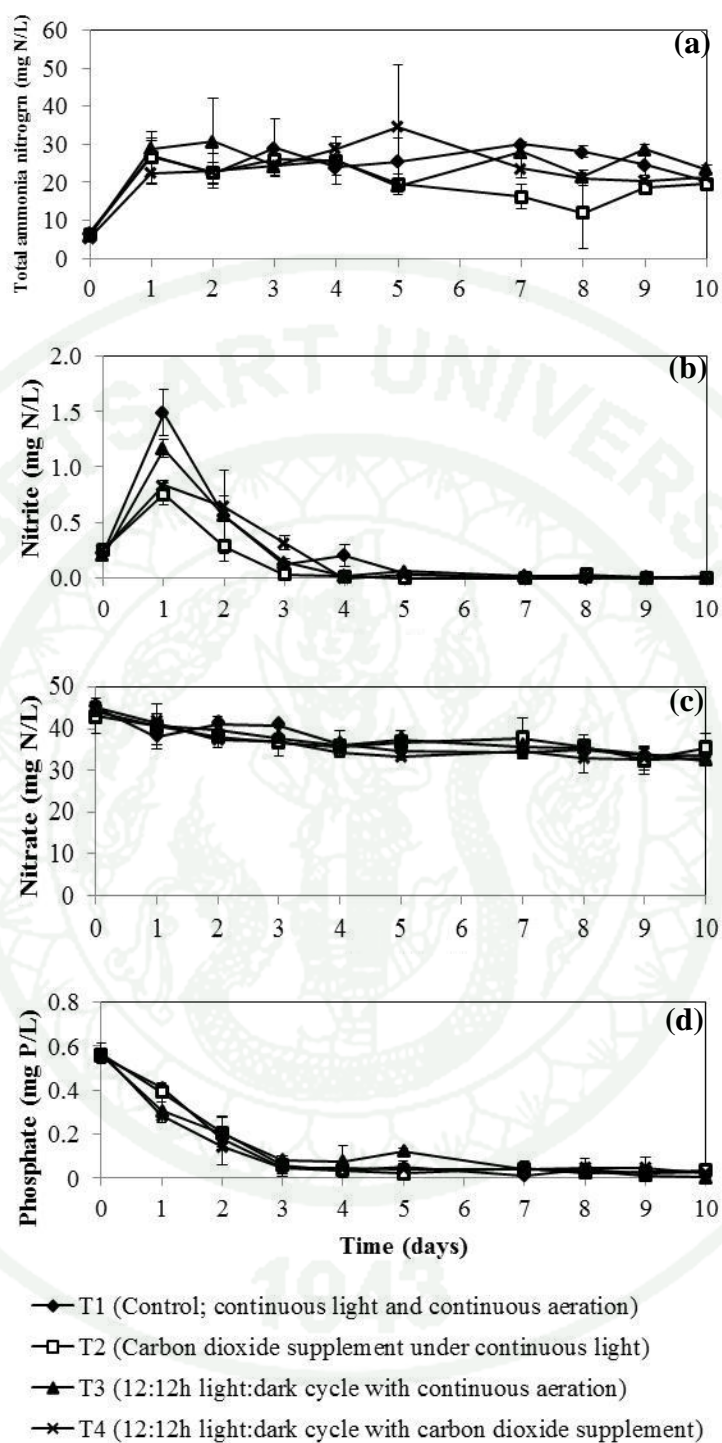


Figure 27 Inorganic nitrogen and inorganic phosphorus profile during *Scenedesmus* sp. cultivation with CO₂ supplement and various lighting period. (a) total ammonia nitrogen (b) nitrite (c) nitrate and (d) phosphate.

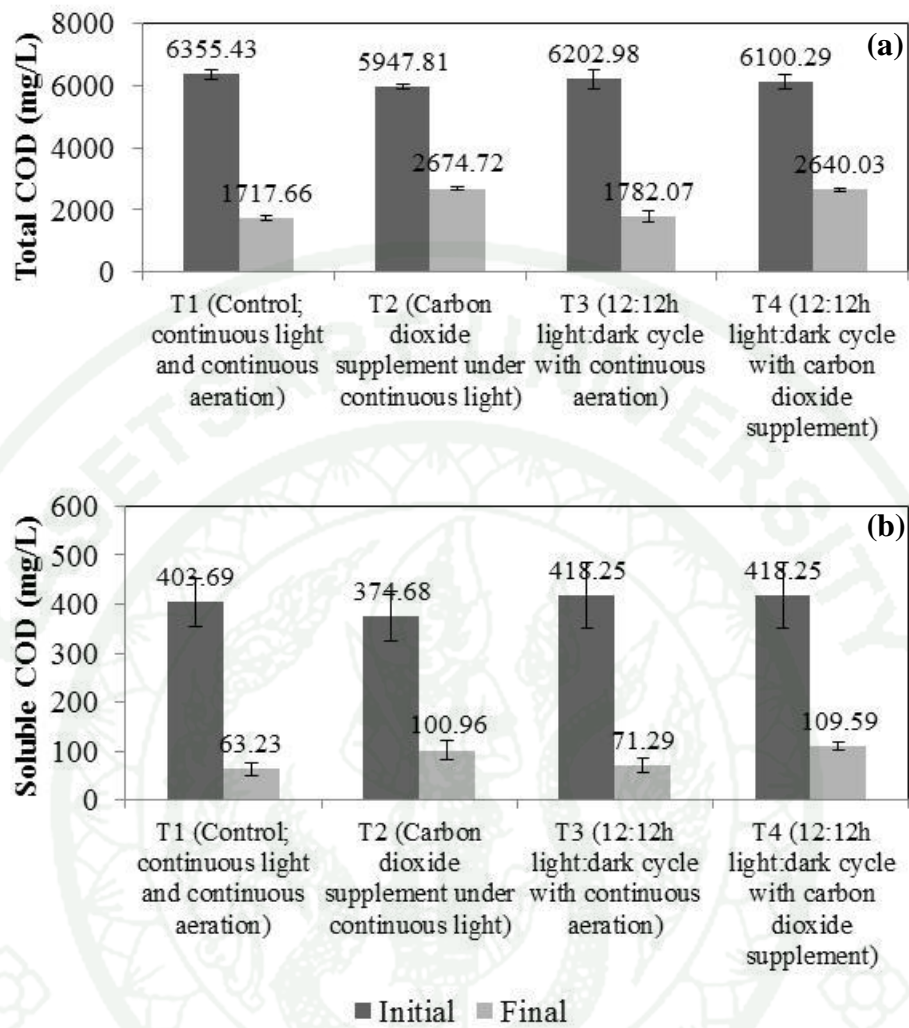


Figure 28 COD during initial and final day of *Scenedesmus* sp. cultivation with CO₂ supplement and various lighting period. (a) total COD (b) soluble COD.

4. Outdoor Semi Continuous Culture Experiments

4.1 Trial 1: Effect of CO₂ supplement on microalgal growth in wastewater under outdoor semi continuous cultivation

Growth of *Scenedesmus* sp. in this study (Figure 30) was similar to the results in section 3.3. It was found that continuous carbon dioxide supplement was not enhance growth of *Scenedesmus* sp. cultivated in MLSS wastewater. Volumetric productivity of microalgae after each harvested time was between 24.45 ± 2.45 mg/L to 84.02 ± 17.66 mg/L and 16.53 ± 1.11 mg/L to 109.81 ± 37.96 mg/L for T1-1 and T1-2, respectively as shown in Table 12. Environmental conditions especially natural light intensity and temperature were shown in Figure 29. The maximum light intensity and average light intensity were 10333.4 Lux and 3358.98 Lux, respectively. Noted, light intensity in trial-1 was rather low due to shading from nearby building during cold season.

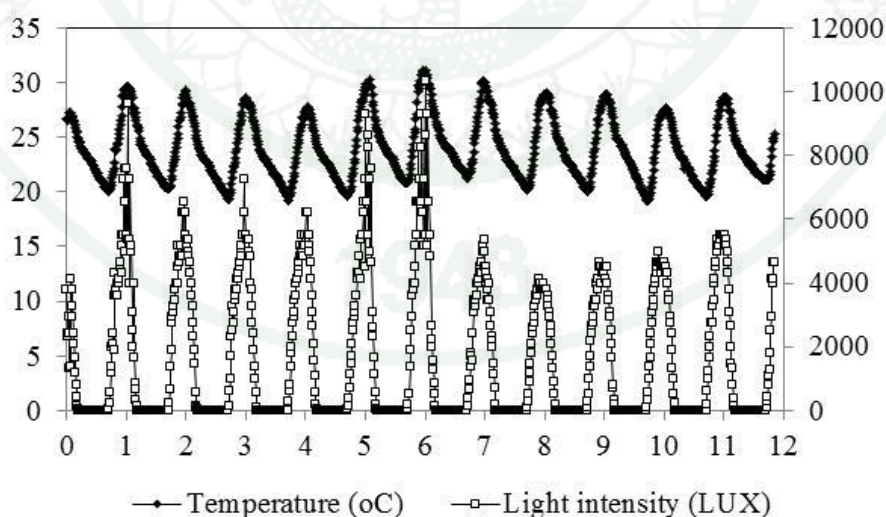


Figure 29 Temperature and natural light intensity during microalgae cultivation in wastewater under outdoor semi continuous experiment in trial 1.

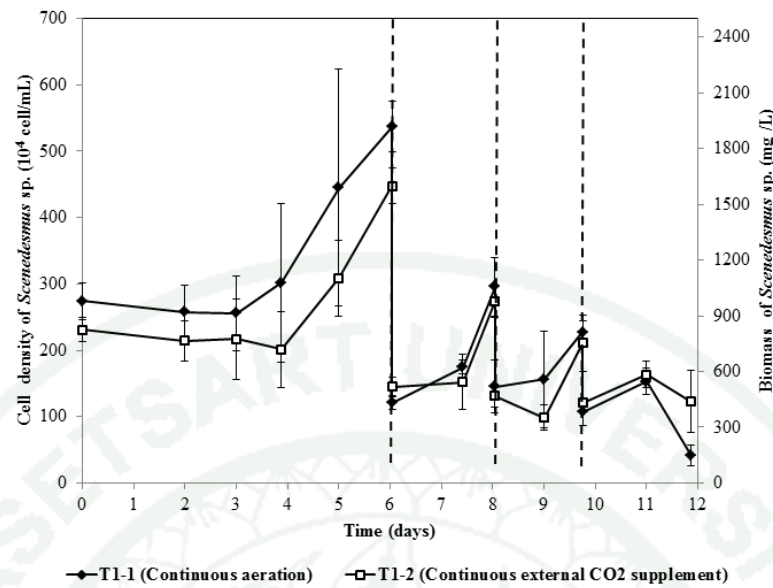


Figure 30 Growth curve of microalgae cultivated in wastewater under outdoor semi continuous experiment in trial 1. Dash line indicates algal harvesting by cross flow filtration.

To evaluate algal productivity, several parameters can be used to indicate productivity of the culture systems. These parameters are volumetric productivity (productivity per unit reactor volume), illuminated surface productivity (productivity per unit of illuminated surface area of the reactor), areal productivity (productivity per unit of ground area occupied by the reactor), and overall productivity (productivity obtained from the overall ground area including empty spaces required for equipment access and space between reactors in a mass cultivation system) (Chinnasamy *et al.*, 2010). Among the mentioned parameters, volumetric productivity and areal productivity were chosen in this study as shown in Table 12. However, volumetric productivity (mg/L/day) was preferred as it can easily compare with other systems.

Table 12 Productivity of *Scenedesmus* sp. cultivated in wastewater under outdoor semi continuous experiment in trial 1.

Harvested	Duration (days)	Volumetric Biomass Productivity of Harvested <i>Scenedesmus thalassiosira</i> sp. (mg /L/d)		Areal Biomass Productivity of Harvested <i>Scenedesmus</i> sp. (mg /m ² /d)	
		T1-1 (Continuous aeration)	T1-2 (Continuous external CO ₂ supplement)	T1-1 (Continuous aeration)	T1-2 (Continuous external CO ₂ supplement)
		1	6.04	24.45 ± 2.45	16.53 ± 1.11
2	2.00	71.59 ± 11.56	55.06 ± 6.81	13671.06 ± 2206.74	10514.83 ± 1301.39
3	1.71	84.02 ± 17.66	55.77 ± 14.61	16044.20 ± 3373.02	10650.42 ± 2790.33
4	2.13	77.16 ± 25.21	109.81 ± 37.96	14734.56 ± 4814.22	20969.24 ± 7248.19
Average		64.30 ± 7.70	59.29 ± 11.92	12279.74 ± 1470.87	11322.72 ± 2275.61

Figure 31 illustrates inorganic nitrogen and phosphorus during outdoor semi-continuous culture of *Scenedesmus*. Similar to batch cultivation, ammonia nitrogen was the nitrogen source for microalgae in MLSS wastewater. In semi continuous culture, however, medium was added (approximately 500 mL MLSS) to compensate the removal of microalgal cells by cross flow filtration. So the nutrients concentration was increased after adding MLSS (dash line). In contrast to previous experiments, phosphate was not a limiting factor under semi-continuous culture due to the medium addition during semi-continuous harvesting.

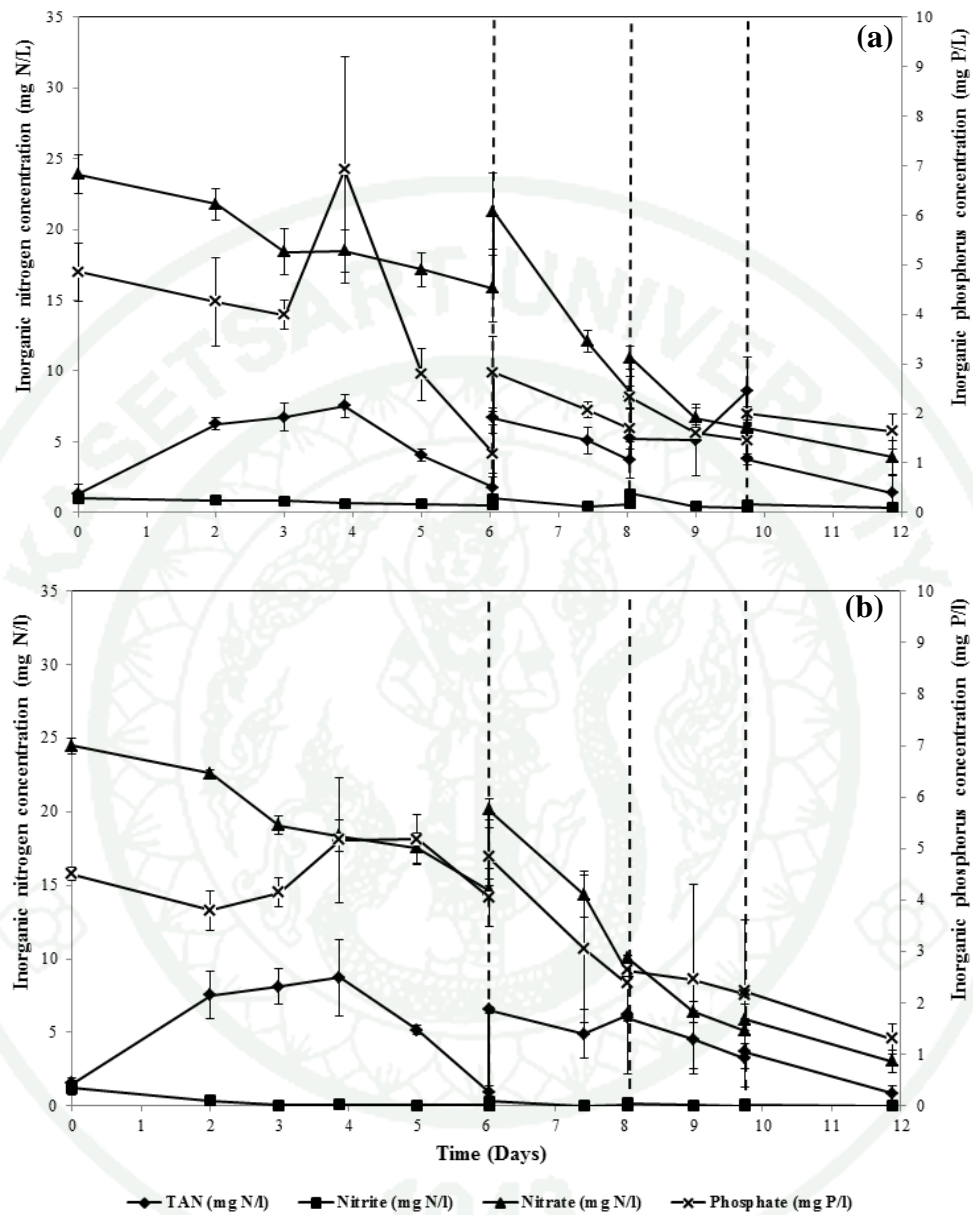


Figure 31 Inorganic nitrogen and inorganic phosphorus during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 1. (a) T1-1 (Continuous aeration) (b) T1-2 (Continuous external CO₂ supplement). Dash line indicates algal harvesting by cross flow filtration.

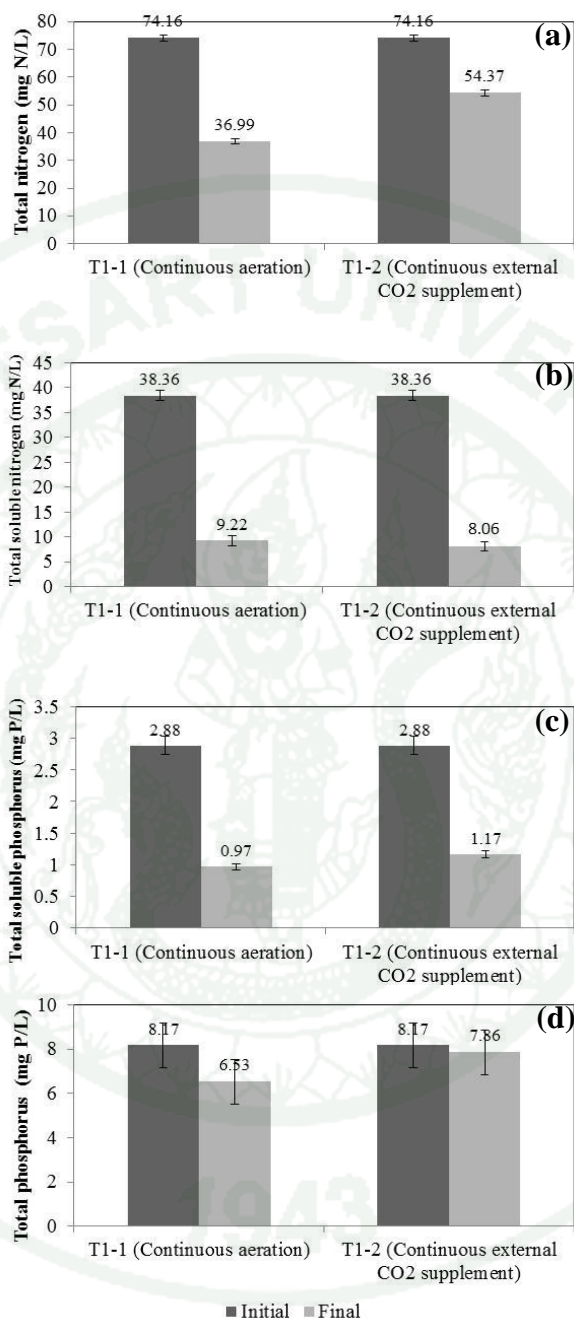


Figure 32 Total nitrogen and total phosphorus during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 1. (a) total nitrogen (b) total soluble nitrogen (c) total phosphorus (d) total soluble phosphorus.

Reduction of inorganic nitrogen, phosphorus and COD are shown in Figure 32 and Figure 33, respectively. Reduction of total nitrogen and total phosphorus might be the results from microalgal assimilation hence nitrogen and phosphorus were removed with cell harvesting (Su *et al.*, 2012; Pegallapati and Nirmalakhandan, 2013). Li *et al.* (2011) demonstrated that microalgae could reduce TN and TP in municipal wastewater by 84 -87% and 13 – 72% respectively.

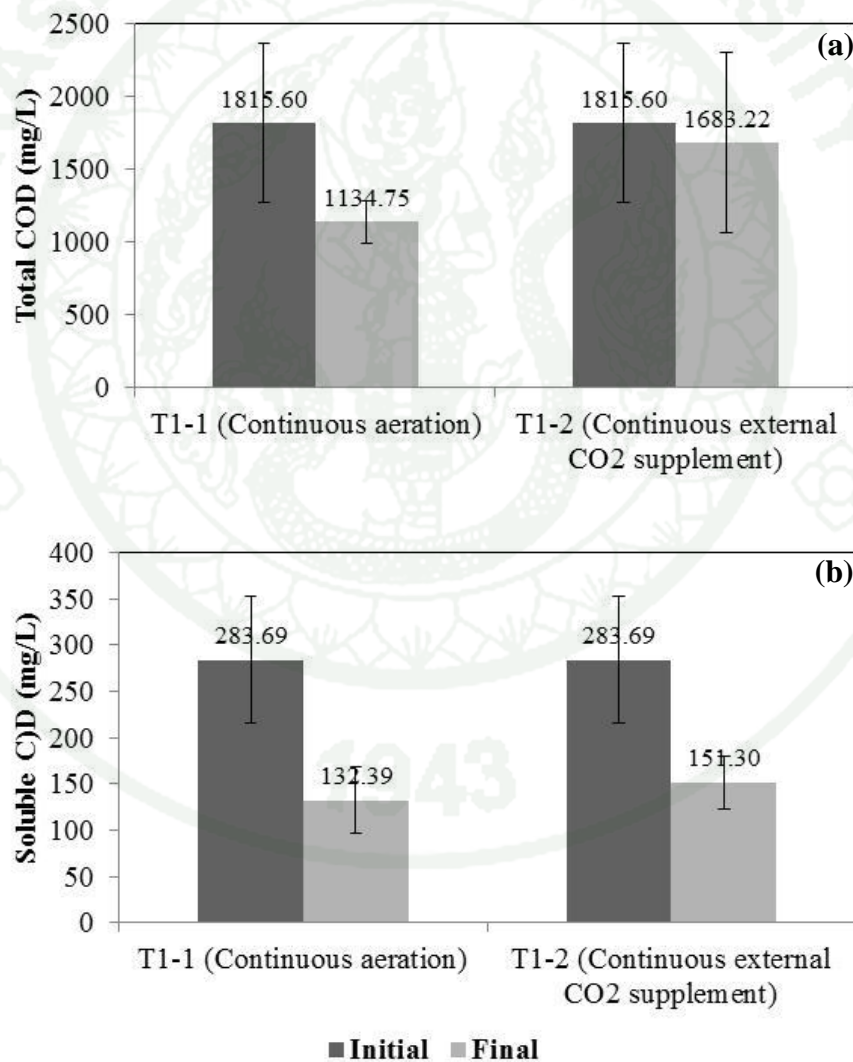


Figure 33 COD during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 1. (a) total COD (b) soluble COD.

4.2 Trial 2: Effect of aeration, and external CO₂ supplement during daytime on growth of *Scenedesmus* sp. in wastewater under outdoor semi continuous cultivation

Figure 35 shows that carbon dioxide supplemented during daytime could significantly promote growth of *Scenedesmus* sp. The highest biomass in T2-1 with carbon dioxide (433.93 ± 44.60 mg/L) was approximately 4 times of control (140.28 ± 33.55 mg/L). With 5 semi-continuous harvesting, average volumetric productivity of T2-1 and T2-2 was 4.21 ± 0.52 mg/L/d and 17.20 ± 5.31 mg/L/d, respectively. Data concerning growth and productivity of *Scenedesmus* sp. is shown in Table 13. Light intensity and temperature during the experiment are shown in Figure 34. It was found that the maximum light intensity and average light intensity were 12756.4 Lux and 13583.61 Lux, respectively. Light intensity in this experiment was much higher than previous experiment because the experiment was operated in early summer without shading from nearby building. With sufficient light intensity, supplement with 2% CO₂ during daytime could strongly promote photosynthesis of *Scenedesmus* sp.. This leads to an assumption that sufficient illumination enhanced photoautotrophic growth of the algae in wastewater with high particulate organic carbon content. Chinnasamy *et al.* (2011) and Li *et al.* (2011) reported that high light intensity could promote microalgae biomass, biodiesel production, as well as the removal of COD and nitrogen. Therefore, light availability for photosynthesis is one of the most important parameter for the design of photobioreactor.

To optimize the photosynthesis, carbon dioxide supplement is an essential factor. However, optimal CO₂ concentrations are vary among algal species and growth condition. Some research showed that some microalgae could grow well with high CO₂ supplement up to 24% CO₂ (Makarevičienė *et al.*, 2011) while growth of some algae was inhibited by only 2% CO₂ supplement. High CO₂ generally decrease pH of the culture medium which can inhibit algal growth (Cheng *et al.*,

2006). With this study, supplement of a mixture of air with 2% CO₂ was used. This optimal CO₂ concentration in this study was similar to those of Chiu *et al.* (2008).

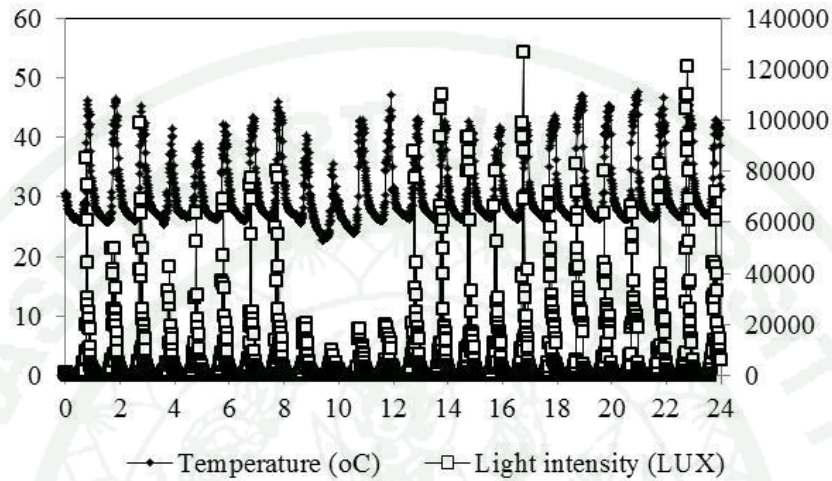


Figure 34 Temperature and natural light intensity during microalgae cultivation in wastewater under outdoor semi continuous experiment in trial 2.

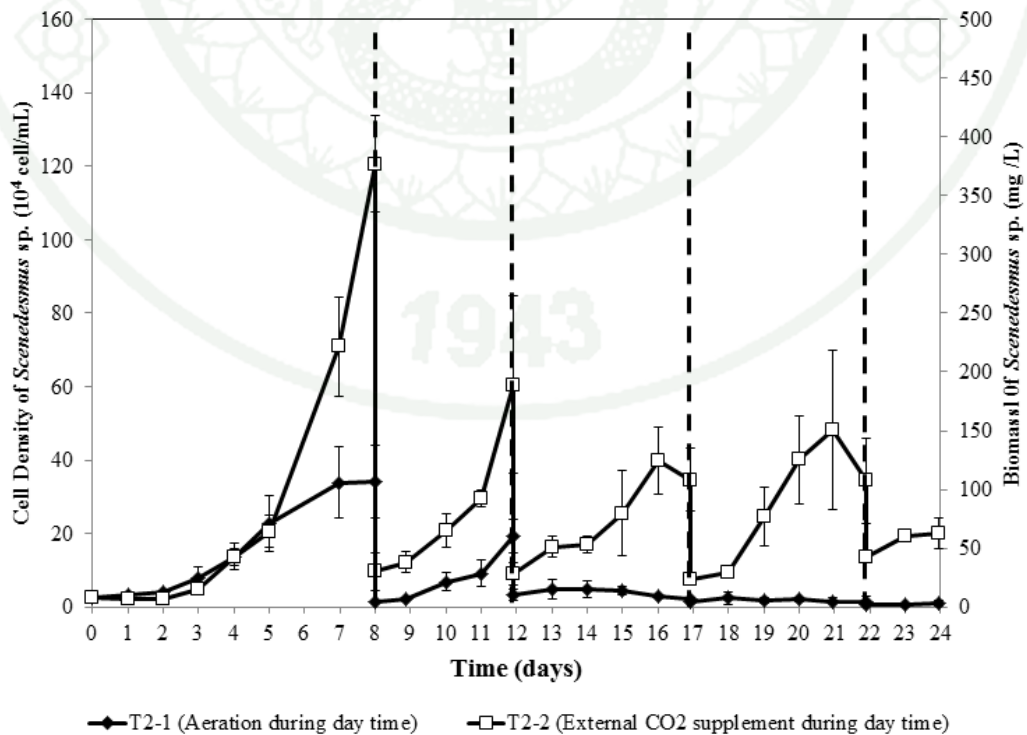


Figure 35 Growth of *Scenedesmus* sp. in wastewater under outdoor semi continuous cultivation (trial 2) with aeration during daytime (T2-1) and carbon dioxide supplement during daytime (T2-2). Dash line indicates algal harvesting by cross flow filtration.

Table 13 Productivity of *Scenedesmus* sp. cultivated in wastewater under outdoor semi continuous experiment in trial 2.

Harvested	Duration (days)	Volumetric Biomass Productivity of Harvested <i>Scenedesmus</i> sp. (mg /L/d)		Areal Biomass Productivity of Harvested <i>Scenedesmus</i> sp. (mg /m ² /d)	
		T2-1 (Aeration during daytime)	T2-2 (External CO ₂ supplement during daytime)	T2-1 (Aeration during daytime)	T2-2 (External CO ₂ supplement during daytime)
1	0.0	0.34 ± 0.01	0.40 ± 0.02	65.85 ± 2.14	75.85 ± 3.50
2	3.9	3.36 ± 0.58	15.59 ± 9.78	641.67 ± 111.37	2976.53 ± 1868.18
3	5.0	2.58 ± 0.72	13.35 ± 8.22	492.50 ± 138.09	2549.85 ± 1569.18
4	5.0	1.24 ± 0.98	12.251 ± 4.88	236.55 ± 187.08	2339.71 ± 931.26
5	2.1	13.51 ± 1.06	44.40 ± 6.84	2579.49 ± 202.42	8447.76 ± 1305.47
Average		4.21 ± 0.52	17.20 ± 5.31	803.21 ± 99.32	3283.94 ± 1013.68

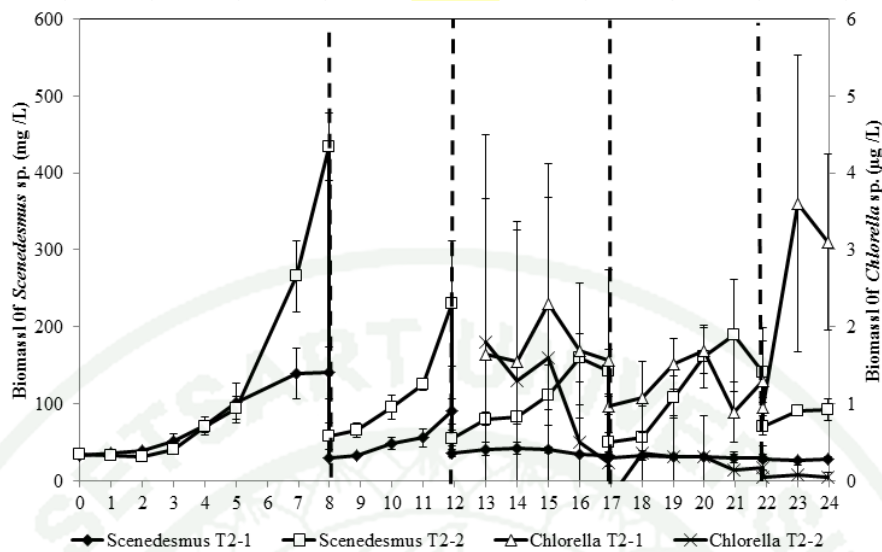


Figure 36 *Chlorella* sp. contamination in *Scenedesmus* sp. culture in wastewater under outdoor semi continuous experiment in trial 2. Dash line indicates algal harvesting by cross flow filtration.

After second algal harvesting, contamination of *Chlorella* sp. was found in the photobioreactors. However, number of contaminant alga was approximately 0.98 µg/L which was rather low in comparison with 29.33 mg/L of *Scenedesmus* sp.. Hence, contamination was and it was not affect growth of *Scenedesmus* sp.. This finding was unexpected because *Chlorella* is one of the most common microalga in freshwater condition. Both *Chlorella* and *Scenedesmus* have the ability to grow in phototrophic, mixotrophic and heterotrophic conditions (Gonzales *et al.*, 1997). The reason that *Chlorella* could not compete with *Scenedesmus* under CO₂ supplement condition was still unclear.

Reduction of inorganic nitrogen and phosphorus in Figure 37 illustrates that nutrient removal was due to cell harvesting. With CO₂ supplement, higher growth of *Scenedesmus* was obtained. This resulted in higher efficiency of nutrients removal by *Scenedesmus* culture (Figure 37 b).

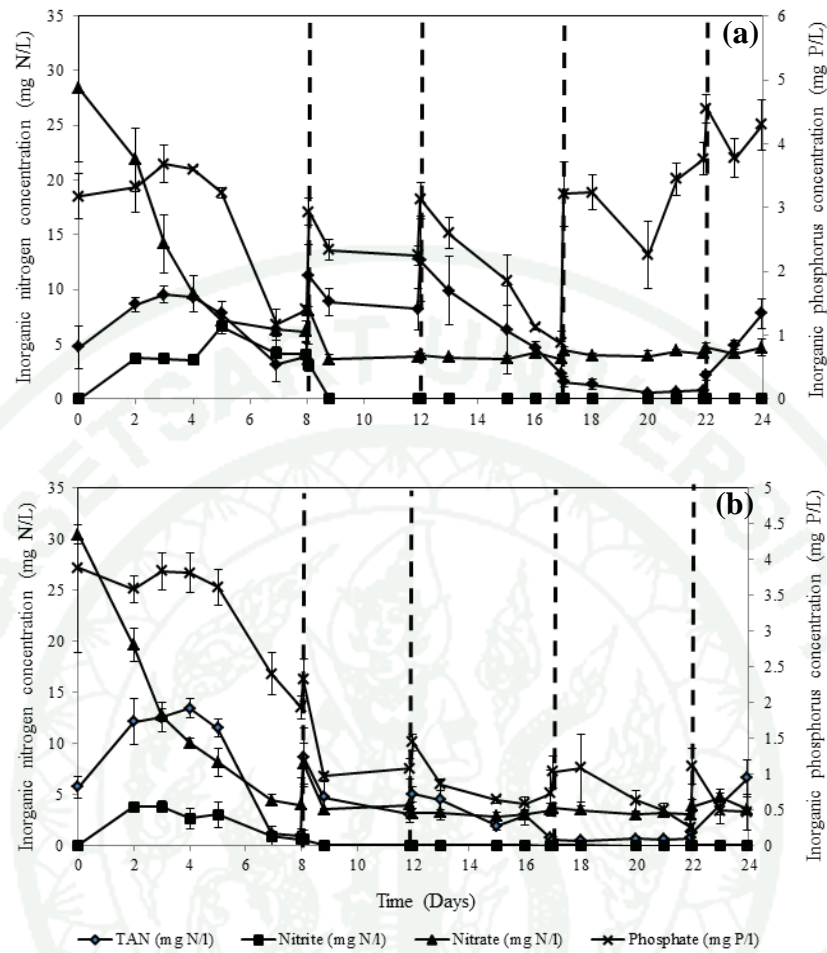


Figure 37 Inorganic nitrogen and inorganic phosphorus during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 2. (a) T2-1 (Aeration during daytime) (b) T2-2 (External CO₂ supplement during daytime). Dash line indicates algal harvesting by cross flow filtration.

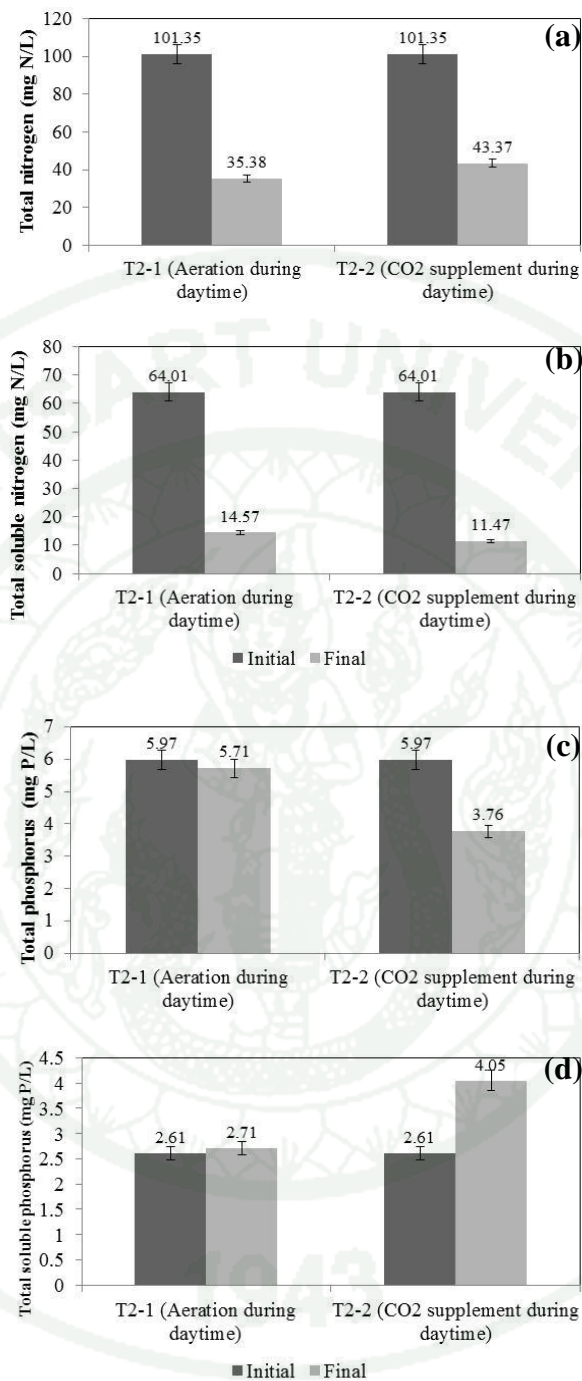


Figure 38 Total nitrogen and total phosphorus during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 2. (a) total nitrogen (b) total soluble nitrogen (c) total phosphorus (d) total soluble phosphorus.

Reduction of total nutrients and COD (Figures 38 and 39, respectively) was resembled with previous experiments. Both treatments reduced both total COD and soluble COD at the similar manner.

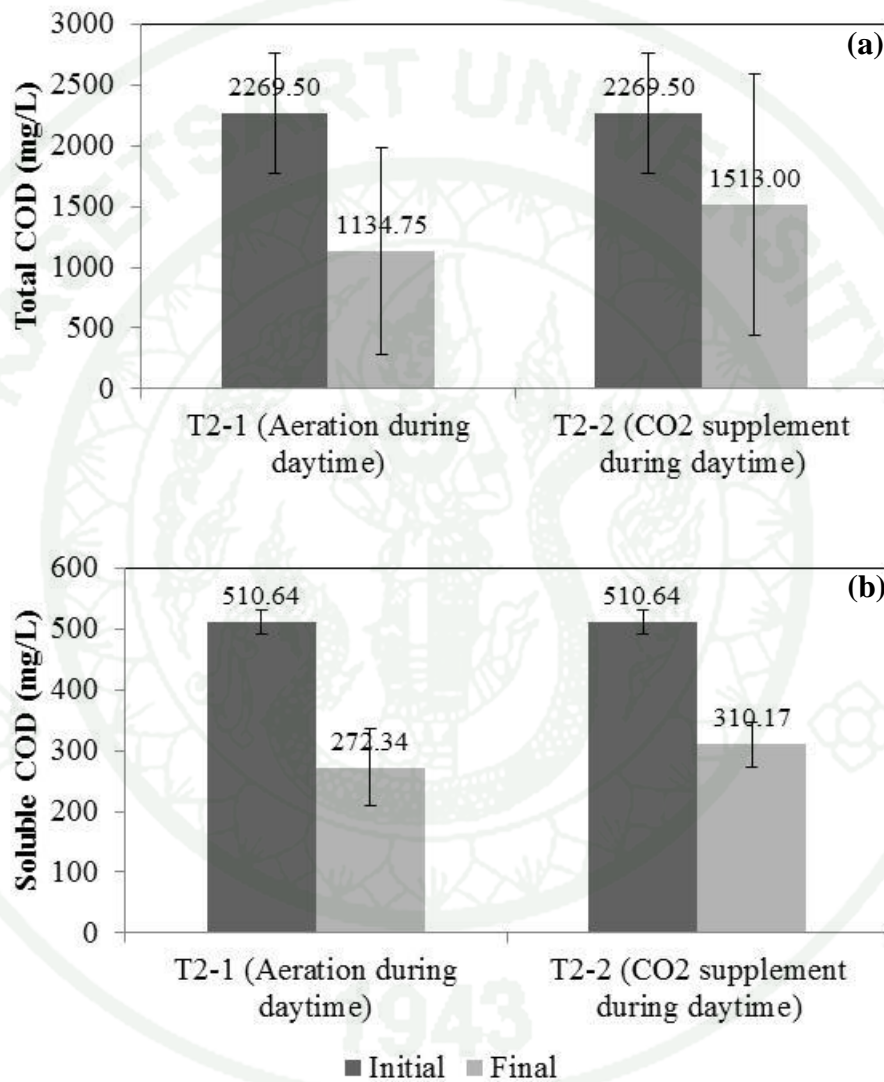


Figure 39 COD during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 2. (a) total COD (b) soluble COD.

4.3 Trial 3: Effect of continuous aeration and external CO₂ supplement during daytime on microalgae growth in wastewater under outdoor semi continuous cultivation

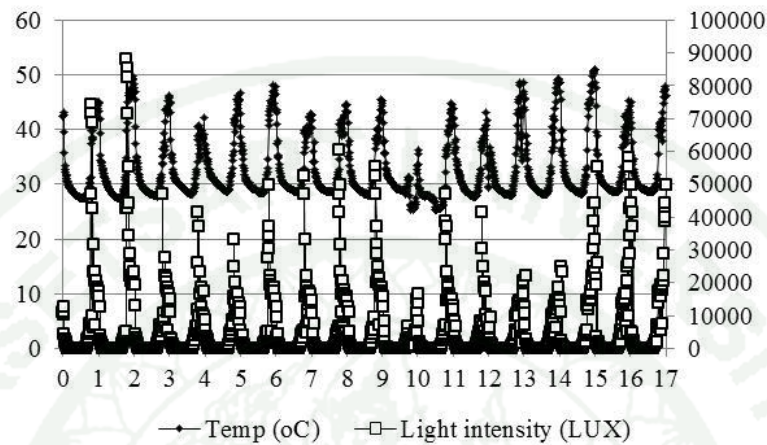


Figure 40 Temperature and natural light intensity during *Scenedesmus* sp. cultivation in wastewater under outdoor semi continuous experiment in trial 3.

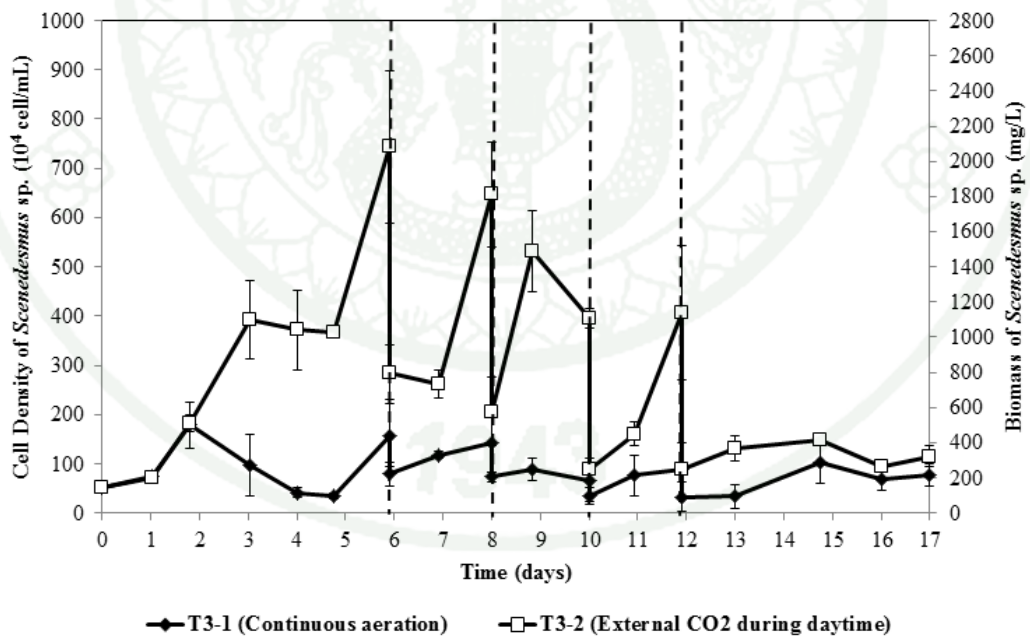


Figure 41 Growth of *Scenedesmus* sp. cultivated in wastewater under outdoor semi continuous experiment in trial 3. The alga was cultivated with continuous aeration (T3-1) or CO₂ supplement during daytime (T3-2). Dash line indicates algal harvesting by cross flow filtration.

Growth of *Scenedesmus* sp. in this study (Figure 41) was significantly higher in treatment T2-2 with CO₂ supplemented aeration only during daytime. Continuous aeration (24 hrs.) provided the maximum cells density of $157.41 \pm 64.26 \times 10^4$ cell/mL while CO₂ supplement during daytime enhanced the maximum cells density up to $743.83 \pm 154.20 \times 10^4$ cell/mL. Average volumetric productivity of T3-2 was approximately 2 times higher than T3-1. Productivity of *Scenedesmus* sp. after each harvesting was shown in Table 14. Environmental condition especially light intensity and temperature (Figure 40) revealed that the maximum light intensity and average light intensity were 88178.4 Lux and 10414.56 Lux, respectively. This result confirms the results from previous experiment that the external CO₂ supplement during daytime can promote growth of *Scenedesmus* sp. when cultivated with high light intensity. Therefore this condition was selected for further outdoor continuous experiment.

Table 14 Productivity of *Scenedesmus* sp. cultivated in wastewater under outdoor semi continuous experiment in trial 3.

Harvested	Duration time (days)	Volumetric Biomass Productivity of Harvested <i>Scenedesmus</i> sp. (mg /L/d)		Areal Biomass Productivity of Harvested <i>Scenedesmus</i> sp. (mg /m ² /d)	
		T3-1 (Continuous aeration)	T3-2 (External CO ₂ during daytime)	T3-1 (Continuous aeration)	T3-2 (External CO ₂ during daytime)
		1	5.9	24.26 ± 5.86	41.68 ± 14.71
2	2.1	76.02 ± 20.01	131.57 ± 34.24	14517.13 ± 3820.57	25124.09 ± 6538.87
3	2.0	54.30 ± 13.74	110.41 ± 4.09	10368.90 ± 2624.74	21084.25 ± 781.14
4	1.9	55.98 ± 6.74	118.17 ± 13.22	10689.20 ± 1287.68	22566.55 ± 2525.27
5	5.1	56.50 ± 15.70	81.94 ± 14.67	10789.45 ± 2997.43	15647.72 ± 2800.81
Average		53.41 ± 9.30	96.75 ± 4.93	10199.43 ± 1775.69	18476.24 ± 941.83

Similar to trial 2, treatment which had higher microalgae growth exhibited the higher nutrient removal (Figure 42 b). Moreover, reduction of total nitrogen, phosphorus and COD were found as shown in Figures 43 and 44, respectively.

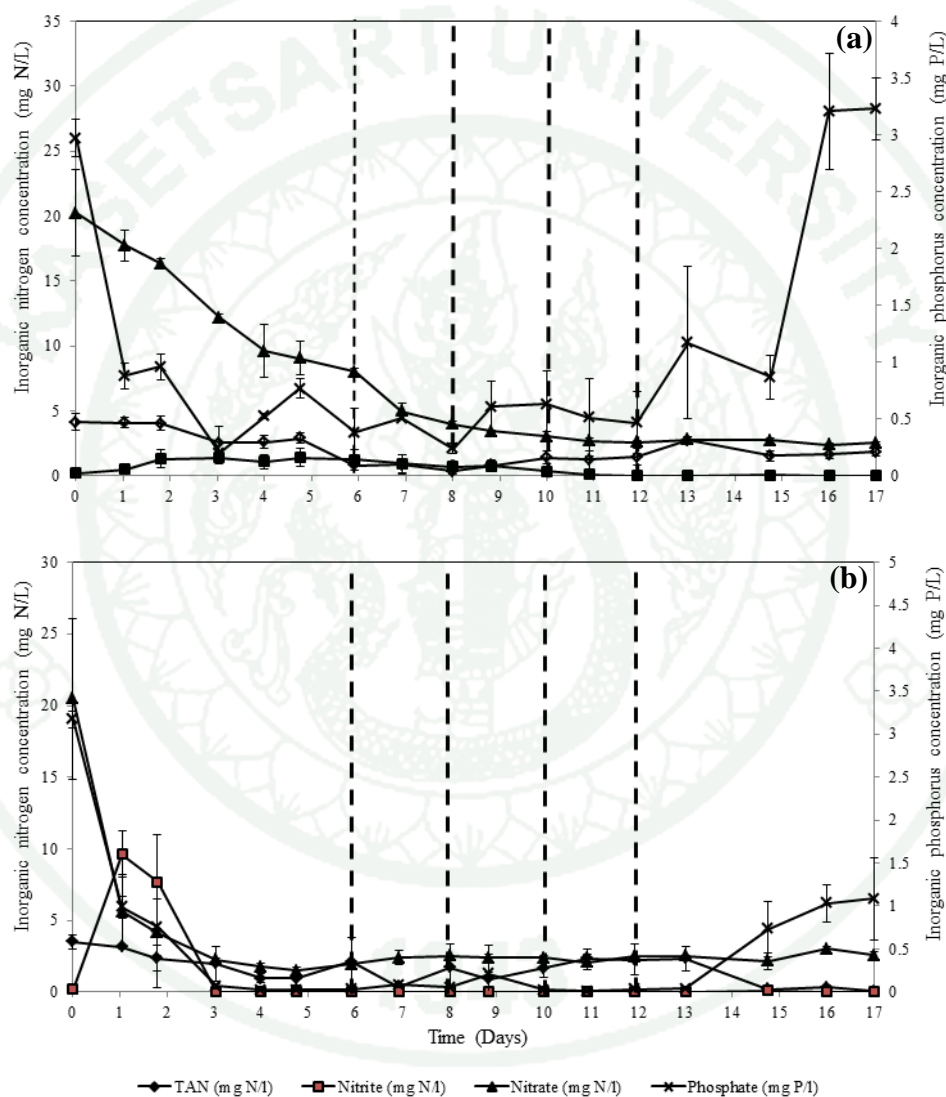


Figure 42 Inorganic nitrogen and inorganic phosphorus during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 3. (a) T3-1 (Continuous aeration) (b) T3-2 (External CO₂ supplement during daytime). Dash line indicates algal harvesting by cross flow filtration.

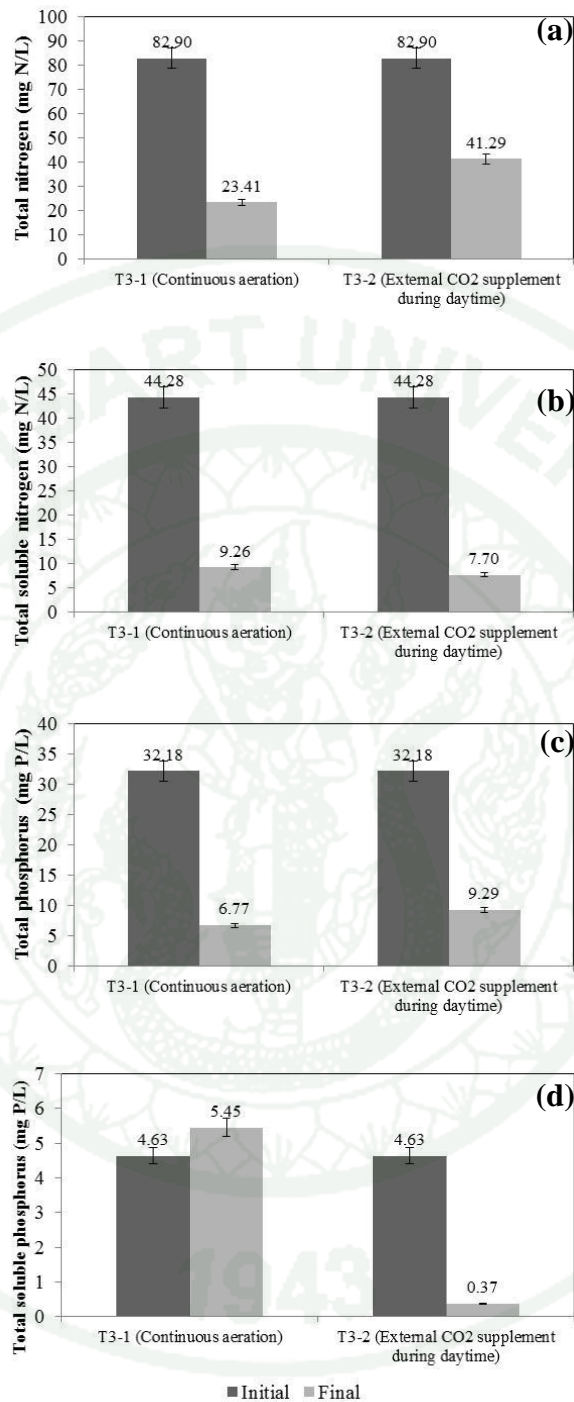


Figure 43 Total nitrogen and total phosphorus during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 3. (a) total nitrogen (b) total soluble nitrogen (c) total phosphorus (d) total soluble phosphorus.

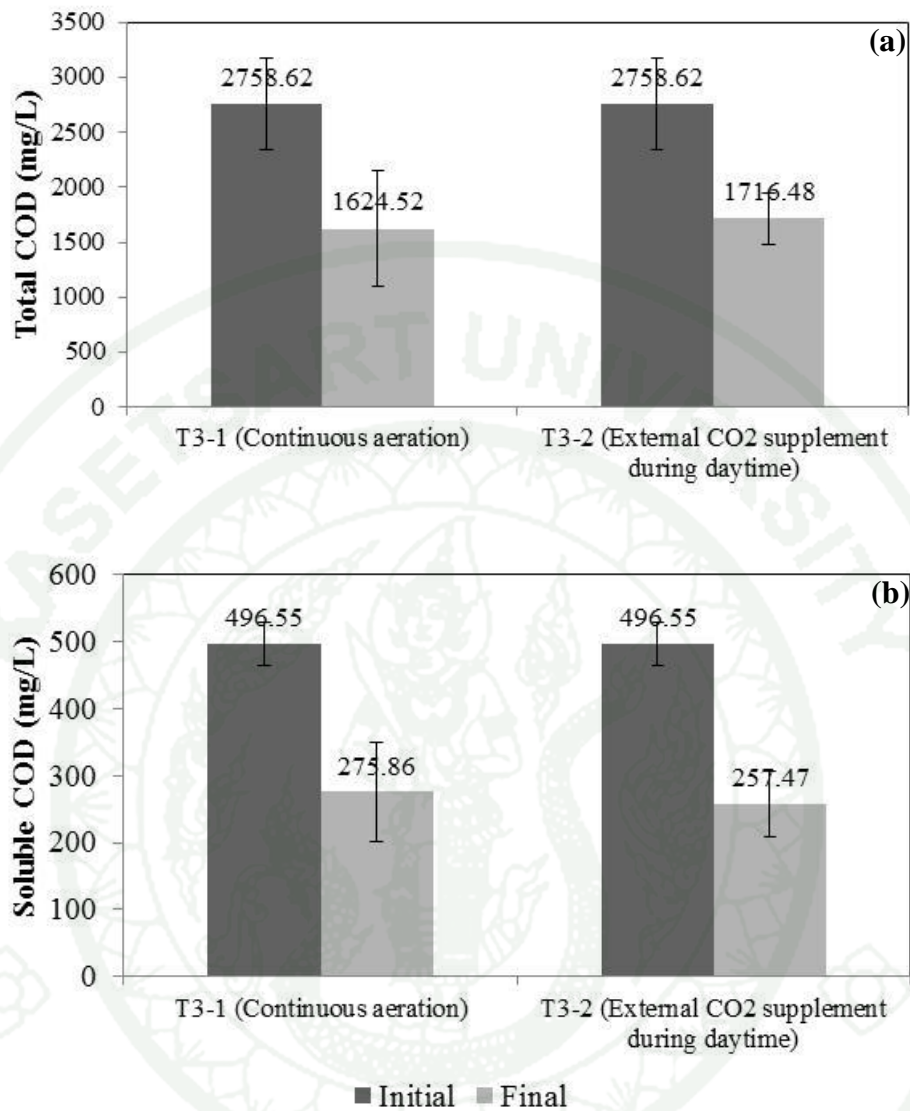


Figure 44 COD during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 3. (a) total COD (b) soluble COD.

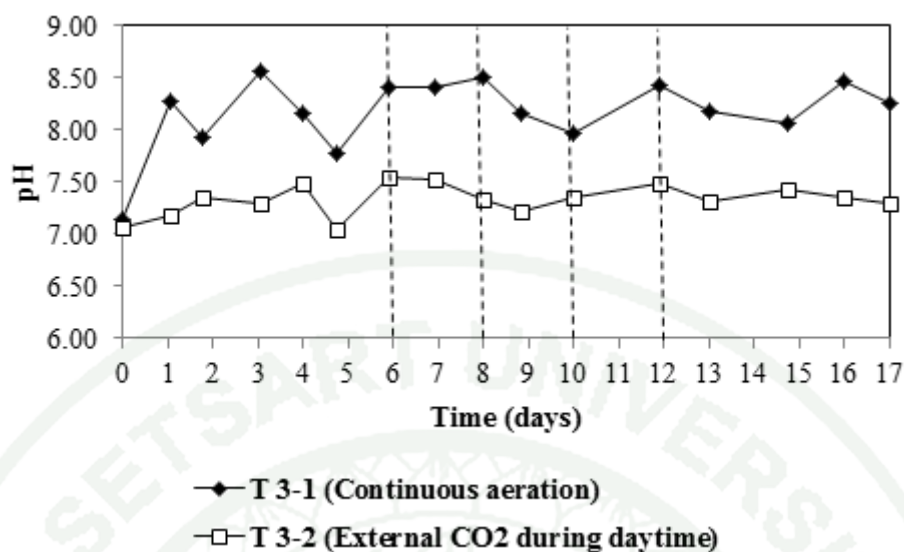
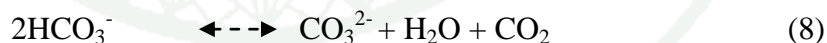


Figure 45 pH profile during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 3. Dash line indicates algal harvesting by cross flow filtration.

The pH profile is shown in Figure 45, average pH in T3-1 and T3-2 was 8.17 ± 0.03 and 7.33 ± 0.03 , respectively. The result indicates pH in treatment with CO₂ supplement was lower than treatment without CO₂ supplement. Decrease of pH from CO₂ supplement was due to the bicarbonate–carbonate buffer systems in photosynthesis through the following reactions (Li *et al.*, 2011):



5. Growth of *Scenedesmus* sp. and Nutrient Removal from Wastewater under Outdoor Continuous Cultivation

Figure 46 shows natural light intensity and temperature during continuous culture experiment. The maximum light intensity and average light intensity were 46844.8 Lux and 4118.62 Lux, respectively. These light intensity was lower than most of the previous experiments.

Photograph of *Scenedesmus* sp. cells under outdoor cultivation is shown in Figure 47 and growth of *Scenedesmus* sp. under continuous culture is shown in Figure 48. During the experiment, dilution rate was varied from 0.5 day⁻¹ (day 7-15) to 1.0 day⁻¹. The results illustrated that dilution rate at 0.5 day⁻¹ was appropriate for continuous culture of *Scenedesmus* sp. with continuous MLSS feeding. Increase the dilution rate to 1.0 day⁻¹ (Figure 48 at day 15 -18) caused suspended solids overloading in the photobioreactor column since the medium flow rate was too high to retain solid settlement in the column. Therefore, MLSS feeding was stop at day 18 – 21, this allowed the settlement of suspended solids in the column. Thereafter, continuous culture was performed by adjusting the dilution late of 0.5 day⁻¹ until it reached steady state. During steady state growth (day 21 – 38), average dilution rate of 0.46 ± 0.03 produced the average volumetric microalgal productivity and areal productivity of 167.43 ± 13.02 mg/L/day and 32.18 ± 2.57 g/m²/day, respectively. This volumetric productivity was lower than productivity of microalgae cultivated in municipal wastewater using vertical reactor (320 ± 0.02 mg/L/day) reported by Chinnasamy *et al.* (2011). However, areal productivity in this study was higher than their productivity (20.03 ± 1.04 g/m²/day) because the photobioreactor in this study had smaller footprint.

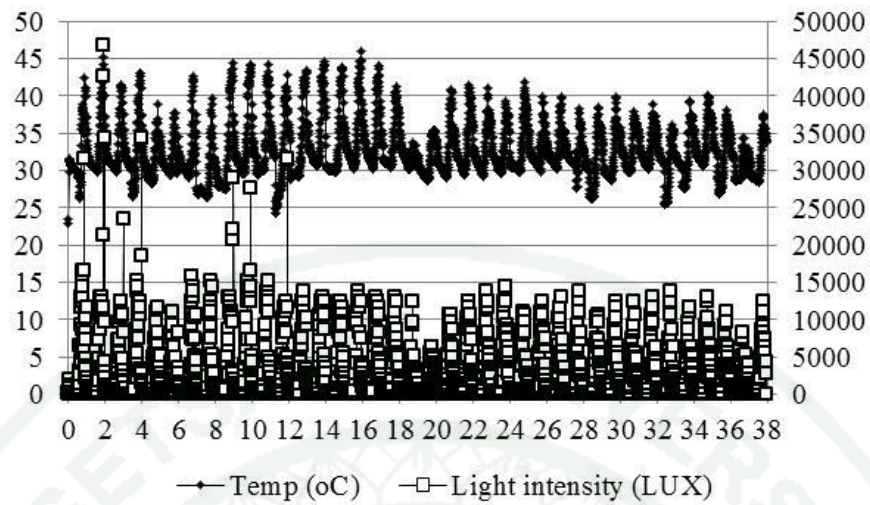


Figure 46 Temperature and natural light intensity during *Scenedesmus* sp. cultivation in wastewater under outdoor continuous culture experiment.

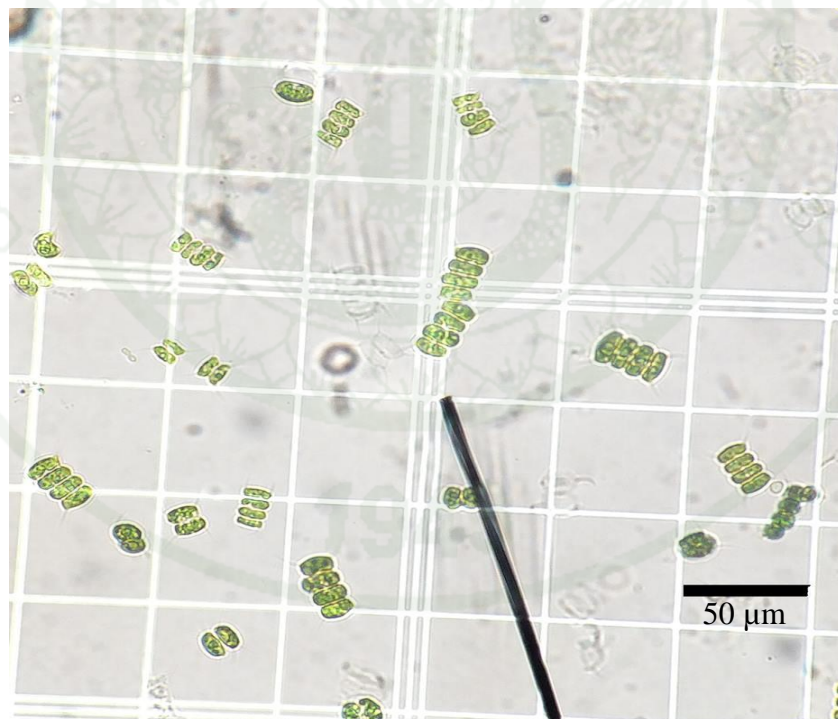


Figure 47 *Scenedesmus* sp. cells in MLSS wastewater from instant noodle factory under outdoor continuous cultivation.

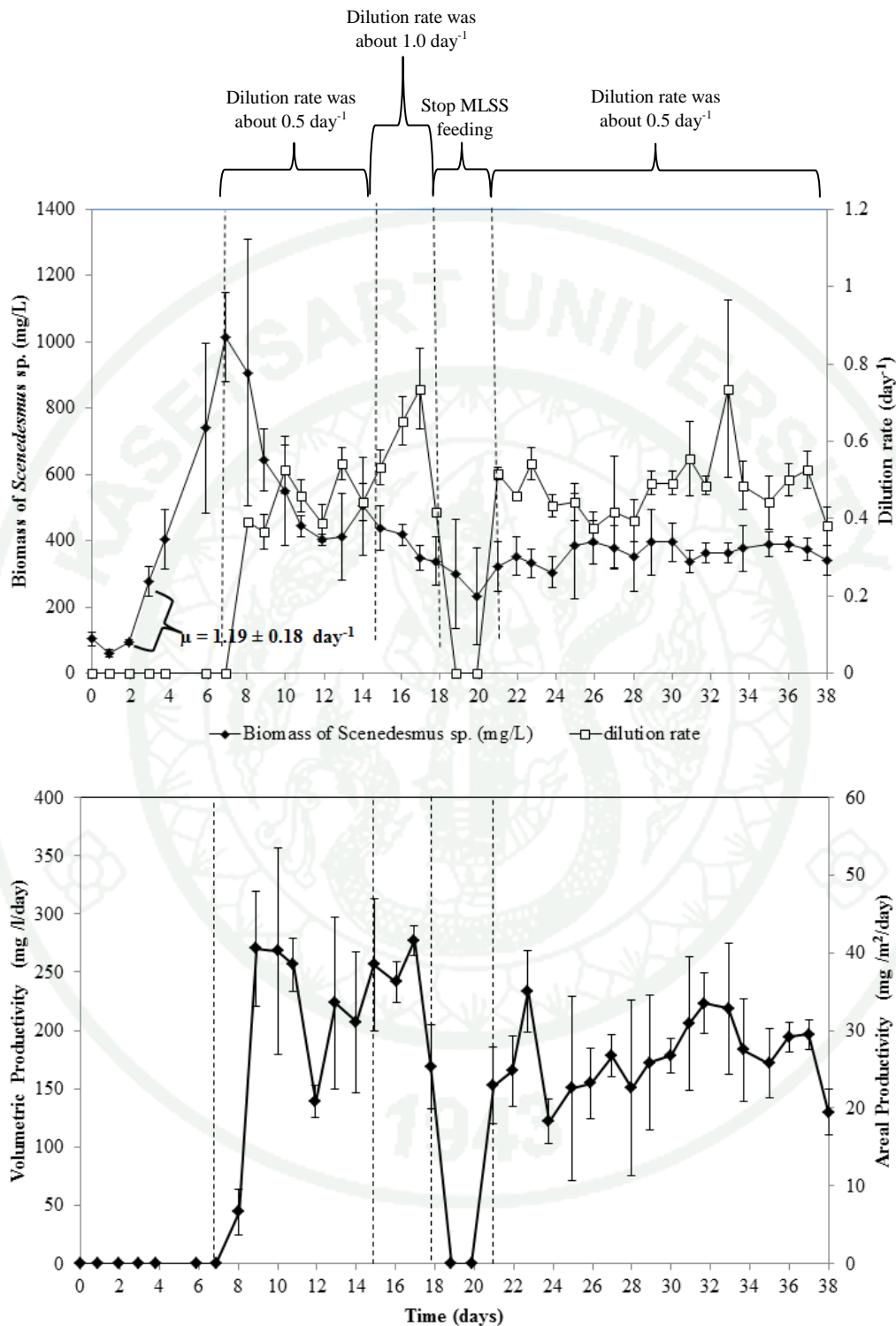


Figure 48 Growth of microalgae cultivated in wastewater under outdoor continuous culture experiment.

Concentrations of nutrients during continuous culture experiment are shown in Figure 50. Ammonia, which is the major nitrogen source for microalgae growth, was released by decomposition of organic particulate. Ammonia uptake by microalgae was therefore a key role for nitrogen removal from wastewater. On the other hand, phosphate in continuous culture experiment was not a limiting factor because phosphate concentration was rather constant throughout the experimental period. A peak of nitrite was found at the initial stage but decline afterward. This indicated the occurrence of nitrification process that convert ammonia to nitrite and finally nitrate under aerobic condition (Bach *et al.*, 1999). This assumption was supported by an increase of nitrate concentration in the effluent, in which nitrate is the end product of nitrification process. Total COD and soluble COD were also removed by algal treatment (Figure 51). ORP measured in water layer in photobioreactor (Table 15) indicated the aerobic condition while anaerobic denitrification with ORP below -100 mV (Zumft, 1997) was found in sediment layer. With COD consumption as organic carbon source for denitrification process, apart of algal uptake, the results indicated that nitrogen removal from wastewater might also a result from denitrification process in bottom sediment layer. Average pH during steady state was 7.03 (Figure 49), this pH value was slightly lower than normal culture due to the effect of CO₂ supplement (Li *et al.*, 2011).

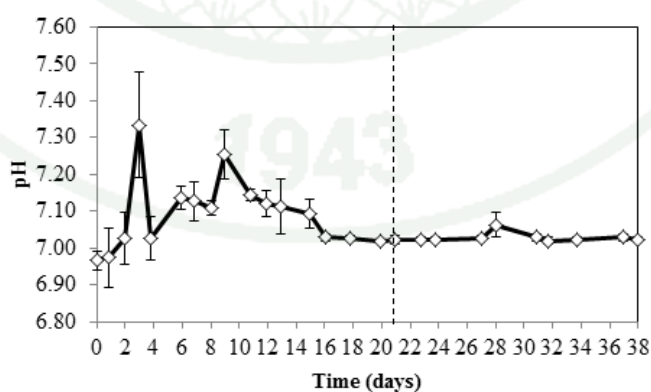


Figure 49 pH profile during *Scenedesmus* sp. cultivation in MLSS wastewater under continuous culture condition. Dash line indicates day that microalgae reach steady state (dilution rate 0.5 L/day⁻¹).

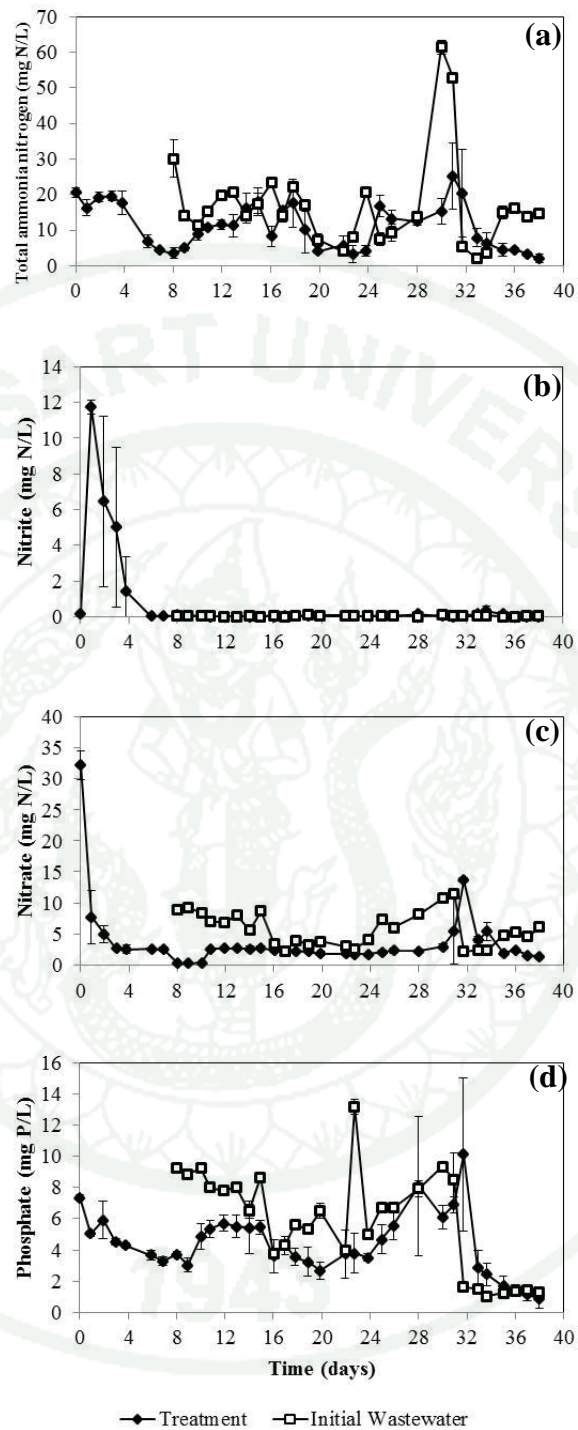


Figure 50 Inorganic nitrogen and inorganic phosphorus during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor continuous culture experiment. (a) total ammonia nitrogen (b) nitrite (c) nitrate and (d) phosphate.

Table 15 Oxidation Reduction Potential (ORP) in water column and bottom sediment layer during *Scenedesmus* sp. continuous culture with MLSS wastewater from instant noodle factory.

Layer	Oxidation reduction potential (mV)
Water	45.24 ± 7.65
Sediment	-297.89 ± 35.63

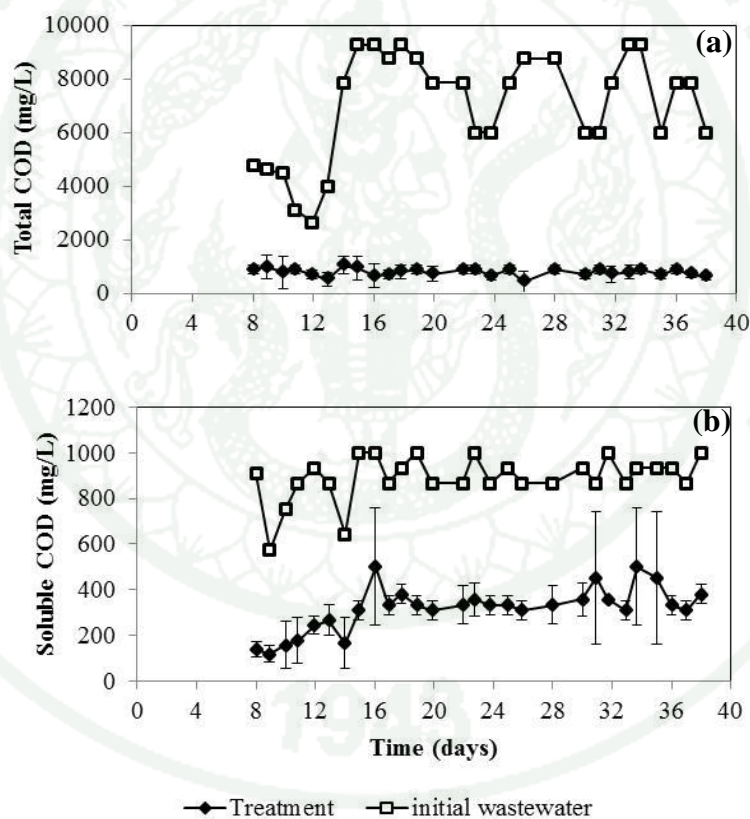


Figure 51 COD changing during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor continuous culture experiment. (a) total COD (b) soluble COD.

5.1 Total lipid content in microalgae

At the 31st day, microalgae productivity was extract according to Bligh and Dyer method (1959) for determining total lipid content. Percentage of total lipid in microalgae cultivation in wastewater from instant noodle factory under outdoor continuous experiment is 7.14 ± 1.78 %. This total lipids content was lower than some previous reports such as 30% in Ma *et al.* (2012) and up to 53% under nitrogen starvation condition in Ren *et al.* (2013). It has to be noted that most of the high lipid content algae were from laboratory culture under specific condition such as unlimited light intensity and physiological stress. Moreover, lipid extraction techniques from classical hexane extraction to advanced methods such as microwave extraction, ultrasonic assisted extraction, or supercritical fluid extraction (Cyber Lipid Center, n.d.) also influence the lipid analysis.

5.2 C H N component in algae and wastewater sludge

After microalgae reach steady state (day 21 – 38), sludge and microalgae was taken from photobioreactor once at day 25 and they were analyzed for C H N content as shown in Table 16. It was found that C and N in sludge after *Scenedesmus* sp. cultivated in photobioreactor using MLSS wastewater from instant noodle factory was lower than initial sludge due to the aerobic and anaerobic digestion in the sediment layer and it released carbon as CO₂ to culture medium which later utilized by microalgae. However, external CO₂ supplement was also provided to *Scenedesmus* sp. culture. So, *Scenedesmus* sp. should have excess CO₂ for growth and CO₂ fixation. Base on average volumetric productivity at steady state which was approximately 167.43 mg/L/day, carbon fixation was 24.02 ± 1.06 mg C/L/day. Carbon fixation in this study was slightly higher than previous research (Boonnorat, 2011) which was 19 mg C/L/day of microalgae consortium cultivated in domestic wastewater by membrane photobioreactor.

Similarly, hydrogen and nitrogen content in MLSS sludge after *Scenedesmus* sp. cultivation in photobioreactor were lower than initial sludge. Emphasizing on nitrogen, *Scenedesmus* sp. could assimilate nitrogen at 4.16 ± 0.23

mg N/L/day, based on 167.43 mg/L/day volumetric productivity of and 189.87 ± 14.80 mg TN/L nitrogen content in MLSS wastewater.

Table 16 C H N component in *Scenedesmus* sp. and wastewater sludge during outdoor continuous cultivation.

Sample	C H N component (%)		
	C	H	N
Initial sludge from MLSS	33.47 ± 0.02	6.09 ± 0.06	6.17 ± 0.09
Sludge remained after <i>Scenedesmus</i> sp. cultivation in photobioreactor	31.67 ± 0.01	5.79 ± 0.09	5.15 ± 0.04
<i>Scenedesmus</i> sp. cells cultivated in photobioreactor using MLSS	14.35 ± 0.76	2.68 ± 0.11	2.48 ± 0.14

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. MLSS wastewater from aeration tank of the instant noodle factory contained high suspended solids (5500.00 ± 244.34 mg/L) and high COD (3366.00 ± 200.92 mg/L). Release of ammonia from suspended solids decomposition (ammonification) could supply ammonia-nitrogen to the microalga *Scenedesmus* sp. culture. Effluent from sedimentation tank, on the other hand, contains low suspended solids (126.67 ± 5.77 mg/L) so it could be stated that most of nitrogen in effluent was a soluble form.

2. Preliminary experiment in 24 wells microplate revealed that both MLSS and effluent could be used as culture medium for *Scenedesmus* sp. without the need of dilution. Specific growth rate during the second day of algal cultivation using 100% MLSS and 100% effluent were 1.63 ± 0.11 day⁻¹ and 1.57 ± 0.16 day⁻¹, respectively. Both specific growth rates were significantly ($p < 0.05$) higher than BG11 medium (1.08 ± 0.14 day⁻¹).

3. Similar to the preliminary experiment, cultivation of *Scenedesmus* sp. in 2000 mL Duran bottle under laboratory condition also showed the possibility of using undiluted MLSS and effluent as the medium for *Scenedesmus* sp..

3.1 There was no significant ($p < 0.05$) difference on growth and biomass of *Scenedesmus* sp. cultured in wastewater from instant noodle factory and control (BG11), hence, it could be stated that both wastewater types had a potential to be used as sole nutrients supplement for microalgal cultivation. Moreover, ammonia is the major nitrogen source for *Scenedesmus* sp. cultivated in MLSS, while nitrate is possibly a crucial nitrogen source for in the effluent. Phosphate, however, seems to be the limiting nutrient in all treatments since phosphate concentration was substantially low in both MLSS and effluent treatments..

3.2 K_2HPO_4 was added as phosphate supplement for MLSS and effluent to investigate effect of phosphate addition for microalgae growth. After

phosphate adding, Treatment with phosphate adding exhibited higher growth and biomass (482.02 ± 144.46 mg/L and 300.73 ± 182.35 mg/L for MLSS and effluent, respectively) than treatment without phosphate addition (200.19 ± 20.13 mg/L and 174.15 ± 45.08 mg/L for MLSS and effluent, respectively). This result suggested that phosphate addition can enhance growth of microalgae cultivated in wastewater from instant noodle factory. MLSS wastewater was therefore chosen for further investigation.

3.3 Growth analysis results indicated that, under laboratory condition, external carbon dioxide did not clearly enhance growth of microalga *Scenedesmus* sp. in all treatments using MLSS wastewater from instant noodle factory. In addition, light period either continuous light or 12:12 light: dark cycle also provided similar growth of *Scenedesmus* sp..

4. With outdoor semi continuous experiment, aeration with 2% external CO₂ supplement during daytime can enhance growth rate of *Scenedesmus* sp.. Average productivity of 96.75 ± 4.93 mg/L/d was obtained from this experiment.

5. MLSS was used for outdoor continuous experiment using external CO₂ supplement during daytime (from 6 am to 6 pm). The optimal dilution rate from this experiment was 0.5 day^{-1} . Suspended solids in MLSS could not settle when the dilution rate was increased to 1 day^{-1} . At steady state (day 21 – 38), average dilution rate of 0.46 ± 0.03 provided the volumetric microalgal productivity and areal productivity of 167.43 ± 13.02 mg/L/day and 32.18 ± 2.57 g/m²/day, respectively.

6. With outdoor cultivation in photobioreactor, total lipid content of *Scenedesmus* sp. cultivated in MLSS wastewater from instant noodle factory was 7.14 ± 1.78 %. CHN analysis revealed the cellular content of *Scenedesmus* was 14.35% C, 2.68% H and 2.48% N.

Recommendations

1. Other microalgae species or indigenous species should be tested for microalgae cultivation in wastewater from instant noodle factory. Longer cultivation period is recommended.

2. Apart of macronutrients such as nitrogen and phosphorus, other micronutrients especially essential metals should be analyzed. Supplement of micronutrients may be needed with long cultivation period.

3. It was found that the microalga utilized ammonia-nitrogen from ammonification process as the major nitrogen source. To enhance the efficiency of organic-nitrogen digestion, ammonification process must be enhanced by adding a special device for ammonification and supply high ammonia water into the photobioreactor.

4. For further research using wastewater from instant noodle factory as medium for microalgae cultivation in photobioreactor, recommendation of operational guideline from this study are as following:

Parameters	Operational Guideline
Wastewater types	MLSS without dilution
Aeration types	2 % external CO ₂ supplement during daytime
Hydraulic retention time or dilution rate	0.5 day ⁻¹

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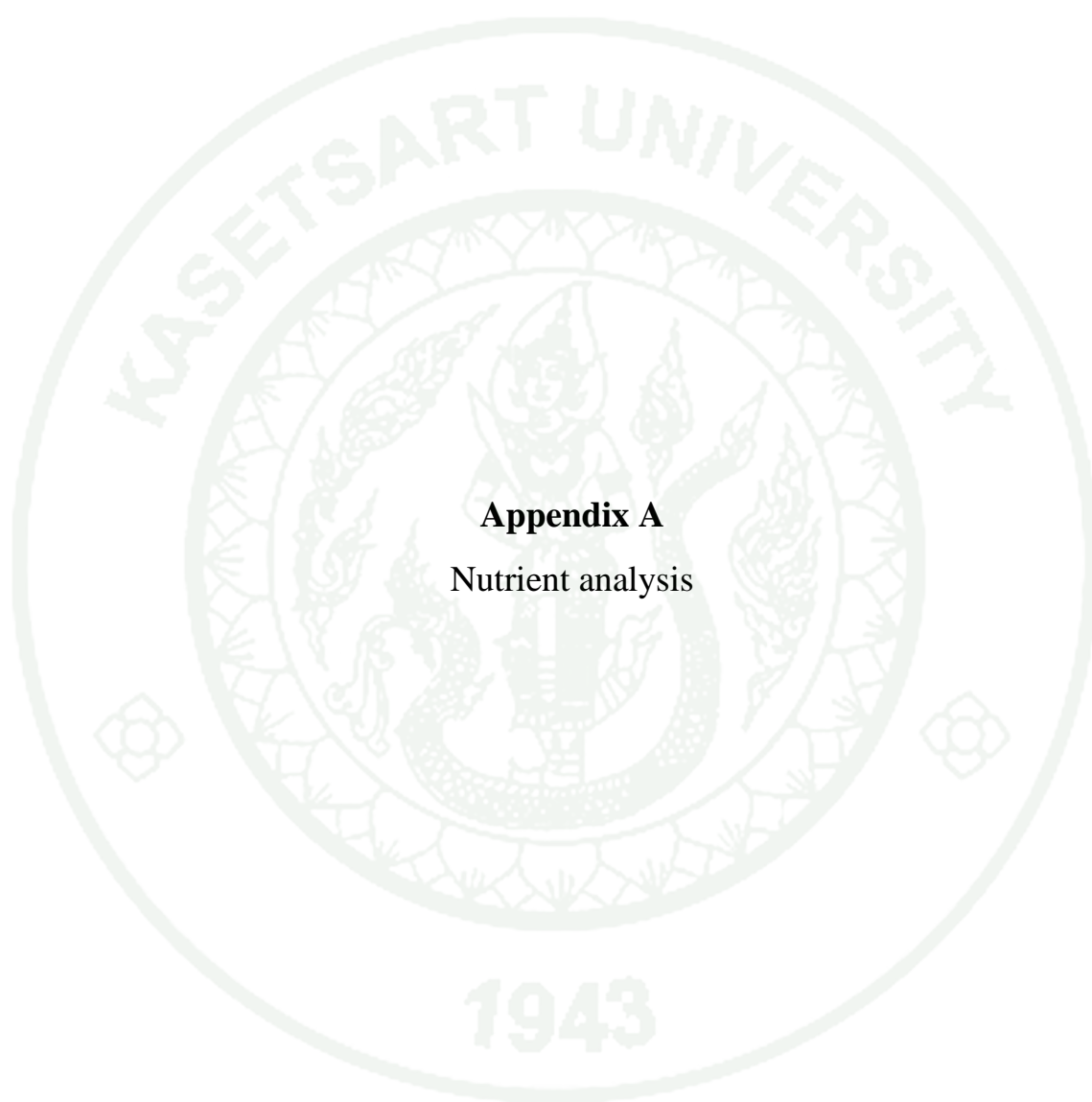
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APPENDICES



Appendix A
Nutrient analysis

Appendix A1: Determination of total ammonia nitrogen

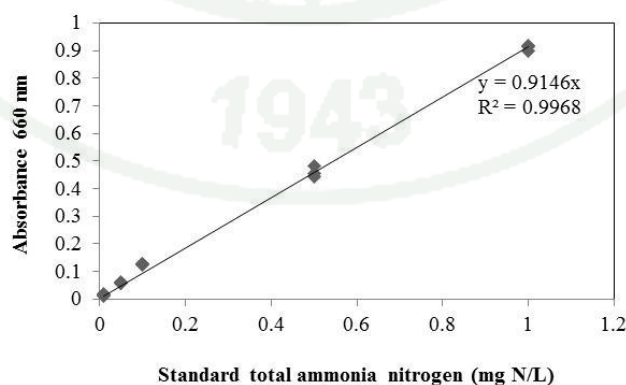
(Salicylate-Hypochlorite method; Bower and Hansen, 1980)

Reagent

1. Salicylate-catalyst solution: 440 g of sodium salicylate plus 0.28 g of sodium nitroprusside/L
2. Alkaline citrate solution: 18.5 g of sodium hydroxide plus 100 g of sodium citrate/L
3. Sodium hypochlorite solution: A stabilized commercial i.e. Clorox (5.25% NaOCl) is suitable.
4. Alkaline hypochlorite solution: One volume of sodium hypochlorite solution diluted to 10 volumes with alkaline citrate solution. Use within 1 h of preparation.

Procedure

1. Add 30 μ L of salicylate-catalyst solution in 0.25 mL of water sample, blank (de-ionized water), and standard solution (0.01, 0.05, 0.1, 0.5, 1.0 mg N/L standard solution which was prepared from 100 mg N/L of ammonia stock solution).
2. Then add 50 μ L of alkaline hypochlorite solution into sample. Mix sample and reagent well.
3. Allow 1 h for reaction time.
4. Measure by spectrophotometer at wavelength of 660 nm.
5. Calculation concentration of total ammonia nitrogen (mg N/L) with standard curve as shown in Figure A1.



Appendix Figure A1 Calibration curve of total ammonia nitrogen.

Appendix A2: Determination of nitrite

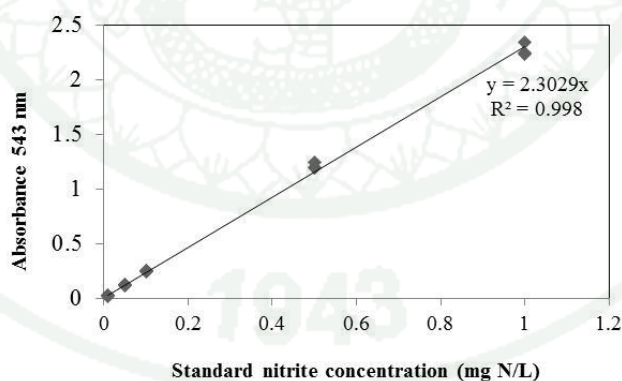
(Spectrometric method; Srickland and Parsons, 1972)

Reagent

1. Sulphanilamide solution: 5g sulphanilamide and 50 mL conc HCl/ 0.5L
2. NNED solution: 0.5 g N-(1-Naphthyl)-Ethylenediamine Dihydrochloride/0.5 L

Procedure

1. Add 5 μ L of sulphanilamide solution in 0.25 mL of water sample, blank (de-ionized water), and standard solution (0.01, 0.05, 0.1, 0.5, 1.0 mg N/L standard solution which was prepared from 100 mg N/L of nitrite stock solution).
2. Then add 5 μ L of NNED solution into sample. Mix sample and reagent well.
3. Allow 30 minutes for reaction time.
4. Measure by spectrophotometer at wavelength of 543 nm.
5. Calculation concentration of nitrite (mg N/L) with standard curve as shown in Figure A2.



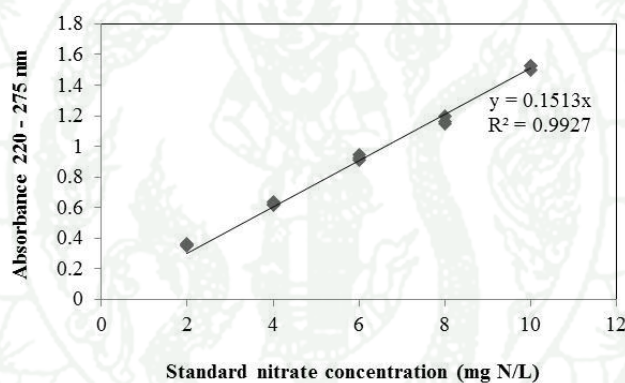
Appendix Figure A2 Calibration curve of nitrite.

Appendix A3: Determination of nitrate

(Ultraviolet Spectrometric screening method; APHA, 2005)

Procedure

1. Measure the water sample, blank (de-ionized water), and standard solution (2, 4, 6, 8, 10 mg N/L standard solution which was prepared from 100 mg N/L of nitrate stock solution) by spectrophotometer at wavelength of 220 nm to obtain NO_3^- and a wavelength 275 nm to determine interference due to dissolved organic matter.
2. Calculation concentration of nitrate (mg N/L) with standard curve as shown in Figure A3.



Appendix Figure A3 Calibration curve of nitrate.

Appendix A4: Determination of phosphate

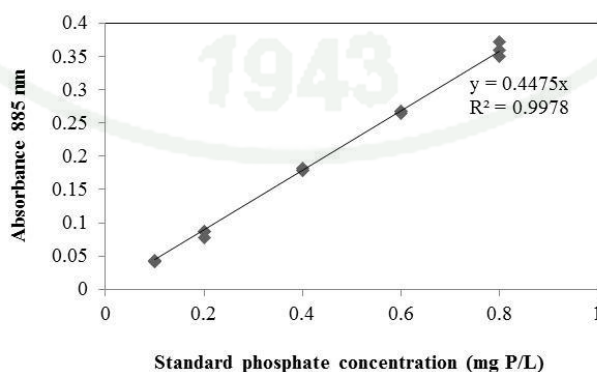
(Spectrometric method; Strickland and Parsons, 1972)

Reagent

1. Ammonium molybdate solution: 15 g of $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24}\cdot 4\text{H}_2\text{O}$ / 500 mL and store the solution in a plastic bottle.
2. Sulfuric acid solution: 15 mL of conc sulfuric acid/ 500 mL and store the solution in a glass bottle and keep in refrigerator.
3. Ascorbic acid solution: 27 g of ascorbic acid/ 900 mL and store the solution in a glass or plastic bottle and keep in refrigerator.
4. Potassium antimonyle tartrate solution: 0.34 g of $\text{KNaC}_4\text{H}_4\text{C}_6\cdot 4\text{H}_2\text{O}$ / 250 mL and store the solution in a glass or plastic bottle and keep in refrigerator.
5. Mixed reagent Mix 2 mL of ammonium molybdate solution, 5 ml of sulfuric acid solution, 2 mL of ascorbic acid solution, and 1 mL of potassium antimonyle tartrate solution. Prepare afresh each day.

Procedure

1. Add 25 μL of mixed reagent in 0.25 mL of water sample, blank (de-ionized water), and standard solution (0.1, 0.2, 0.4, 0.6, 0.8 mg P/L standard solution which was prepared from 100 mg P/L of phosphate stock solution).
2. Allow 30 minutes for reaction time.
3. Measure by spectrophotometer at wavelength of 885 nm.
4. Calculation concentration of phosphate (mg P/L) with standard curve as shown in Figure A4.



Appendix Figure A4 Calibration curve of phosphate.

Appendix A5: Determination of total nitrogen

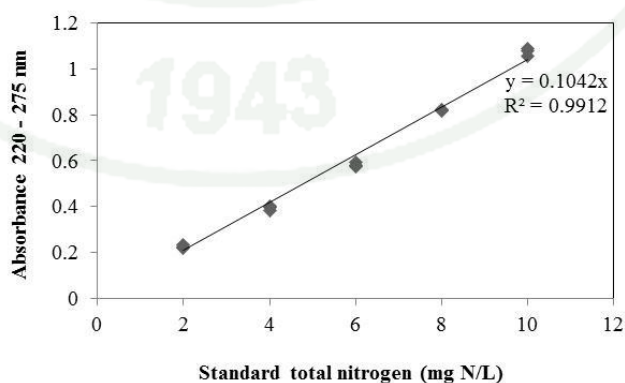
(Oxidizing and nitrate analysis by Spectrometric; Grasshoff, 1999)

Reagent

1. Oxidizing agent: 5 g of potassium peroxodisulphate ($K_2S_2O_8$) plus 0.75 g of sodium hydroxide/ 250 mL
2. Borate buffer: 15.45 g of boric acid plus 2 g sodium hydroxide/ 250 mL

Procedure

1. Add 2.5 ml of oxidizing agent in 5 ml of water sample (with and without filtration), blank (de-ionized water), and standard solution (2, 4, 6, 8, 10 mg N/L standard solution which was prepared from 100 mg N/L of nitrate stock solution).
2. Oxidizing by autoclave at 121 ° C for 30 min.
3. Cool down all samples to room temperature and then add 0.5 ml of borate buffer in sample, blank, and standard solution.
4. Centrifuge at 1000 rpm. for 15 minutes.
5. Measure by spectrophotometer at wavelength of 220 nm to obtain NO_3^- and a wavelength 275 nm to determine interference due to dissolved organic matter.
6. Calculation concentration of nitrate (mg N/L) with standard curve as shown in Figure A5. Concentration of total nitrogen and total soluble nitrogen are the results from nitrate determination of water with filtration and water without filtration, respectively.



Appendix Figure A5 Calibration curve of total nitrogen.

Appendix A6: Determination of total phosphorus

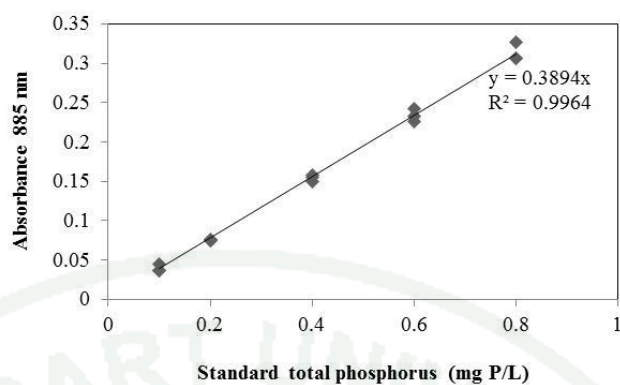
(Oxidizing and nitrate analysis by Spectrometric; Grasshoff, 1999)

Reagent

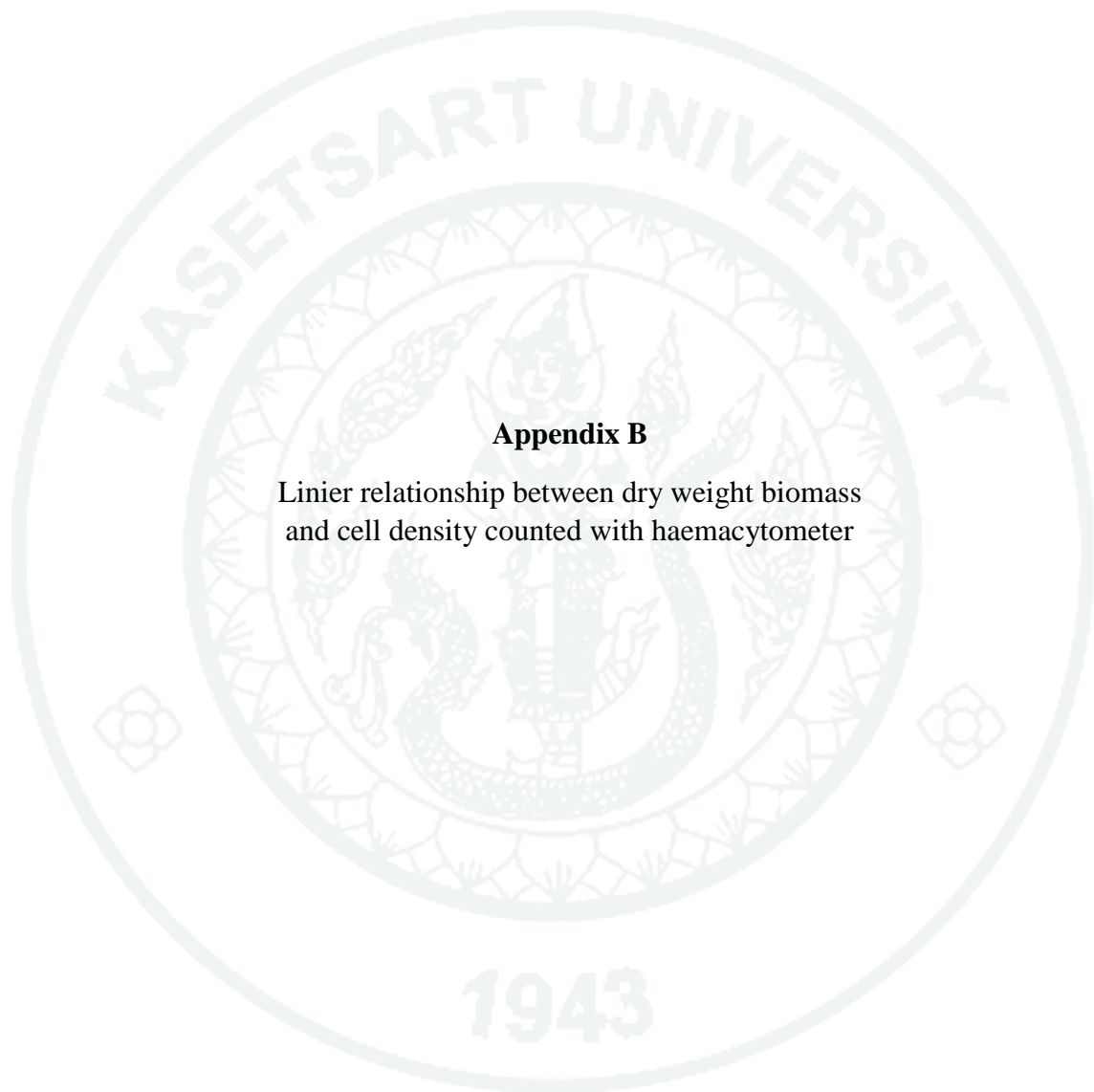
1. 0.075 N sodium hydroxide solution: 0.075 g of sodium hydroxide/ 250 mL
2. Oxidizing agent: 0.5 g of potassium peroxodisulphate ($K_2S_2O_8$) plus 0.3 g of boric acid in 50 mL of 0.075 N sodium hydroxide solution
3. Ammonium molybdate solution: 15 g of $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$ / 500 mL and store the solution in a plastic bottle.
4. Sulfuric acid solution: 15 mL of conc sulfuric acid/ 500 mL and store the solution in a glass bottle and keep in refrigerator.
5. Ascorbic acid solution: 27 g of ascorbic acid/ 900 mL and store the solution in a glass or plastic bottle and keep in refrigerator.
6. Potassium antimonyle tartrate solution: 0.34 g of $KNaC_4H_4C_6 \cdot 4H_2O$ / 250 mL and store the solution in a glass or plastic bottle and keep in refrigerator.
7. Mixed reagent Mix 2 mL of ammonium molybdate solution, 5 ml of sulfuric acid solution, 2 mL of ascorbic acid solution, and 1 mL of potassium antimonyle tartrate solution. Prepare afresh each day.

Procedure

1. Add 1 ml of oxidizing agent in 5 ml of water sample (with and without filtration), blank (de-ionized water), and standard solution (0.1, 0.2, 0.4, 0.6, 0.8 mg P/L standard solution which was prepared from 100 mg P/L of phosphate stock solution).
2. Oxidizing by autoclave at 121 ° C for 30 min.
3. Cool down all samples to room temperature and then centrifuge at 1000 rpm. for 15 minutes.
4. Add 0.5 ml of mix reagent in sample, blank, and standard solution.
5. Measure by spectrophotometer at wavelength of 885 nm.
6. Calculation concentration of phosphate (mg P/L) with standard curve as shown in Figure A6. Concentration of total phosphorus and total soluble phosphorus are the results from phosphate determination of water with filtration and water without filtration, respectively.



Appendix Figure A6 Calibration curve of total phosphorus.



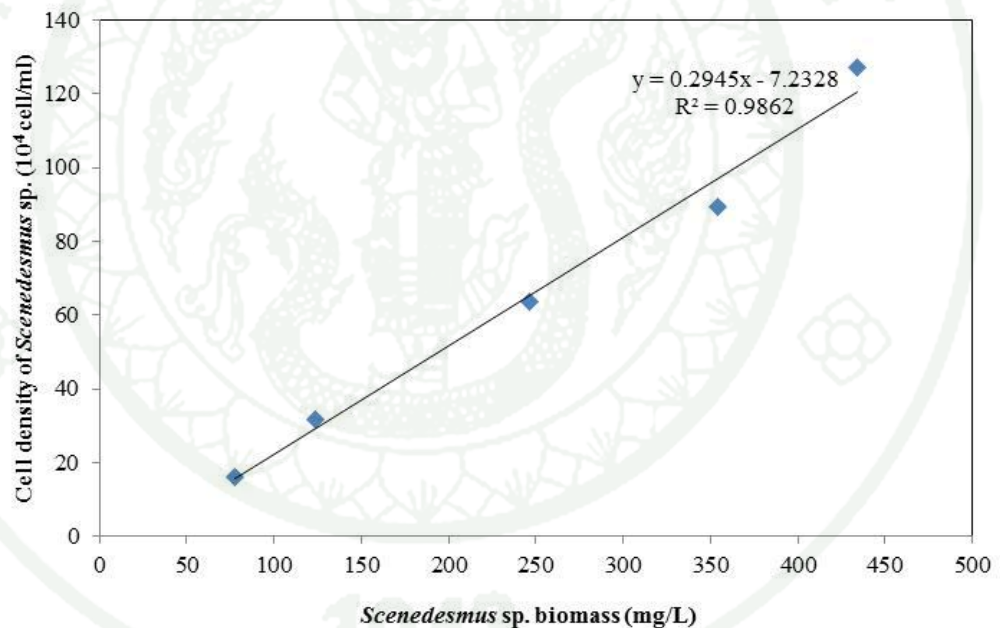
Appendix B

Linier relationship between dry weight biomass
and cell density counted with haemacytometer

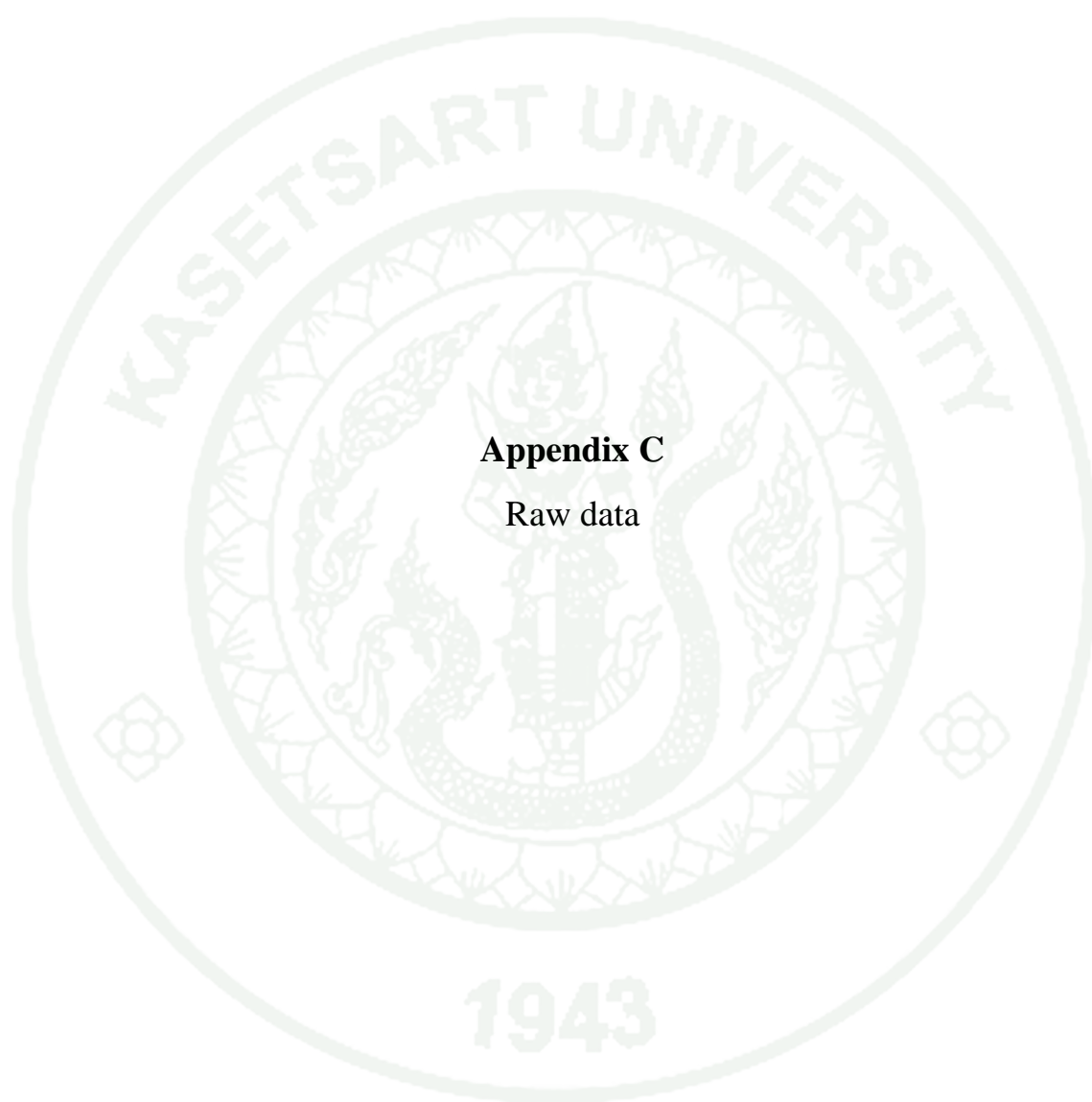
Appendix B: linier relationship between dry weight biomass and cell density counted with haemocytometer

Procedure

1. Five concentrations of *Scenedesmus* sp. which was incubated in BG11 medium under laboratory condition were count by haemocytometer.
2. Then five concentration of *Scenedesmus* sp. as described in 1 were was filtered with GF/C filter.
3. GF/C filters which was filtered *Scenedesmus* sp. was dried at 80 ° C for 24 hrs. and calculation dry weight microalgal biomass in mg/L unit.
4. Plot linier relationship between dry weight microalgal biomass and cell density counted with haemocytometer as shown in Figure B1.



Appendix Figure B1 linier relationship between dry weight biomass and cell density counted with haemocytometer.



Appendix C
Raw data

Appendix C: Raw data

Appendix Table C1 *Scenedesmus* sp. growth using various percentage of wastewater from instant noodle factory as a medium in 24 wells microplate under laboratory condition.

Days	MLSS				Effluent				Control (BG11)	
	100%	75%	50%	25%	100%	75%	50%	25%		
0.0	1	0.024	0.037	0.021	0.022	0.036	0.030	0.024	0.022	0.036
	2	0.031	0.022	0.024	0.028	0.020	0.048	0.046	0.021	0.023
	3	0.032	0.029	0.023	0.019	0.023	0.015	0.017	0.020	0.017
	4	0.023	0.024	0.030	0.028	0.029	0.021	0.024	0.028	0.022
	Average	0.028	0.028	0.025	0.024	0.027	0.029	0.028	0.023	0.025
	SD	0.005	0.007	0.004	0.005	0.007	0.014	0.013	0.004	0.008
0.3	1	0.127	0.098	0.070	0.052	0.035	0.014	0.066	0.017	0.029
	2	0.184	0.105	0.092	0.057	0.027	0.035	0.032	0.017	0.046
	3	0.106	0.110	0.062	0.043	0.013	0.020	0.077	0.013	0.024
	4	0.106	0.088	0.059	0.045	0.016	0.029	0.039	0.014	0.028
	Average	0.131	0.100	0.071	0.049	0.023	0.025	0.054	0.015	0.032
	SD	0.037	0.010	0.015	0.006	0.010	0.009	0.021	0.002	0.010
0.8	1	0.765	0.211	0.176	0.166	0.160	0.102	0.090	0.073	0.086
	2	0.253	0.298	0.176	0.114	0.150	0.101	0.110	0.098	0.091
	3	0.311	0.308	0.197	0.166	0.156	0.110	0.137	0.078	0.110
	4	0.287	0.224	0.126	0.115	0.139	0.135	0.139	0.079	0.014
	Average	0.404	0.260	0.169	0.140	0.151	0.112	0.119	0.082	0.075
	SD	0.242	0.050	0.030	0.030	0.009	0.016	0.023	0.011	0.042
1.0	1	0.354	0.253	0.196	0.186	0.157	0.099	0.061	0.088	0.084
	2	0.327	0.250	0.262	0.175	0.122	0.076	0.094	0.065	0.072
	3	0.223	0.263	0.166	0.133	0.149	0.089	0.089	0.039	0.045
	4	0.229	0.185	0.121	0.115	0.147	0.089	0.046	0.031	0.042
	Average	0.283	0.238	0.186	0.152	0.144	0.088	0.073	0.056	0.061
	SD	0.067	0.036	0.059	0.034	0.015	0.009	0.023	0.026	0.021

Appendix Table C1 (Continued)

Days	MLSS				Effluent				Control (BG11)	
	100%	75%	50%	25%	100%	75%	50%	25%		
1.3	1	0.360	0.353	0.281	0.275	0.273	0.171	0.101	0.115	0.111
	2	0.384	0.326	0.234	0.239	0.210	0.119	0.135	0.079	0.099
	3	0.332	0.291	0.201	0.176	0.172	0.149	0.141	0.098	0.097
	4	0.352	0.213	0.237	0.145	0.164	0.158	0.162	0.082	0.099
	Average	0.357	0.296	0.238	0.209	0.205	0.149	0.135	0.094	0.102
	SD	0.022	0.061	0.033	0.059	0.050	0.022	0.025	0.017	0.006
1.8	1	0.679	0.524	0.460	0.469	0.646	0.662	0.254	0.176	0.249
	2	0.603	0.527	0.494	0.396	0.542	0.485	0.207	0.089	0.213
	3	0.604	0.503	0.339	0.283	0.434	0.505	0.225	0.085	0.105
	4	0.553	0.272	0.298	0.263	0.416	0.376	0.122	0.084	0.190
	Average	0.610	0.457	0.398	0.353	0.510	0.507	0.202	0.109	0.189
	SD	0.052	0.123	0.094	0.097	0.107	0.118	0.057	0.045	0.061
2.1	1	0.961	0.863	0.526	0.447	0.743	0.807	0.473	0.153	0.251
	2	0.722	0.604	0.579	0.485	0.858	0.666	0.556	0.190	0.198
	3	0.943	0.560	0.439	0.324	0.622	0.887	0.701	0.118	0.240
	4	0.737	0.437	0.543	0.294	0.650	0.606	0.468	0.171	0.220
	Average	0.841	0.616	0.522	0.388	0.718	0.742	0.550	0.158	0.227
	SD	0.129	0.179	0.059	0.093	0.107	0.128	0.109	0.031	0.023
2.9	1	1.010	0.864	0.892	0.730	1.208	0.998	0.472	0.321	0.571
	2	1.035	0.681	0.945	0.686	1.143	0.853	0.566	0.361	0.511
	3	1.085	0.796	0.657	0.557	0.696	1.096	0.909	0.228	0.406
	4	0.737	0.541	0.538	0.461	0.796	0.672	0.610	0.138	0.363
	Average	0.967	0.721	0.758	0.609	0.961	0.905	0.639	0.262	0.463
	SD	0.156	0.142	0.193	0.123	0.253	0.185	0.189	0.100	0.095
3.8	1	1.403	1.003	1.261	1.033	1.008	1.100	0.551	0.369	0.855
	2	1.135	0.939	1.194	1.046	1.102	0.928	0.597	0.359	0.866
	3	1.209	1.014	0.903	0.849	0.908	1.135	0.802	0.294	0.699
	4	1.178	0.830	0.926	0.899	0.832	0.903	0.593	0.207	0.674
	Average	1.231	0.947	1.071	0.957	0.963	1.017	0.636	0.307	0.774
	SD	0.118	0.084	0.183	0.098	0.118	0.118	0.113	0.075	0.101

Appendix Table C1 (Continued)

Days	MLSS				Effluent				Control (BG11)	
	100%	75%	50%	25%	100%	75%	50%	25%		
5.2	1	1.581	1.310	1.212	1.278	1.272	1.295	0.694	0.505	1.212
	2	1.285	1.350	1.447	1.298	1.237	1.099	0.804	0.560	1.250
	3	1.497	1.061	1.041	1.072	1.048	1.315	0.754	0.324	1.102
	4	1.111	1.100	1.086	0.936	1.288	1.110	0.768	0.344	1.073
	Average	1.369	1.205	1.197	1.146	1.211	1.205	0.755	0.433	1.159
	SD	0.212	0.146	0.182	0.173	0.111	0.116	0.046	0.117	0.085
5.9	1	1.566	1.297	1.240	1.222	1.581	1.373	0.728	0.679	1.317
	2	1.344	1.049	1.230	1.276	1.280	1.266	0.848	0.664	1.411
	3	1.441	1.172	1.209	1.046	1.092	1.269	0.755	0.404	1.244
	4	1.230	1.013	1.283	1.031	1.405	1.111	0.807	0.444	1.225
	Average	1.395	1.133	1.241	1.144	1.340	1.255	0.785	0.548	1.299
	SD	0.143	0.129	0.031	0.124	0.206	0.108	0.054	0.144	0.084
6.8	1	1.777	1.239	1.505	1.289	1.629	1.275	0.820	0.920	1.725
	2	1.258	1.275	1.472	1.311	1.410	1.078	0.942	0.787	1.793
	3	1.401	1.242	1.003	1.114	1.217	1.244	0.837	0.534	1.676
	4	1.440	1.334	1.179	1.032	1.223	1.230	0.893	0.535	1.666
	Average	1.469	1.273	1.290	1.187	1.370	1.207	0.873	0.694	1.715
	SD	0.220	0.044	0.241	0.136	0.195	0.088	0.056	0.192	0.058
8.2	1	2.022	1.350	1.781	1.457	1.540	1.564	0.810	0.929	2.034
	2	1.476	1.286	1.473	1.346	1.474	1.038	0.968	0.931	2.062
	3	1.534	1.401	1.244	1.250	1.019	1.409	0.919	0.636	1.609
	4	1.468	1.365	1.303	1.200	1.096	1.200	0.998	0.691	1.979
	Average	1.625	1.351	1.450	1.313	1.282	1.303	0.924	0.797	1.921
	SD	0.266	0.048	0.241	0.113	0.263	0.231	0.083	0.155	0.211
10.0	1	2.090	1.504	1.763	1.527	1.492	1.563	0.865	0.909	2.219
	2	1.545	1.606	1.624	1.610	1.518	1.139	0.946	0.964	2.263
	3	1.699	1.603	1.574	1.255	1.095	1.209	0.655	0.715	1.935
	4	1.514	1.228	1.456	1.331	1.039	0.973	0.673	0.615	2.296
	Average	1.712	1.485	1.604	1.431	1.286	1.221	0.785	0.801	2.178
	SD	0.265	0.178	0.127	0.166	0.254	0.249	0.143	0.164	0.165

Appendix Table C2 Cell density of *Scenedesmus* sp. using wastewater from instant noodle factory as a medium under continuous light and aeration.

Time	Cell density (10^4 cell/mL)														
	Control (BG11)			MLSS						Effluent					
Days	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3
0.0	8.76	0.10	8.81	8.81	8.65	8.84	0.14	8.75	9.00	8.76	8.90	0.22	9.04	9.01	8.64
0.8	17.67	0.60	18.36	17.33	17.31	9.29	1.05	10.50	8.78	8.58	8.65	1.90	6.61	10.36	8.97
2.1	14.50	1.63	15.81	15.03	12.67	28.64	5.12	33.00	23.00	29.92	18.53	1.80	20.25	16.67	18.67
3.1	40.50	5.16	39.50	46.08	35.92	37.11	1.13	37.25	35.92	38.17	60.64	15.75	43.75	63.25	74.92
4.0	155.03	34.11	193.67	129.12	142.30	153.33	57.11	182.92	189.58	87.50	211.25	19.41	212.50	191.25	230.00
5.1	144.39	25.45	172.15	138.83	122.17	37.28	37.36	80.42	15.17	16.25	151.25	44.26	100.42	172.08	181.25
6.1	217.74	100.36	231.85	310.29	111.07	49.28	55.62	113.33	13.25	21.25	131.53	31.63	95.00	149.58	150.00
7.1	190.20	44.08	199.23	229.08	142.30	30.06	17.85	50.00	15.58	24.58	150.97	41.37	118.33	197.50	137.08
7.8	174.47	53.52	226.30	177.71	119.40	103.75	32.45	134.17	69.58	107.50	145.97	32.74	125.83	183.75	128.33
9.1	199.23	26.73	226.30	198.53	172.85	104.58	34.17	130.42	65.83	117.50	122.36	12.78	112.08	136.67	118.33
10.0	223.06	33.77	261.70	199.23	208.25	113.06	32.61	147.08	82.08	110.00	130.83	8.20	123.33	139.58	129.58

Appendix Table C3 Biomass of *Scenedesmus* sp. using wastewater from instant noodle factory as a medium under continuous light and aeration.

Time	Biomass (mg/L)														
	Control (BG11)			MLSS						Effluent					
Days	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3
0.0	54.30	0.33	54.49	54.49	53.93	54.56	0.48	54.27	55.12	54.30	54.76	0.75	55.25	55.15	53.89
0.8	84.55	2.04	86.91	83.42	83.32	56.09	3.58	60.21	54.37	53.71	53.93	6.44	47.01	59.74	55.03
2.1	73.80	5.55	78.23	75.59	67.57	121.81	17.39	136.61	102.66	126.14	87.47	6.10	93.32	81.15	87.94
3.1	162.08	17.51	158.69	181.04	146.52	150.57	3.84	151.05	146.52	154.16	230.46	53.47	173.12	239.33	278.95
4.0	550.98	115.82	682.19	462.98	507.77	545.22	193.92	645.67	668.31	321.67	741.88	65.89	746.12	673.97	805.54
5.1	514.84	86.41	609.12	495.98	439.41	151.14	126.87	297.62	76.06	79.74	538.14	150.29	365.53	608.88	640.01
6.1	763.90	340.78	811.83	1078.18	401.70	191.89	188.85	409.39	69.55	96.72	471.17	107.42	347.14	532.48	533.90
7.1	670.41	149.69	701.05	802.40	507.77	126.62	60.61	194.34	77.47	108.03	537.20	140.48	426.37	695.19	490.04
7.8	616.98	181.75	792.97	627.98	429.98	376.85	110.20	480.13	260.84	389.59	520.22	111.17	451.84	648.50	460.33
9.1	701.05	90.77	792.97	698.69	611.48	379.68	116.04	467.40	248.10	423.54	440.05	43.39	405.15	488.62	426.37
10.0	781.98	114.66	913.19	701.05	731.69	408.45	110.72	523.99	303.28	398.07	468.82	27.83	443.35	498.53	464.57

Appendix Table C4 Inorganic nitrogen and inorganic phosphorus during *Scenedesmus* sp. cultivation under continuous light and aeration.

Time	TAN (mg N/L)														
	Control (BG11)					MLSS					Effluent				
	Days	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2
0.0	0.44	0.11	0.55	0.45	0.33	1.32	0.15	1.42	1.40	1.15	1.24	0.10	1.27	1.32	1.13
0.8	0.22	0.04	0.24	0.17	0.24	28.13	7.42	35.19	20.40	28.79	8.71	3.47	12.71	6.65	6.76
2.1	1.27	0.68	1.96	1.25	0.60	51.82	13.42	39.55	66.15	49.75	1.51	0.69	2.29	1.00	1.24
3.1	2.84	2.36	5.48	0.92	2.14	43.42	11.60	30.14	51.57	48.55	0.93	0.71	1.70	0.76	0.31
4.0	1.54	0.28	1.23	1.60	1.79	35.04	5.49	41.14	30.49	33.49	1.40	0.12	1.54	1.36	1.31
5.1	1.25	0.10	1.33	1.14	1.29	28.62	2.06	30.39	29.12	26.36	1.16	0.12	1.20	1.02	1.25
6.1	1.15	0.43	1.44	1.37	0.66	13.38	3.09	15.76	14.49	9.89	0.81	0.24	0.68	1.09	0.67
7.1	0.63	0.27	0.91	0.37	0.61	11.98	0.66	12.63	12.01	11.31	0.36	0.12	0.23	0.41	0.45
7.8	0.45	0.17	0.32	0.63	0.39	6.64	3.56	2.53	8.64	8.76	0.56	0.21	0.43	0.80	0.45
9.1	0.88	0.34	0.59	1.25	0.78	13.27	3.64	13.14	16.97	9.69	0.73	0.63	0.78	1.34	0.08
10.0	2.14	0.30	2.26	2.36	1.80	19.59	2.04	18.78	18.07	21.91	0.42	0.04	0.44	0.45	0.37

Appendix Table C4 (Continued)

Time	Nitrite (mg N/L)														
	Control (BG11)			MLSS						Effluent					
	Days	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2
0.0	0.06	0.00	0.06	0.06	0.07	0.04	0.00	0.04	0.04	0.04	0.00	0.00	0.00	0.00	0.01
0.8	0.11	0.01	0.11	0.11	0.10	0.47	0.09	0.53	0.50	0.37	0.03	0.01	0.04	0.03	0.03
2.1	0.41	0.09	0.31	0.45	0.49	0.13	0.02	0.14	0.14	0.10	0.07	0.02	0.06	0.06	0.10
3.1	0.59	0.19	0.37	0.74	0.64	0.14	0.11	0.26	0.09	0.06	0.09	0.04	0.04	0.11	0.12
4.0	0.85	0.34	0.48	1.16	0.91	0.03	0.02	0.05	0.02	0.01	0.08	0.04	0.08	0.13	0.05
5.1	1.27	0.53	0.72	1.77	1.32	0.03	0.00	0.03	0.02	0.03	0.23	0.11	0.11	0.33	0.25
6.1	1.58	0.72	0.82	2.25	1.66	0.03	0.01	0.02	0.03	0.04	0.31	0.16	0.14	0.46	0.34
7.1	1.88	0.99	0.83	2.80	2.00	0.03	0.01	0.03	0.02	0.04	0.47	0.25	0.19	0.70	0.52
7.8	2.71	1.18	1.59	3.93	2.60	0.02	0.01	0.03	0.02	0.01	0.46	0.24	0.18	0.59	0.59
9.1	2.90	1.13	1.81	4.07	2.82	0.04	0.03	0.03	0.06	0.01	0.37	0.07	0.31	0.45	0.36
10.0	3.74	1.21	2.41	4.76	4.04	0.06	0.06	0.02	0.12	0.03	0.35	0.13	0.22	0.48	0.36

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Appendix Table C4 (Continued)

Time	Nitrate (mg N/L)														
	Control (BG11)						MLSS					Effluent			
	Days	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2
0.0	260.29	6.94	258.17	268.04	254.67	44.77	3.63	40.59	47.25	46.46	46.28	0.38	46.50	45.84	46.50
0.8	256.41	5.30	252.49	262.44	254.29	27.38	5.78	34.06	24.20	23.89	49.89	3.58	45.79	52.40	51.47
2.1	248.70	5.61	248.16	254.57	243.38	27.16	4.36	31.79	23.12	26.56	46.86	4.66	46.64	42.31	51.63
3.1	240.89	12.18	243.08	251.83	227.77	21.51	4.40	26.25	17.56	20.73	43.60	3.22	39.96	46.05	44.80
4.0	240.46	11.28	227.45	247.43	246.52	22.82	4.36	23.09	27.04	18.34	42.08	6.25	49.29	38.38	38.56
5.1	234.15	3.68	237.74	230.38	234.31	20.84	4.38	19.36	17.38	25.77	34.46	0.83	35.41	34.13	33.84
6.1	238.65	10.85	234.11	230.81	251.03	27.47	3.10	29.39	29.12	23.90	35.46	1.43	34.00	35.52	36.86
7.1	215.98	12.67	224.42	201.41	222.11	21.22	4.89	19.08	17.77	26.81	37.27	2.70	40.28	36.49	35.06
7.8	230.24	14.99	214.53	231.80	244.39	19.74	0.67	20.00	20.23	18.97	31.91	0.20	31.70	31.92	32.10
9.1	223.22	9.59	212.18	229.45	228.05	19.03	1.60	20.07	17.18	19.83	30.22	1.82	32.20	29.84	28.61
10.0	207.41	9.12	197.08	210.76	214.38	22.57	1.83	24.29	22.76	20.65	29.75	0.81	29.22	30.69	29.35

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Appendix Table C4 (Continued)

Time	Phosphate (mg P/L)														
	Control (BG11)						MLSS					Effluent			
	Days	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2
0.0	1.94	0.62	2.62	1.40	1.79	1.82	0.38	1.38	2.01	2.07	1.10	0.04	1.14	1.06	1.10
0.8	1.40	1.72	3.38	0.48	0.34	0.90	0.72	0.90	1.63	0.18	0.56	0.18	0.39	0.57	0.74
2.1	1.10	1.20	2.48	0.48	0.33	0.64	0.56	0.25	1.28	0.39	0.39	0.11	0.27	0.48	0.43
3.1	1.30	0.41	1.25	1.73	0.91	0.43	0.11	0.42	0.53	0.32	0.12	0.04	0.10	0.09	0.16
4.0	1.48	0.39	1.44	1.90	1.11	0.49	0.07	0.57	0.46	0.44	0.16	0.04	0.17	0.20	0.13
5.1	1.58	1.15	0.86	2.91	0.98	0.46	0.08	0.50	0.51	0.37	0.10	0.07	0.02	0.15	0.13
6.1	0.68	0.22	0.70	0.90	0.45	0.35	0.03	0.36	0.38	0.32	0.07	0.04	0.03	0.06	0.12
7.1	0.59	0.10	0.60	0.67	0.48	0.53	0.06	0.60	0.50	0.49	0.11	0.02	0.09	0.13	0.09
7.8	1.08	0.14	1.20	1.09	0.93	0.44	0.05	0.48	0.45	0.39	0.27	0.13	0.41	0.17	0.21
9.1	0.90	0.12	0.87	1.03	0.79	0.40	0.04	0.44	0.39	0.36	0.05	0.01	0.04	0.05	0.07
10.0	0.24	0.03	0.27	0.23	0.22	0.37	0.05	0.43	0.35	0.34	0.04	0.01	0.03	0.04	0.06

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Appendix Table C5 Chemical oxygen demand (COD) during initial and final day of microalgae cultivation in wastewater from instant noodle factory under continuous light and aeration.

Wastewater	Total COD (mg/L)														
	Initial					Final					% Reduction				
	AV	SD	1	2	3	AV	SD	1	2	3	AV	SD	1	2	3
MLSS	3366.00	200.92	3250.00	3598.00	3250.00	942.33	111.24	1065.00	848.00	914.00	71.85	4.60	67.23	76.43	71.88
Effluent	198.33	6.51	192.00	205.00	198.00	119.33	13.32	116.00	134.00	108.00	39.89	5.42	39.58	34.63	45.45

Wastewater	Soluble COD (mg/L)														
	Initial					Final					% Reduction				
	AV	SD	1	2	3	AV	SD	1	2	3	AV	SD	1	2	3
MLSS	367.16	8.08	375.57	366.45	359.45	119.33	11.02	114.00	132.00	112.00	67.49	3.07	69.65	63.98	68.84
Effluent	148.88	10.81	137.56	159.10	149.98	39.31	4.24	44.20	36.54	37.20	73.37	4.85	67.87	77.03	75.20

Appendix Table C6 Cell density of *Scenedesmus* sp. cultivation in MLSS or effluent.

Cell density (10^4 cell/mL)																			
T1 (MLSS)					T2 (MLSS with phosphate addition)					T3 (Effluent)					T4 (Effluent with phosphate addition)				
Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3
6.78	0.63	7.11	7.17	6.06	7.00	0.60	7.17	6.33	7.50	7.11	0.35	7.50	6.83	7.00	6.35	0.21	6.44	6.11	6.50
8.38	1.46	6.78	8.74	9.63	7.73	1.38	7.13	6.76	9.31	10.42	1.68	8.48	11.43	11.35	11.28	1.15	10.04	12.31	11.48
19.50	4.89	15.50	18.06	24.94	23.64	2.40	25.44	20.91	24.56	23.04	7.49	14.67	25.33	29.11	22.89	11.11	15.56	35.67	17.44
49.72	12.08	60.50	52.00	36.67	46.89	23.49	32.50	74.00	34.17	43.11	14.68	32.33	37.17	59.83	40.94	23.78	16.50	64.00	42.33
51.72	5.93	58.17	46.50	50.50	65.72	9.17	59.00	76.17	62.00	44.06	13.28	37.50	35.33	59.33	51.17	15.23	47.17	68.00	38.33
31.50	8.66	36.33	21.50	36.67	134.72	42.54	85.83	163.33	155.00	44.50	24.36	32.83	28.17	72.50	81.33	53.70	51.33	143.33	49.33
24.80	14.56	24.83	10.22	39.33	112.33	34.39	84.67	101.50	150.83	45.00	25.50	28.17	74.33	32.50	80.11	42.76	46.83	128.33	65.17
28.14	23.73	18.50	10.75	55.17	99.28	18.43	78.00	110.33	109.50	63.72	8.25	55.33	64.00	71.83	72.39	17.68	60.17	92.67	64.33
38.73	26.19	30.00	18.03	68.17	134.06	28.41	148.33	152.50	101.33	89.44	66.19	26.33	158.33	83.67	112.94	88.30	47.33	213.33	78.17
34.10	21.93	25.67	17.65	59.00	177.22	22.08	161.67	167.50	202.50	128.67	90.24	25.17	170.00	190.83	122.72	83.74	28.17	187.50	152.50
33.27	16.95	23.00	23.97	52.83	125.50	71.38	43.17	170.00	163.33	124.02	99.00	10.39	191.67	170.00	111.65	126.45	15.94	255.00	64.00

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Appendix Table C7 Biomass of *Scenedesmus* sp. cultivation in MLSS or effluent.

Biomass (mg /L)																			
T1 (MLSS)					T2 (MLSS with phosphate addition)					T3 (Effluent)					T4 (Effluent with phosphate addition)				
Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3
47.57	2.13	48.71	48.89	45.12	48.33	2.04	48.89	46.06	50.03	48.71	1.18	50.03	47.76	48.33	46.13	0.71	46.44	45.31	46.63
53.02	4.95	47.57	54.24	57.26	50.82	4.69	48.77	47.51	56.19	59.94	5.70	53.36	63.36	63.11	62.85	3.91	58.64	66.38	63.55
90.77	16.59	77.19	85.87	109.26	104.82	8.16	110.96	95.55	107.94	102.78	25.44	74.36	110.58	123.41	102.28	37.71	77.38	145.67	83.79
193.40	41.01	229.99	201.13	149.06	183.77	79.77	134.92	275.83	140.58	170.95	49.85	134.35	150.76	227.73	163.59	80.75	80.59	241.88	168.31
200.19	20.13	222.07	182.45	196.04	247.73	31.13	224.90	283.19	235.09	174.15	45.08	151.89	144.54	226.03	198.30	51.72	184.72	255.46	154.72
131.52	29.41	147.93	97.56	149.06	482.02	144.46	316.01	579.17	550.88	175.66	82.72	136.05	120.20	270.74	300.73	182.35	198.87	511.26	192.08
108.76	49.42	108.88	59.27	158.12	406.00	116.77	312.05	369.21	536.73	177.36	86.57	120.20	276.96	134.92	296.58	145.18	183.59	460.33	245.84
120.11	80.56	87.38	61.06	211.88	361.67	62.59	289.42	399.21	396.38	240.93	28.03	212.45	241.88	268.48	270.36	60.05	228.86	339.22	243.01
156.08	88.91	126.43	85.77	256.03	479.76	96.48	528.24	542.39	368.65	328.28	224.75	113.98	562.19	308.66	408.07	299.82	185.28	748.95	289.98
140.37	74.46	111.71	84.49	224.90	626.33	74.99	573.51	593.32	712.17	461.46	306.41	110.02	601.81	672.55	441.27	284.33	120.20	661.23	542.39
137.53	57.56	102.66	105.96	203.96	450.71	242.38	171.14	601.81	579.17	445.68	336.17	59.84	675.38	601.81	403.67	429.37	78.70	890.43	241.88

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Appendix Table C8 Inorganic nitrogen and inorganic phosphorus profile during *Scenedesmus* sp. cultivation in MLSS or effluent.

Time	TAN (mg N/L)																			
	T1 (MLSS)					T2 (MLSS with phosphate addition)					T3 (Effluent)					T4 (Effluent with phosphate addition)				
	Days	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2
0.0	8.76	0.98	9.23	9.42	7.64	8.76	0.98	9.23	9.42	7.64	3.34	0.27	3.65	3.14	3.22	3.34	0.27	3.65	3.14	3.22
1.0	18.60	1.35	20.05	17.38	18.36	20.94	2.84	24.10	18.60	20.11	1.60	0.33	1.22	1.81	1.77	1.95	0.37	1.63	1.87	2.36
2.0	27.84	5.18	33.47	23.28	26.76	28.86	6.24	29.75	22.23	34.61	2.79	0.72	3.37	3.01	1.99	2.59	1.70	3.82	0.65	3.29
3.0	24.12	4.53	29.18	22.72	20.45	25.51	4.43	29.07	20.54	26.91	1.59	1.26	2.90	1.48	0.39	2.39	1.87	4.02	0.34	2.80
4.0	23.62	15.37	36.36	27.94	6.55	23.31	2.19	25.25	20.94	23.73	1.34	0.51	1.79	1.44	0.78	6.09	6.32	3.53	1.45	13.29
5.0	36.06	7.22	44.22	33.49	30.48	19.46	3.55	21.61	15.36	21.42	1.35	1.41	2.88	1.06	0.10	8.54	6.11	3.34	15.27	7.00
7.0	29.56	11.52	39.62	32.07	17.00	18.99	9.36	16.22	11.33	29.42	1.78	1.80	3.74	1.40	0.21	1.18	1.20	2.54	0.74	0.26
8.0	29.93	20.86	45.59	37.94	6.25	14.01	4.21	16.98	9.19	15.86	1.59	1.61	3.41	1.01	0.35	4.71	3.86	3.16	1.87	9.11
9.0	39.91	23.89	62.91	41.61	15.22	11.50	3.99	11.31	7.60	15.58	2.37	1.76	3.33	0.33	3.44	0.37	0.30	0.21	0.72	0.18
10.0	38.75	18.21	53.28	44.64	18.32	11.57	5.97	12.68	5.12	16.90	0.57	0.95	1.67	0.05	0.00	0.22	0.38	0.66	0.00	0.00

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Appendix Table C8 (Continued)

Time	Nitrite (mg N/L)																			
	T1 (MLSS)					T2 (MLSS with phosphate addition)					T3 (Effluent)					T4 (Effluent with phosphate addition)				
	Days	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2
0.0	0.12	0.01	0.11	0.11	0.13	0.09	0.01	0.10	0.08	0.10	0.02	0.01	0.01	0.02	0.02	0.03	0.01	0.03	0.03	0.04
1.0	0.40	0.04	0.38	0.44	0.37	0.34	0.04	0.32	0.38	0.31	0.04	0.03	0.02	0.02	0.07	0.05	0.03	0.02	0.08	0.05
2.0	0.35	0.02	0.33	0.34	0.37	0.39	0.06	0.36	0.46	0.34	0.08	0.05	0.03	0.08	0.13	0.14	0.10	0.05	0.24	0.14
3.0	0.11	0.05	0.06	0.11	0.16	0.21	0.14	0.17	0.37	0.10	0.18	0.22	0.02	0.08	0.43	0.32	0.25	0.09	0.59	0.27
4.0	0.13	0.15	0.06	0.03	0.31	0.09	0.02	0.07	0.11	0.08	0.27	0.19	0.25	0.09	0.46	0.23	0.17	0.10	0.42	0.17
5.0	0.04	0.00	0.04	0.04	0.04	0.19	0.24	0.46	0.03	0.07	0.26	0.25	0.07	0.17	0.54	0.17	0.15	0.13	0.04	0.33
7.0	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.00	0.30	0.29	0.06	0.22	0.63	0.33	0.20	0.14	0.31	0.53
8.0	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.00	0.00	0.10	0.23	0.14	0.07	0.30	0.31	0.13	0.15	0.05	0.30	0.03
9.0	0.01	0.00	0.01	0.01	0.01	0.02	0.02	0.01	0.05	0.01	0.26	0.16	0.09	0.41	0.29	0.37	0.27	0.07	0.42	0.61
10.0	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.36	0.26	0.08	0.42	0.58	0.29	0.27	0.04	0.25	0.57

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Appendix Table C8 (Continued)

Time	Nitrate (mg N/L)																			
	T1 (MLSS)					T2 (MLSS with phosphate addition)					T3 (Effluent)					T4 (Effluent with phosphate addition)				
	Days	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2
0.0	35.58	1.36	34.03	36.56	36.14	36.37	2.37	36.93	33.77	38.42	42.23	1.49	40.72	42.26	43.70	43.70	0.67	44.47	43.35	43.28
1.0	25.27	2.72	22.14	27.02	26.65	24.02	0.47	23.49	24.17	24.39	41.96	2.55	43.58	43.28	39.02	44.12	1.08	44.99	42.91	44.46
2.0	11.55	2.69	8.91	14.28	11.45	8.53	1.39	7.08	9.85	8.67	41.05	2.10	41.66	42.77	38.71	41.04	1.03	42.03	39.97	41.12
3.0	10.28	1.30	9.02	11.62	10.21	4.41	0.20	4.40	4.61	4.21	41.26	3.20	43.98	42.06	37.74	40.46	2.35	42.01	37.75	41.61
4.0	2.95	0.26	3.19	2.68	2.99	3.70	0.03	3.73	3.69	3.68	38.91	2.05	40.14	40.05	36.54	36.15	6.27	43.38	32.95	32.13
5.0	4.03	0.51	4.62	3.68	3.80	4.78	1.58	3.81	3.92	6.60	38.08	4.31	40.70	40.43	33.11	33.73	8.86	43.51	26.23	31.44
7.0	3.80	0.86	4.73	3.03	3.64	4.42	0.25	4.68	4.18	4.40	32.75	7.16	38.21	35.40	24.64	35.05	7.17	42.37	28.03	34.75
8.0	3.49	0.27	3.79	3.42	3.26	4.78	0.25	5.01	4.81	4.52	34.52	6.18	40.68	34.54	28.33	34.12	9.16	44.31	26.57	31.49
9.0	3.98	0.45	4.41	3.52	4.01	4.50	1.21	3.50	5.85	4.15	36.19	9.66	45.26	37.29	26.03	29.35	6.98	25.59	25.05	37.40
10.0	3.67	0.61	4.16	2.99	3.87	3.87	0.47	4.41	3.66	3.54	29.91	9.74	39.62	29.95	20.15	29.42	13.44	40.48	14.46	33.33

Appendix Table C8 (Continued)

Time	Phosphate (mg P/L)																			
	T1 (MLSS)					T2 (MLSS with phosphate addition)					T3 (Effluent)					T4 (Effluent with phosphate addition)				
Days	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3
0.0	0.22	0.06	0.15	0.25	0.27	0.30	0.08	0.29	0.22	0.38	0.46	0.03	0.47	0.42	0.48	0.46	0.04	0.44	0.44	0.51
1.0	0.19	0.02	0.17	0.20	0.20	0.29	0.04	0.26	0.27	0.34	0.21	0.06	0.20	0.27	0.16	0.18	0.01	0.18	0.18	0.19
2.0	0.12	0.03	0.11	0.10	0.15	0.41	0.15	0.51	0.48	0.23	0.23	0.13	0.13	0.17	0.38	0.23	0.15	0.40	0.13	0.16
3.0	0.11	0.02	0.11	0.10	0.13	0.21	0.01	0.21	0.22	0.20	0.10	0.02	0.08	0.11	0.11	0.12	0.02	0.14	0.11	0.11
4.0	0.03	0.01	0.02	0.04	0.04	0.11	0.09	0.08	0.21	0.04	0.02	0.01	0.01	0.01	0.03	0.06	0.04	0.06	0.09	0.02
4.0	0.07	0.04	0.02	0.10	0.08	0.36	0.05	0.37	0.30	0.40	0.02	0.01	0.03	0.01	0.02	0.45	0.04	0.41	0.45	0.49
5.0	0.04	0.04	0.09	0.02	0.02	0.31	0.18	0.49	0.32	0.13	0.02	0.00	0.02	0.02	0.02	0.26	0.10	0.37	0.19	0.21
7.0	0.15	0.02	0.17	0.13	0.16	0.34	0.01	0.35	0.34	0.33	0.13	0.05	0.10	0.10	0.19	0.18	0.09	0.28	0.11	0.15
8.0	0.22	0.06	0.28	0.16	0.22	0.45	0.06	0.49	0.47	0.38	0.12	0.02	0.10	0.11	0.14	0.15	0.05	0.19	0.10	0.17
9.0	0.26	0.08	0.33	0.28	0.18	0.43	0.22	0.26	0.68	0.35	0.06	0.01	0.07	0.05	0.07	0.14	0.05	0.19	0.09	0.13
10.0	0.06	0.02	0.08	0.05	0.05	0.19	0.12	0.27	0.25	0.06	0.01	0.01	0.00	0.01	0.01	0.03	0.03	0.07	0.02	0.01

Appendix Table C9 Chemical oxygen demand (COD) during initial and final day of microalgae cultivation in MLSS or effluent.

Treatment	Total COD (mg/L)														
	Initial					Final					% Reduction				
	AV	SD	1	2	3	AV	SD	1	2	3	AV	SD	1	2	3
T1 (MLSS)	7407.41	855.33	7901.23	7901.23	6419.75	1072.80	351.16	1379.31	689.66	1149.43	85.30	5.17	82.54	91.27	82.10
T2 (MLSS with phosphate addition)	7407.41	855.33	7901.23	7901.23	6419.75	804.60	304.11	919.54	1034.48	459.77	89.37	3.09	88.36	86.91	92.84
T3 (Effluent)	118.52	17.11	108.64	138.27	108.64	90.42	11.57	101.15	91.95	78.16	22.82	14.05	6.90	33.50	28.06
T4 (Effluent with phosphate addition)	118.52	17.11	108.64	138.27	108.64	79.69	10.62	91.95	73.56	73.56	31.48	15.73	15.36	46.80	32.29
Treatment	Soluble COD (mg/L)														
	Initial					Final					% Reduction				
	AV	SD	1	2	3	AV	SD	1	2	3	AV	SD	1	2	3
T1 (MLSS)	306.17	34.21	345.68	286.42	286.42	32.18	20.04	18.39	55.17	22.99	89.13	7.39	94.68	80.74	91.97
T2 (MLSS with phosphate addition)	306.17	34.21	345.68	286.42	286.42	193.10	9.20	193.10	202.30	183.91	36.43	7.40	44.14	29.37	35.79
T3 (Effluent)	59.26	17.11	79.01	49.38	49.38	42.91	5.31	45.98	36.78	45.98	24.74	17.47	41.81	25.52	6.90
T4 (Effluent with phosphate addition)	59.26	17.11	79.01	49.38	49.38	39.85	10.62	45.98	27.59	45.98	30.95	20.86	41.81	44.14	6.90

Appendix Table C10 Cell density of *Scenedesmus* sp. using MLSS wastewater from instant noodle factory as a medium with aeration or external carbon dioxide supplement under continuous illumination or 12:12 h light: dark cycle.

Cell density (10^4 cell/mL)																			
T1 (Control; continuous light and continuous aeration)					T2 (Carbon dioxide supplement under continuous light)					T3 (12:12h light:dark cycle with continuous aeration)					T4 (12:12h light:dark cycle with carbon dioxide supplement)				
Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3
6.44	0.29	6.45	6.15	6.73	6.35	0.14	6.22	6.33	6.50	6.11	0.35	6.50	5.83	6.00	6.02	0.54	5.44	6.11	6.50
8.45	0.31	8.52	8.11	8.71	8.10	0.45	7.77	8.61	7.92	9.53	1.79	7.48	10.76	10.35	10.16	0.98	9.08	11.01	10.38
19.18	1.27	18.34	18.56	20.65	17.22	2.54	19.11	18.22	14.34	19.99	7.33	12.67	27.33	19.98	16.95	1.35	16.66	15.77	18.43
42.76	1.79	40.71	43.56	44.00	37.59	1.91	35.44	39.11	38.22	36.67	4.92	34.11	33.55	42.34	29.07	14.24	17.89	24.22	45.11
55.08	2.61	53.00	54.23	58.00	45.78	2.93	49.11	44.65	43.58	46.07	6.90	47.55	52.11	38.55	43.85	4.68	39.45	43.33	48.77
40.26	3.28	43.11	41.00	36.67	43.29	2.22	43.22	41.11	45.55	48.78	10.53	46.55	60.25	39.55	39.05	0.91	39.65	38.00	39.51
30.11	2.03	29.11	28.77	32.44	36.63	2.88	39.23	33.54	37.11	46.56	11.35	42.39	59.41	37.89	29.82	8.61	39.11	28.23	22.11
16.55	1.64	15.45	18.44	15.77	23.00	4.85	18.45	22.43	28.11	33.00	15.06	19.89	49.45	29.67	16.43	5.42	10.18	19.23	19.87
24.78	4.93	27.23	19.11	28.00	18.12	2.22	19.98	18.72	15.67	19.48	3.88	16.23	18.44	23.77	15.95	4.32	10.98	18.71	18.17
20.44	3.31	18.99	18.11	24.23	20.26	1.17	19.11	20.22	21.45	21.49	3.19	20.26	19.09	25.11	14.31	4.61	10.87	19.55	12.50
19.74	2.53	18.99	17.67	22.56	19.34	0.32	19.58	18.98	19.45	14.30	2.67	14.22	11.67	17.00	16.32	6.29	9.23	21.22	18.51

Appendix Table C11 Biomass of *Scenedesmus* sp. using MLSS wastewater from instant noodle factory as a medium with aeration or external carbon dioxide supplement under continuous illumination or 12:12 h light: dark cycle.

Biomass (mg /L)																			
T1 (Control; continuous light and continuous aeration)					T2 (Carbon dioxide supplement under continuous light)					T3 (12:12h light:dark cycle with continuous aeration)					T4 (12:12h light:dark cycle with carbon dioxide supplement)				
Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3
46.44	0.98	46.46	45.44	47.41	46.12	0.48	45.68	46.05	46.63	45.31	1.18	46.63	44.36	44.93	44.99	1.82	43.03	45.31	46.63
53.24	1.04	53.49	52.10	54.14	52.06	1.52	50.94	53.80	51.45	56.92	6.07	49.96	61.10	59.70	59.05	3.34	55.39	61.94	59.81
89.70	4.33	86.83	87.58	94.68	83.04	8.61	89.45	86.43	73.25	92.45	24.89	67.58	117.36	92.40	82.13	4.60	81.13	78.11	87.14
169.74	6.06	162.79	172.47	173.97	152.20	6.50	144.90	157.36	154.34	149.06	16.71	140.38	138.48	168.33	123.28	48.37	85.31	106.80	177.73
211.58	8.85	204.53	208.70	221.50	180.01	9.96	191.32	176.17	172.54	180.99	23.43	186.02	201.50	155.46	173.46	15.90	158.52	171.69	190.16
161.26	11.15	170.94	163.78	149.06	171.57	7.54	171.32	164.15	179.23	190.21	35.75	182.62	229.14	158.86	157.17	3.11	159.19	153.59	158.72
126.79	6.89	123.41	122.25	134.71	148.93	9.76	157.77	138.45	150.57	182.67	38.54	168.50	226.29	153.22	125.80	29.24	157.36	120.42	99.64
80.77	5.57	77.02	87.17	78.11	102.65	16.49	87.21	100.72	120.01	136.63	51.14	92.10	192.47	125.31	80.34	18.40	59.13	89.86	92.03
108.70	16.72	117.02	89.45	119.64	86.10	7.52	92.40	88.12	77.77	90.71	13.16	79.67	87.17	105.27	78.73	14.65	61.84	88.09	86.26
93.98	11.24	89.04	86.05	106.83	93.35	3.97	89.45	93.22	97.39	97.52	10.84	93.35	89.38	109.82	73.14	15.67	61.47	90.94	67.00
91.59	8.59	89.04	84.56	101.16	90.22	1.07	91.05	89.01	90.60	73.11	9.05	72.84	64.19	82.28	79.98	21.35	55.90	96.61	87.41

Appendix Table C12 Inorganic nitrogen and inorganic phosphorus during *Scenedesmus* sp. cultivation with CO₂ supplement and various lighting period.

TAN (mg N/L)																				
Time	T1 (Control; continuous light and continuous aeration)					T2 (Carbon dioxide supplement under continuous light)					T3 (12:12h light:dark cycle with continuous aeration)					T4 (12:12h light:dark cycle with carbon dioxide supplement)				
Days	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3
0.0	6.81	0.94	6.43	6.12	7.88	6.44	0.79	5.78	6.22	7.31	6.12	0.31	6.24	6.35	5.76	5.37	1.21	4.13	6.54	5.43
1.0	26.97	4.73	21.55	30.22	29.15	26.60	6.63	22.13	23.44	34.22	28.78	2.19	30.56	29.45	26.33	22.36	2.74	19.22	23.65	24.22
2.0	22.50	0.14	22.34	22.54	22.62	22.51	2.67	21.88	20.22	25.44	30.68	11.32	19.54	42.18	30.33	22.92	4.61	28.19	19.65	20.91
3.0	29.06	7.59	20.38	34.45	32.34	26.03	1.40	24.55	26.22	27.33	24.23	2.53	23.25	22.34	27.11	24.48	2.00	22.44	26.43	24.57
4.0	24.02	2.19	26.45	23.44	22.18	25.70	6.31	24.11	20.33	32.65	25.84	1.51	24.65	27.54	25.33	28.89	1.53	30.25	27.23	29.18
5.0	25.38	6.35	23.15	20.45	32.55	19.52	2.63	22.48	18.65	17.44	19.14	1.68	19.86	17.22	20.33	34.54	16.33	23.34	53.27	27.00
7.0	30.06	0.57	30.54	30.22	29.43	16.26	3.16	16.77	19.13	12.88	27.92	1.68	29.43	26.11	28.22	23.60	2.58	22.54	21.73	26.54
8.0	27.95	1.55	26.44	27.88	29.54	11.92	9.25	19.56	14.56	1.63	21.59	1.69	22.65	22.48	19.65	21.05	2.03	23.16	20.87	19.11
9.0	24.55	2.71	22.65	23.35	27.65	18.58	0.95	19.54	18.55	17.65	28.71	1.28	30.14	28.33	27.66	20.36	0.95	21.00	19.27	20.81
10.0	20.34	0.80	19.67	20.13	21.22	19.61	0.56	19.65	19.04	20.15	23.46	0.97	22.65	24.53	23.21	21.34	1.33	22.66	20.00	21.35

Appendix Table C12 (Continued)

Time	Nitrite (mg N/L)																			
	T1 (Control; continuous light and continuous aeration)					T2 (Carbon dioxide supplement under continuous light)					T3 (12:12h light:dark cycle with continuous aeration)					T4 (12:12h light:dark cycle with carbon dioxide supplement)				
Days	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3
0.0	0.24	0.01	0.23	0.25	0.23	0.26	0.05	0.30	0.28	0.20	0.21	0.01	0.22	0.20	0.20	0.26	0.06	0.21	0.32	0.24
1.0	1.49	0.21	1.33	1.41	1.73	0.76	0.10	0.87	0.69	0.71	1.16	0.08	1.20	1.22	1.07	0.83	0.04	0.82	0.88	0.80
2.0	0.56	0.02	0.55	0.56	0.58	0.29	0.06	0.26	0.36	0.24	0.56	0.41	0.80	0.79	0.09	0.65	0.10	0.55	0.74	0.65
3.0	0.12	0.03	0.10	0.11	0.16	0.03	0.02	0.01	0.03	0.05	0.14	0.03	0.12	0.18	0.13	0.32	0.06	0.39	0.29	0.27
4.0	0.20	0.10	0.16	0.13	0.32	0.02	0.01	0.01	0.03	0.01	0.02	0.02	0.02	0.01	0.04	0.00	0.00	0.00	0.00	0.00
5.0	0.04	0.00	0.04	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.06	0.01	0.07	0.07	0.05	0.03	0.02	0.01	0.04	0.03
7.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.00	0.00	0.06	0.00	0.01	0.00	0.00	0.01
8.0	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.00	0.00	0.10	0.01	0.02	0.00	0.00	0.04	0.01	0.02	0.00	0.03	0.00
9.0	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.0	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.03	0.01

Appendix Table C12 (Continued)

Time	Nitrate (mg N/L)																			
	T1 (Control; continuous light and continuous aeration)					T2 (Carbon dioxide supplement under continuous light)					T3 (12:12h light:dark cycle with continuous aeration)					T4 (12:12h light:dark cycle with carbon dioxide supplement)				
Days	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3
0.0	45.20	1.19	44.05	46.43	45.13	43.04	4.30	46.93	43.77	38.42	44.07	1.60	42.27	44.62	45.32	44.92	1.37	43.77	44.56	46.43
1.0	37.99	1.94	40.19	37.23	36.55	40.62	5.41	43.29	44.17	34.39	40.55	1.44	40.13	39.36	42.15	41.41	2.13	40.12	40.24	43.87
2.0	41.08	1.89	38.91	42.34	41.98	38.09	0.88	37.08	38.55	38.65	39.57	1.07	40.15	38.34	40.23	37.22	1.93	39.34	36.78	35.55
3.0	40.80	0.68	40.65	41.55	40.21	36.73	3.39	40.13	36.72	33.35	37.70	1.19	37.64	38.92	36.55	37.11	1.27	36.54	38.57	36.23
4.0	36.15	3.20	36.78	32.68	38.99	35.74	1.63	36.71	36.65	33.86	36.13	0.72	36.32	36.73	35.33	34.38	0.89	33.36	34.76	35.01
5.0	34.57	1.54	36.34	33.56	33.80	36.76	2.64	33.98	39.24	37.06	37.39	2.01	39.43	35.41	37.32	33.22	0.84	33.51	32.27	33.88
7.0	34.23	0.80	34.73	33.30	34.65	37.81	4.65	36.22	34.17	43.05	35.68	0.90	36.15	36.24	34.64	34.68	2.02	32.47	36.43	35.14
8.0	34.81	1.23	33.97	34.23	36.22	35.69	2.86	35.23	33.09	38.76	35.38	1.99	37.54	33.61	35.00	32.83	3.45	30.25	36.75	31.49
9.0	33.59	1.94	31.44	35.22	34.10	32.44	3.39	32.09	29.24	36.00	33.77	0.61	34.03	34.21	33.08	32.61	2.41	30.18	35.00	32.65
10.0	33.67	0.61	34.16	32.99	33.87	35.43	3.48	39.44	33.65	33.21	32.34	1.41	32.05	31.09	33.87	32.77	1.14	32.05	32.18	34.09

Appendix Table C12 (Continued)

Time	Phosphate (mg P/L)																			
	T1 (Control; continuous light and continuous aeration)					T2 (Carbon dioxide supplement under continuous light)					T3 (12:12h light:dark cycle with continuous aeration)					T4 (12:12h light:dark cycle with carbon dioxide supplement)				
Days	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3	Average	SD	1	2	3
0.0	0.55	0.02	0.54	0.55	0.57	0.56	0.02	0.55	0.56	0.58	0.56	0.03	0.57	0.58	0.52	0.57	0.05	0.54	0.54	0.62
1.0	0.41	0.02	0.43	0.40	0.40	0.39	0.04	0.36	0.37	0.44	0.31	0.06	0.29	0.37	0.26	0.28	0.01	0.28	0.28	0.29
2.0	0.18	0.04	0.21	0.19	0.14	0.21	0.08	0.21	0.28	0.13	0.20	0.07	0.14	0.19	0.28	0.14	0.09	0.14	0.23	0.06
3.0	0.05	0.02	0.03	0.06	0.05	0.06	0.04	0.02	0.06	0.10	0.08	0.02	0.08	0.07	0.10	0.05	0.04	0.09	0.03	0.02
4.0	0.04	0.01	0.03	0.05	0.03	0.04	0.02	0.05	0.02	0.04	0.08	0.07	0.04	0.03	0.16	0.04	0.02	0.06	0.05	0.02
5.0	0.05	0.02	0.06	0.06	0.03	0.02	0.01	0.01	0.03	0.02	0.12	0.02	0.14	0.11	0.12	0.04	0.04	0.08	0.00	0.04
7.0	0.01	0.01	0.02	0.01	0.01	0.04	0.01	0.05	0.03	0.05	0.04	0.01	0.04	0.03	0.05	0.04	0.03	0.08	0.02	0.02
8.0	0.04	0.02	0.03	0.06	0.03	0.02	0.02	0.01	0.02	0.04	0.04	0.02	0.02	0.05	0.04	0.05	0.05	0.09	0.05	0.00
9.0	0.02	0.02	0.01	0.04	0.02	0.03	0.03	0.00	0.03	0.05	0.01	0.02	0.03	0.01	0.00	0.05	0.05	0.10	0.04	0.00
10.0	0.03	0.02	0.01	0.05	0.02	0.04	0.03	0.01	0.04	0.06	0.00	0.01	0.00	0.01	0.00	0.02	0.02	0.03	0.04	0.00

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Appendix Table C13 COD during initial and final day of *Scenedesmus* sp. cultivation with CO₂ supplement and various lighting period.

Treatment	Total COD (mg/L)														
	Initial						Final						% Reduction		
	AV	SD	1	2	3	AV	SD	1	2	3	AV	SD	1	2	3
T1 (Control; continuous light and continuous aeration)	6355.43	150.92	6203.29	6357.88	6505.11	1717.66	82.37	1765.22	1622.55	1765.22	72.96	1.47	71.54	74.48	72.86
T2 (Carbon dioxide supplement under continuous light)	5947.81	81.86	5900.55	5900.55	6042.34	2674.72	59.98	2605.47	2709.35	2709.35	55.03	0.89	55.84	54.08	55.16
T3 (12:12h light:dark cycle with continuous aeration)	6202.98	302.28	6203.29	6505.11	5900.55	1782.07	168.57	1958.43	1765.22	1622.55	71.26	2.46	68.43	72.86	72.50
T4 (12:12h light:dark cycle with carbon dioxide supplement)	6100.29	234.09	6357.88	6042.43	5900.55	2640.03	60.03	2605.47	2605.27	2709.35	56.66	2.48	59.02	56.88	54.08

Appendix Table C13 (Continued)

Treatment	Soluble COD (mg/L)														
	Initial					Final					% Reduction				
	AV	SD	1	2	3	AV	SD	1	2	3	AV	SD	1	2	3
T1 (Control; continuous light and continuous aeration)	403.69	50.24	432.69	345.68	432.69	63.23	13.96	55.17	55.17	79.35	84.32	2.80	87.25	84.04	81.66
T2 (Carbon dioxide supplement under continuous light)	374.68	50.24	345.68	345.68	432.69	100.96	19.83	79.35	105.22	118.32	73.09	3.76	77.05	69.56	72.65
T3 (12:12h light:dark cycle with continuous aeration)	418.25	66.54	476.38	345.68	432.69	71.29	13.96	79.35	79.35	55.17	82.55	5.15	83.34	77.05	87.25
T4 (12:12h light:dark cycle with carbon dioxide supplement)	418.25	66.54	476.38	345.68	432.69	109.59	7.56	105.22	105.22	118.32	73.38	4.22	77.91	69.56	72.65

Appendix Table C14 Cell density of microalgae cultivated in wastewater under outdoor semi continuous experiment in trial 1.

Cell Density of <i>Scenedesmus</i> sp. (10^4 cell/mL)												
Date	Hours	Days	T1-1 (Continuous aeration)					T1-2 (Continuous external CO ₂ supplement)				
			AV	SD	1	2	3	AV	SD	1	2	3
18/12/2556	0	0.0	274.07	27.28	298.15	244.44	279.63	231.11	17.96	250.37	228.15	214.81
20/12/2556	48	2.0	258.02	40.42	250.00	301.85	222.22	214.49	30.16	179.75	234.07	229.63
21/12/2556	72	3.0	255.56	56.14	320.37	224.07	222.22	217.28	60.75	278.52	157.04	216.30
22/12/2556	93	3.9	301.85	120.03	329.63	405.56	170.37	201.48	57.40	266.67	179.26	158.52
23/12/2556	120	5.0	445.06	178.22	525.93	568.52	240.74	309.14	57.12	330.37	244.44	352.59
24/12/2556*	145	6.0	537.04	38.67	511.11	518.52	581.48	447.41	27.20	478.52	435.56	428.15
24/12/2556	145	6.0	121.03	9.36	112.00	120.41	130.68	145.19	13.42	149.23	156.12	130.21
25/12/2556	178	7.4	174.69	10.20	185.19	174.07	164.81	152.10	41.81	133.33	200.00	122.96
26/12/2556*	193	8.0	295.68	44.46	344.44	285.19	257.41	274.07	24.48	272.59	299.26	250.37
26/12/2556	193	8.0	145.44	39.69	116.34	129.33	190.66	131.48	17.87	132.24	148.96	113.25
27/12/2556	216	9.0	155.97	72.29	106.17	122.84	238.89	98.60	19.69	116.54	101.73	77.53
28/12/2556*	234	9.8	227.78	15.82	229.63	242.59	211.11	210.86	42.02	241.48	228.15	162.96
28/12/2556	234	9.8	107.33	19.98	84.43	121.22	116.34	121.02	3.88	122.00	124.32	116.74
29/12/2556	264	11.0	153.09	20.40	129.63	162.96	166.67	162.96	19.93	185.19	157.04	146.67
30/12/2556	285	11.9	41.05	15.78	32.41	59.26	31.48	122.96	47.51	148.52	152.22	68.15

* is algal harvesting.

Appendix Table C15 Biomass of microalgae cultivated in wastewater under outdoor semi continuous experiment in trial 1.

Biomass of <i>Scenedesmus</i> sp. (mg/L)												
Date	Hours	Days	T1-1 (Continuous aeration)					T1-2 (Continuous external CO ₂ supplement)				
			AV	SD	1	2	3	AV	SD	1	2	3
18/12/2556	0	0.0	955.20	92.63	1036.95	854.59	974.07	809.32	60.99	874.71	799.26	753.98
20/12/2556	48	2.0	900.70	137.24	873.46	1049.52	779.13	752.86	102.41	634.93	819.38	804.29
21/12/2556	72	3.0	892.32	190.62	1112.40	785.42	779.13	762.37	206.27	970.29	557.79	759.01
22/12/2556	93	3.9	1049.52	407.57	1143.85	1401.66	603.07	708.71	194.90	930.05	633.25	562.82
23/12/2556	120	5.0	1535.80	605.18	1810.39	1955.01	842.02	1074.26	193.94	1146.36	854.59	1221.82
24/12/2556*	145	6.0	1848.11	131.30	1760.08	1785.23	1999.03	1543.77	92.35	1649.41	1503.53	1478.37
24/12/2556	145	6.0	435.53	31.77	404.87	433.42	468.29	517.55	45.57	531.28	554.68	466.70
25/12/2556	178	7.4	617.74	34.63	653.37	615.64	584.20	541.02	141.96	477.30	703.68	442.09
26/12/2556*	193	8.0	1028.56	150.96	1194.15	992.93	898.61	955.20	83.12	950.17	1040.72	874.71
26/12/2556	193	8.0	518.42	134.78	419.60	463.71	671.96	471.02	60.67	473.59	530.37	409.11
27/12/2556	216	9.0	554.16	245.48	385.08	441.67	835.73	359.37	66.87	420.29	369.99	287.82
26/12/2556	193	8.0	798.00	53.73	804.29	848.30	741.41	740.57	142.67	844.53	799.26	577.91
28/12/2556*	234	9.8	389.01	67.85	311.25	436.17	419.60	435.49	13.19	438.82	446.70	420.96
29/12/2556	264	11.0	544.38	69.26	464.73	577.91	590.49	577.91	67.68	653.37	557.79	522.58
30/12/2556	285	11.9	163.95	53.57	134.60	225.78	131.46	442.09	161.31	528.87	541.44	255.96

* is algal harvesting.

Appendix Table C16 Inorganic nitrogen and inorganic phosphorus during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 1 (T1-1 Continuous aeration).

Date	Hours	Day	TAN (mg N/L)		Nitrite (mg N/L)		Nitrate (mg N/L)		Phosphate (mg P/L)	
			Average	SD	Average	SD	Average	SD	Average	SD
18/12/2556	0	0.0	1.33	0.64	0.98	0.09	23.88	1.39	4.85	0.58
20/12/2556	48	2.0	6.27	0.44	0.86	0.19	21.78	1.11	4.25	0.90
21/12/2556	72	3.0	6.74	0.99	0.80	0.24	18.38	1.63	3.99	0.29
22/12/2556	93	3.9	7.53	0.80	0.65	0.09	18.49	1.51	6.91	2.27
23/12/2556	120	5.0	4.03	0.41	0.59	0.02	17.16	1.22	2.78	0.53
24/12/2556*	145	6.0	1.74	0.75	0.54	0.05	15.83	2.37	1.19	0.41
24/12/2556	145	6.0	6.70	0.47	0.98	0.01	21.28	2.69	2.82	0.72
25/12/2556	178	7.4	5.08	0.96	0.46	0.34	12.09	0.80	2.07	0.17
26/12/2556*	193	8.0	3.69	1.31	0.62	0.30	8.49	1.09	1.69	0.09
26/12/2556	193	8.0	5.24	0.78	1.35	0.26	10.91	0.80	2.32	0.24
27/12/2556	216	9.0	5.11	2.53	0.42	0.32	6.68	0.69	1.60	0.18
28/12/2556*	234	9.8	8.56	2.41	0.36	0.25	5.94	0.15	1.46	0.32
28/12/2556	234	9.8	3.77	0.41	0.56	0.07	5.99	0.39	2.00	0.13
30/12/2556	285	11.9	1.39	1.21	0.35	0.27	3.91	1.20	1.64	0.36

* is algal harvesting.

Appendix Table C17 Inorganic nitrogen and inorganic phosphorus during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 1 (T1-2 Continuous external CO₂ supplement).

Date	Hours	Day	TAN (mg N/L)		Nitrite (mg N/L)		Nitrate (mg N/L)		Phosphate (mg P/L)	
			Average	SD	Average	SD	Average	SD	Average	SD
18/12/2556	0	0.0	1.53	0.39	1.21	0.49	24.47	0.52	4.50	0.13
20/12/2556	48	2.0	7.54	1.63	0.35	0.10	22.58	0.25	3.79	0.38
21/12/2556	72	3.0	8.12	1.21	0.07	0.08	19.07	0.65	4.14	0.28
22/12/2556	93	3.9	8.71	2.60	0.08	0.08	18.35	1.07	5.16	1.21
23/12/2556	120	5.0	5.16	0.34	0.07	0.08	17.53	1.04	5.18	0.48
24/12/2556*	145	6.0	0.96	0.41	0.07	0.07	14.67	0.72	4.05	0.57
24/12/2556	145	6.0	6.52	0.25	0.32	0.11	20.14	0.74	4.84	0.56
25/12/2556	178	7.4	4.90	1.68	0.02	0.02	14.38	1.57	3.06	1.43
26/12/2556*	193	8.0	6.19	4.04	0.06	0.01	9.10	0.24	2.38	0.56
26/12/2556	193	8.0	5.99	0.23	0.18	0.04	10.08	0.15	2.64	0.09
27/12/2556	216	9.0	4.53	1.95	0.04	0.03	6.40	0.71	2.46	1.85
28/12/2556*	234	9.8	3.23	1.91	0.02	0.01	5.09	1.83	2.17	1.44
28/12/2556	234	9.8	3.70	0.50	0.08	0.01	5.85	0.08	2.22	0.10
30/12/2556	285	11.9	0.84	0.54	0.00	0.01	3.03	0.79	1.30	0.30

* is algal harvesting.

Appendix Table C18 Total nitrogen and total phosphorus during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 1.

Total Nitrogen (mg N/L)										
Day	T1-1 (Continuous aeration)					T1-2 (Continuous carbon dioxide supplement)				
	Average	SD	1	2	3	Average	SD	1	2	3
Initial	74.16	2.04	75.94	71.93	74.60	74.16	2.04	75.94	71.93	74.60
Final	36.99	17.76	23.98	29.77	57.22	54.37	5.02	53.12	50.09	59.89

Total Soluble Nitrogen (mg N/L)										
Day	T1-1 (Continuous aeration)					T1-2 (Continuous carbon dioxide supplement)				
	Average	SD	1	2	3	Average	SD	1	2	3
Initial	38.36	2.68	41.07	38.29	35.72	38.36	2.68	41.07	38.29	35.72
Final	9.22	0.97	8.63	8.70	10.34	8.06	1.46	6.63	9.55	7.99

Appendix Table C18 (Continued)

Total Phosphorus (mg P/L)										
Day	T1-1 (Continuous aeration)					T1-2 (Continuous carbon dioxide supplement)				
	Average	SD	1	2	3	Average	SD	1	2	3
Initial	8.17	0.08	8.09	8.19	8.24	8.17	0.08	8.09	8.19	8.24
Final	6.53	2.10	4.16	8.17	7.25	7.86	2.88	5.66	6.79	11.12

Total Soluble phosphorus (mg P/L)										
Day	T1-1 (Continuous aeration)					T1-2 (Continuous carbon dioxide supplement)				
	Average	SD	1	2	3	Average	SD	1	2	3
Initial	2.88	0.05	2.93	2.83	2.89	2.88	0.05	2.93	2.83	2.89
Final	0.97	0.28	0.78	1.29	0.84	1.17	0.92	0.59	0.52	2.39

Appendix Table C19 COD during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 1.

Total COD (mg/L)															
Treatment	Initial					Final					Reduction (%)				
	AV	SD	1	2	3	AV	SD	1	2	3	AV	SD	1	2	3
T1-1 (Continuous aeration)	1815.60	547.16	2439.72	1588.65	1418.44	1134.75	150.11	1078.01	1021.28	1304.96	33.18	24.01	55.81	35.71	8.00
T1-2 (Continuous aeration)	1815.60	547.16	2439.72	1588.65	1418.44	1683.22	622.39	1475.18	2382.98	1191.49	1.84	46.42	39.53	-50.00	16.00
Soluble COD (mg/L)															
Treatment	Initial					Final					Reduction (%)				
	AV	SD	1	2	3	AV	SD	1	2	3	AV	SD	1	2	3
T1-1 (Continuous aeration)	283.69	68.09	351.77	215.60	283.69	132.39	36.48	158.87	147.52	90.78	51.47	18.44	54.84	31.58	68.00
T1-2 (Continuous aeration)	283.69	68.09	351.77	215.60	283.69	151.30	28.56	181.56	147.52	124.82	45.32	12.50	48.39	31.58	56.00

Appendix Table C20 Cell density of *Scenedesmus* sp. in wastewater under outdoor semi continuous cultivation (trial 2).

Cell Density of <i>Scenedesmus</i> sp. (10^4 cell/mL)												
Date	Hours	Days	T2-1 (Aeration during daytime)					T2-2 (External CO ₂ supplement during daytime)				
			AV	SD	1	2	3	AV	SD	1	2	3
11/2/2557	0	0.0	2.43	0.82	2.90	1.48	2.90	2.72	0.55	3.33	2.53	2.28
12/2/2557	24	1.0	3.31	0.42	3.79	3.17	2.98	2.20	0.43	1.71	2.43	2.47
13/2/2557	48	2.0	3.99	0.47	3.46	4.20	4.32	2.08	0.56	1.54	2.04	2.65
14/2/2557	72	3.0	7.72	3.07	7.41	4.81	10.93	4.81	1.61	3.70	6.67	4.07
15/2/2557	96	4.0	13.70	3.57	17.78	11.11	12.22	13.52	2.25	15.56	11.11	13.89
16/2/2557	120	5.0	22.59	7.58	26.11	27.78	13.89	20.56	4.41	17.22	25.56	18.89
18/2/2557	167	7.0	33.89	9.73	33.33	43.89	24.44	70.93	13.57	60.00	66.67	86.11
19/2/2557*	192	8.0	34.07	9.88	23.33	42.78	36.11	120.56	13.14	115.00	111.11	135.56
19/2/2557	192	8.0	1.40	0.18	1.30	1.60	1.30	9.63	5.01	4.44	10.00	14.44
20/2/2557	213	8.9	2.16	0.27	1.85	2.35	2.28	12.16	2.83	10.00	15.37	11.11
21/2/2557	240	10.0	6.93	2.38	4.20	8.15	8.46	20.74	4.56	15.93	25.00	21.30
22/2/2557	264	11.0	9.09	3.64	5.12	9.88	12.28	29.51	2.36	27.96	32.22	28.33
23/2/2557*	286	11.9	19.32	4.73	15.56	17.78	24.63	60.56	24.08	88.33	45.56	47.78

Appendix Table C20 (Continued)

Cell Density of <i>Scenedesmus</i> sp. (10^4 cell/mL)												
Date	Hours	Days	T2-1 (Aeration during daytime)					T2-2 (External CO ₂ supplement during daytime)				
			AV	SD	1	2	3	AV	SD	1	2	3
23/2/2557	286	11.9	3.29	1.51	1.73	3.40	4.75	9.01	2.96	8.89	6.11	12.04
24/2/2557	312	13.0	4.90	2.54	1.98	6.17	6.54	16.42	2.70	14.26	15.56	19.44
25/2/2557	336	14.0	4.94	2.28	2.90	4.51	7.41	16.91	2.34	14.26	17.78	18.70
26/2/2557	360	15.0	4.51	0.99	4.63	3.46	5.43	25.43	11.59	13.52	36.67	26.11
27/2/2557	384	16.0	2.82	0.34	2.65	2.59	3.21	39.81	9.25	42.78	47.22	29.44
28/2/2557*	406	16.9	2.16	0.39	1.73	2.28	2.47	34.63	8.50	25.00	37.78	41.11
28/2/2557	406	16.9	1.56	0.13	1.67	1.60	1.42	7.47	1.19	6.11	7.96	8.33
1/3/2557	432	18.0	2.49	1.79	1.85	1.11	4.51	9.38	0.39	9.26	9.07	9.81
2/3/2557	456	19.0	1.81	0.82	1.60	1.11	2.72	24.63	8.10	18.89	21.11	33.89
3/3/2557	480	20.0	2.06	0.63	1.79	1.60	2.78	40.19	11.97	41.11	27.78	51.67
4/3/2557	503	21.0	1.28	1.46	0.43	0.43	2.96	48.33	21.63	31.67	72.78	40.56
5/3/2557*	525	21.9	1.50	1.28	2.96	0.99	0.56	34.44	11.64	31.67	47.22	24.44
5/3/2557	525	21.9	0.78	0.39	0.56	0.56	1.23	13.52	0.32	13.33	13.89	13.33
6/3/2557	552	23.0	0.74	0.34	0.43	0.68	1.11	19.44	1.11	18.33	19.44	20.56
7/3/2557	575	24.0	1.05	0.65	0.37	1.11	1.67	20.00	4.19	24.44	16.11	19.44

* is algal harvesting.

Appendix Table C21 Biomass density of Growth of *Scenedesmus* sp. in wastewater under outdoor semi continuous cultivation (trial 2).

Biomass of <i>Scenedesmus</i> sp. (mg/L)												
Date	Hours	Days	T2-1 (Aeration during daytime)					T2-2 (External CO ₂ supplement during daytime)				
			AV	SD	1	2	3	AV	SD	1	2	3
11/2/2557	0	0.0	32.82	2.78	34.43	29.61	34.43	33.80	1.86	35.90	33.17	32.33
12/2/2557	24	1.0	35.83	1.43	37.43	35.34	34.71	32.05	1.45	30.38	32.82	32.96
13/2/2557	48	2.0	38.13	1.59	36.32	38.83	39.25	31.63	1.89	29.82	31.50	33.59
14/2/2557	72	3.0	50.78	10.42	49.73	40.93	61.68	40.93	5.48	37.15	47.22	38.41
15/2/2557	96	4.0	71.11	12.13	84.94	62.31	66.08	70.48	7.62	77.40	62.31	71.74
16/2/2557	120	5.0	101.29	25.75	113.24	118.90	71.74	94.38	14.97	83.06	111.35	88.72
18/2/2557	167	7.0	139.65	33.05	137.76	173.61	107.58	265.41	46.07	228.31	250.95	316.98
19/2/2557*	192	8.0	140.28	33.55	103.81	169.83	147.20	433.93	44.60	415.07	401.87	484.87
19/2/2557*	192	8.0	29.33	0.61	28.98	30.03	28.98	57.28	17.01	39.67	58.53	73.63
20/2/2557	213	8.9	31.91	0.91	30.87	32.54	32.33	65.87	9.63	58.53	76.77	62.31
21/2/2557	240	10.0	48.12	8.06	38.83	52.25	53.29	95.01	15.49	78.66	109.47	96.89
22/2/2557	264	11.0	55.46	12.37	41.98	58.11	66.29	124.77	8.01	119.53	133.99	120.79
23/2/2557*	286	11.9	90.18	16.06	77.40	84.94	108.21	230.20	81.77	324.52	179.27	186.81
23/2/2557	286	11.9	35.76	5.14	30.45	36.11	40.72	55.18	10.07	54.76	45.33	65.45
24/2/2557	312	13.0	41.21	8.62	31.29	45.54	46.80	80.33	9.16	73.00	77.40	90.60

Appendix Table C21 (Continued)

Biomass Density of <i>Scenedesmus</i> sp. (mg ss/l)												
Date	Hours	Days	T2-1 (Aeration during daytime)					T2-2 (External CO ₂ supplement during daytime)				
			AV	SD	1	2	3	AV	SD	1	2	3
25/2/2557	336	14.0	41.35	7.76	34.43	39.88	49.73	82.01	7.96	73.00	84.94	88.09
26/2/2557	360	15.0	39.88	3.37	40.30	36.32	43.02	110.94	39.35	70.48	149.08	113.24
27/2/2557	384	16.0	34.15	1.15	33.59	33.38	35.48	159.77	31.42	169.83	184.93	124.56
28/2/2557*	406	16.9	31.91	1.31	30.45	32.33	32.96	142.17	28.88	109.47	152.86	164.17
28/2/2557	406	16.9	29.89	0.44	30.24	30.03	29.40	49.94	4.04	45.33	51.62	52.87
1/3/2557	432	18.0	33.03	6.06	30.87	28.35	39.88	56.44	1.31	56.02	55.39	57.91
2/3/2557	456	19.0	30.73	2.79	30.03	28.35	33.80	108.21	27.49	88.72	96.26	139.65
3/3/2557	480	20.0	31.57	2.14	30.66	30.03	34.01	161.03	40.65	164.17	118.90	200.02
4/3/2557	503	21.0	28.91	4.96	26.05	26.05	34.64	188.70	73.45	132.11	271.70	162.29
5/3/2557*	525	21.9	29.68	4.36	34.64	27.93	26.46	141.54	39.53	132.11	184.93	107.58
5/3/2557	525	21.9	27.23	1.33	26.46	26.46	28.77	70.48	1.09	69.85	71.74	69.85
6/3/2557	552	23.0	27.09	1.17	26.05	26.88	28.35	90.60	3.77	86.83	90.60	94.38
7/3/2557	575	24.0	28.14	2.21	25.84	28.35	30.24	92.49	14.24	107.58	79.28	90.60

* is algal harvesting.

Appendix Table C22 Cell density of *Chlorella* sp. contamination in *Scenedesmus* sp. culture in wastewater under outdoor semi continuous experiment in trial 2.

Cell Density of <i>Chlorella</i> sp. Contamination (10 ⁴ cell/mL)												
Date	Hours	Days	T2-1 (Aeration during daytime)					T2-2 (External CO ₂ supplement during daytime)				
			AV	SD	1	2	3	AV	SD	1	2	3
24/2/2557	312	13.0	286.85	355.81	38.33	694.44	127.78	317.04	471.18	43.89	46.11	861.11
25/2/2557	336	14.0	270.56	321.31	47.78	638.89	125.00	228.52	343.38	27.22	33.33	625.00
26/2/2557	360	15.0	402.78	242.43	425.00	633.33	150.00	281.30	442.03	20.56	31.67	791.67
27/2/2557	384	16.0	296.30	154.39	416.67	350.00	122.22	86.30	86.48	38.89	33.89	186.11
28/2/2557*	406	16.9	274.07	207.80	513.89	161.11	147.22	39.81	68.96	0.00	0.00	119.44
28/2/2557	406	16.9	171.30	21.03	186.11	180.56	147.22	-45.37	78.58	0.00	0.00	-136.11
1/3/2557	432	18.0	189.81	80.62	244.44	227.78	97.22	62.04	107.45	0.00	0.00	186.11
2/3/2557	456	19.0	265.74	57.82	219.44	247.22	330.56	54.63	94.62	0.00	0.00	163.89
3/3/2557	480	20.0	296.30	52.88	300.00	241.67	347.22	53.70	93.02	0.00	0.00	161.11
4/3/2557	503	21.0	156.48	68.57	175.00	80.56	213.89	24.44	42.34	0.00	0.00	73.33
5/3/2557*	525	21.9	226.67	122.67	269.44	88.33	322.22	28.89	50.04	0.00	0.00	86.67
5/3/2557	525	21.9	168.52	21.03	183.33	144.44	177.78	8.52	14.75	0.00	0.00	25.56
6/3/2557	552	23.0	632.41	338.23	916.67	258.33	722.22	12.59	21.81	0.00	0.00	37.78
7/3/2557	575	24.0	544.44	200.75	680.56	313.89	638.89	6.48	11.23	0.00	0.00	19.44

* is algal harvesting.

Appendix Table C23 Biomass of *Chlorella* sp. contamination in *Scenedesmus* sp. culture in wastewater under outdoor semi continuous experiment in trial 2.

Biomass of <i>Chlorella</i> sp. Contamination ($\mu\text{g/mL}$)												
Date	Hours	Days	T2-1 (Aeration during daytime)					T2-2 (External CO ₂ supplement during daytime)				
			AV	SD	1	2	3	AV	SD	1	2	3
24/2/2557	312	13.0	1.64	2.03	0.22	3.96	0.73	1.81	2.69	0.25	0.26	4.91
25/2/2557	336	14.0	1.54	1.83	0.27	3.64	0.71	1.30	1.96	0.16	0.19	3.56
26/2/2557	360	15.0	2.30	1.38	2.42	3.61	0.86	1.60	2.52	0.12	0.18	4.51
27/2/2557	384	16.0	1.69	0.88	2.38	2.00	0.70	0.49	0.49	0.22	0.19	1.06
28/2/2557*	406	16.9	1.56	1.18	2.93	0.92	0.84	0.23	0.39	0.00	0.00	0.68
28/2/2557	406	16.9	0.98	0.12	1.06	1.03	0.84	0.26	0.45	0.00	0.00	0.78
1/3/2557	432	18.0	1.08	0.46	1.39	1.30	0.55	0.35	0.61	0.00	0.00	1.06
2/3/2557	456	19.0	1.51	0.33	1.25	1.41	1.88	0.31	0.54	0.00	0.00	0.93
3/3/2557	480	20.0	1.69	0.30	1.71	1.38	1.98	0.31	0.53	0.00	0.00	0.92
4/3/2557	503	21.0	0.89	0.39	1.00	0.46	1.22	0.14	0.24	0.00	0.00	0.42
5/3/2557*	525	21.9	1.29	0.70	1.54	0.50	1.84	0.16	0.29	0.00	0.00	0.49
5/3/2557	525	21.9	0.96	0.12	1.05	0.82	1.01	0.05	0.08	0.00	0.00	0.15
6/3/2557	552	23.0	3.60	1.93	5.23	1.47	4.12	0.07	0.12	0.00	0.00	0.22
7/3/2557	575	24.0	3.10	1.14	3.88	1.79	3.64	0.04	0.06	0.00	0.00	0.11

* is algal harvesting.

Appendix Table C24 Inorganic nitrogen and inorganic phosphorus during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 2 (T2-1 Aeration during daytime).

Date	Hours	Day	TAN (mg N/l)		Nitrite (mg N/l)		Nitrate (mg N/l)		Phosphate (mg P/l)		
			Average	SD	Average	SD	Average	SD	Average	SD	
11/2/2557		0.0	0.0	4.74	1.93	0.05	0.01	28.37	6.72	3.18	0.36
13/2/2557		48.0	2.0	8.65	0.66	3.75	0.21	21.85	2.92	3.32	0.40
14/2/2557		72.0	3.0	9.52	0.79	3.69	0.29	14.19	2.65	3.68	0.30
15/2/2557		96.0	4.0	9.31	0.23	3.58	0.29	9.64	1.66	3.60	0.04
16/2/2557		120.0	5.0	7.82	1.11	6.65	0.70	7.18	0.81	3.23	0.08
18/2/2557		166.5	6.9	3.14	1.59	4.16	1.21	6.37	0.63	1.17	0.25
19/2/2557		191.5	8.0	3.85	0.64	4.12	1.00	6.19	0.91	1.40	0.07
19/2/2557*		193.5	8.1	11.26	2.82	3.13	0.63	8.13	3.14	2.93	0.21
20/2/2557		211.0	8.8	8.90	1.25	0.01	0.01	3.61	0.41	2.34	0.16
23/2/2557		285.5	11.9	8.20	1.94	0.01	0.00	3.84	0.41	2.25	0.15
23/2/2557*		287.5	12.0	12.68	3.78	0.02	0.01	4.04	0.16	3.13	0.27
24/2/2557		311.5	13.0	9.89	3.10	0.02	0.01	3.79	0.11	2.60	0.24
26/2/2557		360.0	15.0	6.29	3.99	0.01	0.00	3.67	0.31	1.86	0.40
27/2/2557		384.0	16.0	4.66	0.58	0.01	0.01	4.22	0.34	1.13	0.04
28/2/2557		406.0	16.9	2.34	2.87	0.01	0.00	3.66	0.41	0.87	0.19
28/2/2557*		408.0	17.0	1.58	0.49	0.01	0.00	4.44	0.33	3.21	0.51

Appendix Table C24 (Continued)

Date	Hours	Day	TAN (mg N/l)		Nitrite (mg N/l)		Nitrate (mg N/l)		Phosphate (mg P/l)	
			Average	SD	Average	SD	Average	SD	Average	SD
1/3/2557	432.0	18.0	1.32	0.46	0.01	0.01	3.96	0.19	3.23	0.27
3/3/2557	479.5	20.0	0.58	0.08	0.00	0.01	3.92	0.49	2.26	0.52
4/3/2557	503.0	21.0	0.70	0.12	0.01	0.01	4.37	0.20	3.44	0.25
5/3/2557	526.0	21.9	0.80	0.11	0.00	0.01	4.18	0.14	3.76	0.26
5/3/2557*	528.0	22.0	2.13	0.42	0.01	0.01	4.70	0.41	4.55	0.23
6/3/2557	552.0	23.0	4.87	0.53	0.02	0.01	4.15	0.41	3.77	0.30
7/3/2557	575.0	24.0	7.81	1.38	0.03	0.01	4.70	0.75	4.30	0.40

* is algal harvesting.

Appendix Table C25 Inorganic nitrogen and inorganic phosphorus during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 2 (T2-2 External CO₂ supplement during daytime).

Date	Hours	Day	TAN (mg N/l)		Nitrite (mg N/l)		Nitrate (mg N/l)		Phosphate (mg P/l)	
			Average	SD	Average	SD	Average	SD	Average	SD
11/2/2557	0.0	0.0	5.70	1.09	0.05	0.03	30.41	0.96	3.88	1.19
13/2/2557	48.0	2.0	12.11	2.27	3.81	0.20	19.63	1.62	3.58	0.18
14/2/2557	72.0	3.0	12.55	1.44	3.80	0.53	12.75	0.63	3.84	0.25
15/2/2557	96.0	4.0	13.42	0.92	2.65	1.03	10.07	0.39	3.81	0.28
16/2/2557	120.0	5.0	11.48	0.89	3.03	1.23	8.18	1.38	3.61	0.25
18/2/2557	166.5	6.9	1.16	0.68	0.91	0.99	4.43	0.59	2.40	0.30
19/2/2557	191.5	8.0	1.00	0.59	0.59	0.82	3.98	2.67	1.93	0.16
19/2/2557*	193.5	8.1	8.66	2.88	0.62	0.93	8.04	2.02	2.32	0.30
20/2/2557	211.0	8.8	4.71	1.60	0.02	0.01	3.57	0.08	0.97	0.06
23/2/2557	285.5	11.9	3.05	0.76	0.01	0.01	3.99	0.12	1.07	0.14
23/2/2557*	287.5	12.0	5.06	0.74	0.01	0.01	3.17	0.44	1.44	0.12
24/2/2557	311.5	13.0	4.48	1.92	0.01	0.00	3.26	0.23	0.86	0.08
26/2/2557	360.0	15.0	1.89	0.44	0.01	0.01	2.86	0.44	0.64	0.04
27/2/2557	384.0	16.0	3.00	1.01	0.02	0.01	3.06	0.29	0.59	0.09

Appendix Table C25 (Continued)

Date	Hours	Day	TAN (mg N/l)		Nitrite (mg N/l)		Nitrate (mg N/l)		Phosphate (mg P/l)	
			Average	SD	Average	SD	Average	SD	Average	SD
28/2/2557	406.0	16.9	0.71	0.14	0.00	0.01	3.51	0.60	0.73	0.32
28/2/2557*	408.0	17.0	0.56	0.37	0.01	0.00	3.66	0.51	1.03	0.22
1/3/2557	432.0	18.0	0.45	0.21	0.01	0.00	3.48	0.41	1.09	0.48
3/3/2557	479.5	20.0	0.65	0.22	0.00	0.01	3.06	0.24	0.63	0.14
4/3/2557	503.0	21.0	0.62	0.13	0.01	0.01	3.22	0.05	0.50	0.09
5/3/2557	526.0	21.9	0.72	0.17	0.00	0.00	3.04	0.05	0.25	0.05
5/3/2557*	528.0	22.0	1.29	0.10	0.02	0.02	3.85	0.63	1.11	0.26
6/3/2557	552.0	23.0	4.12	1.05	0.01	0.00	4.72	0.77	0.49	0.18
7/3/2557	575.0	24.0	6.60	1.81	0.02	0.01	3.55	0.10	0.47	0.26

* is algal harvesting.

Appendix Table C26 Total nitrogen and total phosphorus during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 2.

Total Nitrogen (mg N/L)										
Day	T2-1 (Aeration during daytime)					T2-2 (External CO₂ supplement during daytime)				
	Average	SD	1	2	3	Average	SD	1	2	3
Initial	101.35	1.00	102.02	100.20	101.82	101.35	1.00	102.02	100.20	101.82
Final	35.38	7.58	41.62	37.58	26.94	43.37	7.17	42.56	50.91	36.63

Total Soluble Nitrogen (mg N/L)										
Day	T2-1 (Aeration during daytime)					T2-2 (External CO₂ supplement during daytime)				
	Average	SD	1	2	3	Average	SD	1	2	3
Initial	64.01	0.51	63.54	63.94	64.55	64.01	0.51	63.54	63.94	64.55
Final	14.57	2.01	16.30	15.05	12.36	11.47	1.05	12.49	11.52	10.40

Total Phosphorus (mg P/L)										
Day	T2-1 (Aeration during daytime)					T2-2 (External CO₂ supplement during daytime)				
	Average	SD	1	2	3	Average	SD	1	2	3
Initial	5.97	0.05	6.02	5.98	5.92	5.97	0.05	6.02	5.98	5.92
Final	5.71	0.30	6.06	5.52	5.56	3.76	1.86	5.84	3.20	2.25

Appendix Table C26 (Continued)

Total Soluble phosphorus (mg P/L)										
Day	T2-1 (Aeration during daytime)					T2-2 (External CO ₂ supplement during daytime)				
	Average	SD	1	2	3	Average	SD	1	2	3
Initial	2.61	0.01	2.62	2.61	2.60	2.61	0.01	2.62	2.61	2.60
Final	2.71	0.36	2.91	2.92	2.29	4.05	0.92	0.85	0.90	10.40

Appendix Table C27 COD during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 2.

Treatment	Total COD (mg/L)														
	Initial					Final					Reduction (%)				
	AV	SD	1	2	3	AV	SD	1	2	3	AV	SD	1	2	3
T1-1 (Aeration during day time)	2269.50	491.36	1985.82	1985.82	2836.88	1134.75	851.06	1985.82	1134.75	283.69	44.29	45.02	0.00	42.86	90.00
T1-2 (External CO₂ supplement during daytime)	2269.50	491.36	1985.82	1985.82	2836.88	1513.00	1074.03	1985.82	2269.50	283.69	25.24	56.54	0.00	-14.29	90.00
Treatment	Soluble COD (mg/L)														
	Initial					Final					Reduction (%)				
	AV	SD	1	2	3	AV	SD	1	2	3	AV	SD	1	2	3
T1-1 (Aeration during day time)	510.64	19.65	521.99	487.94	521.99	272.34	63.18	329.08	283.69	204.26	46.56	12.63	36.96	41.86	60.87
T1-2 (External CO₂ supplement during daytime)	510.64	19.65	521.99	487.94	521.99	310.17	36.48	295.04	283.69	351.77	39.32	5.86	43.48	41.86	32.61

Appendix Table C28 Cell density of *Scenedesmus* sp. cultivated in wastewater under outdoor semi continuous experiment in trial 3.

Cell Density of <i>Scenedesmus</i> sp. (10^4 cell/mL)												
Date	Hours	Days	T3-1 (Continuous aeration)					T3-2 (External CO ₂ during daytime)				
			AV	SD	1	2	3	AV	SD	1	2	3
12/3/2557	0	0.0	50.80	2.83	54.07	49.07	49.26	50.62	3.16	54.26	48.70	48.89
13/3/2557	25	1.0	73.52	9.82	63.89	83.52	73.15	71.30	3.15	71.30	68.15	74.44
14/3/2557	43	1.8	178.40	45.98	231.48	152.78	150.93	183.64	16.88	201.85	168.52	180.56
15/3/2557	73	3.0	97.72	62.33	154.63	31.11	107.41	391.98	80.22	338.89	484.26	352.78
16/3/2557	96	4.0	41.42	10.75	36.85	53.70	33.70	371.60	81.75	330.56	465.74	318.52
17/3/2557	114	4.8	33.70	5.89	32.78	40.00	28.33	366.36	8.75	369.44	356.48	373.15
18/3/2557*	142	5.9	157.41	64.26	227.78	101.85	142.59	743.83	154.20	916.67	620.37	694.44
18/3/2557	142	5.9	79.63	24.31	107.41	69.26	62.22	285.43	55.89	348.89	263.89	243.52
19/3/2557	166	6.9	118.21	7.07	116.67	112.04	125.93	261.73	27.19	266.67	286.11	232.41
20/3/2557*	192	8.0	143.21	59.81	208.33	90.74	130.56	646.60	106.82	768.52	601.85	569.44
20/3/2557	192	8.0	73.15	9.76	72.22	63.89	83.33	205.86	70.05	248.15	125.00	244.44
21/3/2557	212	8.8	88.58	23.45	113.89	67.59	84.26	532.41	81.91	606.48	546.30	444.44
22/3/2557*	240	10.0	66.60	43.64	109.26	22.04	68.52	395.06	20.88	393.52	416.67	375.00
22/3/2557	240	10.0	35.37	16.74	51.11	17.78	37.22	87.96	10.52	83.33	80.56	100.00
23/3/2557	262	10.9	76.48	40.75	100.93	29.44	99.07	160.80	23.59	145.37	187.96	149.07

Appendix Table C28 (Continued)

Cell Density of <i>Scenedesmus</i> sp. (10^4 cell/mL)												
Date	Hours	Days	T3-1 (Continuous aeration)					T3-2 (External CO ₂ during daytime)				
			AV	SD	1	2	3	AV	SD	1	2	3
24/3/2557*	286	11.9	88.83	54.42	134.26	28.52	103.70	407.41	136.40	527.78	259.26	435.19
24/3/2557	286	11.9	32.96	29.19	66.67	16.67	15.56	89.81	10.52	94.44	77.78	97.22
25/3/2557	312	13.0	34.51	23.98	62.04	23.33	18.15	131.79	25.50	114.81	161.11	119.44
27/3/2557	354	14.8	104.07	43.83	64.07	97.22	150.93	148.15	11.38	139.81	161.11	143.52
28/3/2557	384	16.0	68.70	22.87	45.93	68.52	91.67	93.83	11.05	86.11	106.48	88.89
29/3/2557	408	17.0	77.35	23.50	52.41	80.56	99.07	115.43	21.96	138.89	112.04	95.37

* is algal harvesting.

Appendix Table C29 Biomass of *Scenedesmus* sp. cultivated in wastewater under outdoor semi continuous experiment in trial 3.

Biomass of <i>Scenedesmus</i> sp. (mg/L)												
Date	Hours	Days	T3-1 (Continuous aeration)					T3-2 (External CO ₂ during daytime)				
			AV	SD	1	2	3	AV	SD	1	2	3
12/3/2557	0	0.0	197.08	47.61	208.19	191.21	191.84	196.45	10.71	208.82	189.96	190.58
13/3/2557	25	1.0	274.22	219.64	241.52	308.17	272.96	266.67	10.69	266.67	255.98	277.36
14/3/2557	43	1.8	630.33	224.02	810.59	543.35	537.06	648.15	57.32	709.98	596.80	637.67
15/3/2557	73	3.0	356.38	171.50	549.64	130.22	389.29	1355.56	272.40	1175.30	1668.92	1222.47
16/3/2557	96	4.0	165.22	29.99	149.71	206.93	139.02	1286.39	277.58	1147.01	1606.04	1106.14
17/3/2557	114	4.8	139.02	268.58	135.88	160.40	120.79	1268.58	29.72	1279.06	1235.04	1291.63
18/3/2557*	142	5.9	559.07	156.81	798.02	370.42	508.76	2550.31	523.59	3137.20	2131.10	2382.62
19/3/2557	166	6.9	425.97	137.44	420.73	405.01	452.17	913.30	92.33	930.07	996.09	813.74
20/3/2557*	192	8.0	510.86	171.34	731.99	332.70	467.89	2220.18	362.70	2634.15	2068.22	1958.18
21/3/2557	212	8.8	325.36	113.98	411.30	254.09	310.69	1832.41	278.12	2083.94	1879.57	1533.73
22/3/2557*	240	10.0	250.74	129.53	395.58	99.41	257.24	1366.04	70.89	1360.80	1439.41	1297.92
23/3/2557	262	10.9	284.28	147.79	367.28	124.56	360.99	570.60	80.12	518.20	662.82	530.77
24/3/2557*	286	11.9	326.20	162.84	480.47	121.42	376.71	1407.97	463.15	1816.69	904.92	1502.29
25/3/2557	312	13.0	141.75	168.09	235.23	103.81	86.20	472.08	86.58	414.44	571.64	430.16
27/3/2557	354	14.8	377.97	124.90	242.15	354.70	537.06	527.63	38.63	499.33	571.64	511.91
28/3/2557	384	16.0	257.87	72.23	180.52	257.24	335.84	343.18	37.51	316.98	386.15	326.41
29/3/2557	408	17.0	287.21	675.93	202.53	298.11	360.99	416.54	74.56	496.19	405.01	348.42

Appendix Table C30 Inorganic nitrogen and inorganic phosphorus during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 3 (T3-1 Continuous aeration).

Date	Hours	Day	TAN (mg N/L)		Nitrite (mg N/L)		Nitrate (mg N/L)		Phosphate (mg P/L)	
			Average	SD	Average	SD	Average	SD	Average	SD
12/3/2557	0	0.0	4.14	0.62	0.19	0.02	20.24	3.32	2.97	0.17
13/3/2557	25	1.0	4.09	0.41	0.52	0.04	17.75	1.19	0.88	0.11
14/3/2557	43	1.8	4.04	0.53	1.31	0.69	16.36	0.37	0.96	0.11
15/3/2557	73	3.0	2.52	1.30	1.39	0.21	12.21	0.27	0.20	0.10
16/3/2557	96	4.0	2.61	0.46	1.10	0.57	9.61	2.03	0.52	0.02
17/3/2557	114	4.8	2.89	0.38	1.41	0.71	9.07	1.27	0.77	0.08
18/3/2557*	142	5.9	0.79	0.04	1.25	0.79	8.00	0.31	0.38	0.21
19/3/2557	166	6.9	0.87	0.75	0.95	0.73	4.96	0.64	0.51	0.02
20/3/2557*	192	8.0	0.37	0.20	0.70	0.38	4.00	0.23	0.24	0.05
21/3/2557	212	8.8	0.79	0.29	0.77	0.44	3.45	0.04	0.61	0.23
22/3/2557*	240	10.0	1.40	0.51	0.36	0.16	3.04	0.33	0.63	0.29
23/3/2557	262	10.9	1.25	0.69	0.12	0.19	2.69	0.23	0.51	0.34
24/3/2557*	286	11.9	1.47	0.68	0.02	0.03	2.59	0.14	0.47	0.28
25/3/2557	312	13.0	2.74	0.26	0.00	0.00	2.81	0.25	1.17	0.67
27/3/2557	354	14.8	1.55	0.39	0.04	0.03	2.74	0.21	0.87	0.19
28/3/2557	384	16.0	1.67	0.39	0.02	0.01	2.41	0.12	3.21	0.51
29/3/2557	408	17.0	1.84	0.26	0.01	0.01	2.52	0.08	3.23	0.27

Appendix Table C31 Inorganic nitrogen and inorganic phosphorus during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 3 (T3-2 External CO₂ supplement during daytime).

Date	Hours	Day	TAN (mg N/L)		Nitrite (mg N/L)		Nitrate (mg N/L)		Phosphate (mg P/L)	
			Average	SD	Average	SD	Average	SD	Average	SD
12/3/2557	0	0.0	3.51	0.50	0.18	0.06	20.49	5.62	3.17	0.10
13/3/2557	25	1.0	3.14	0.16	9.60	1.63	5.63	2.53	0.99	0.13
14/3/2557	43	1.8	2.34	0.92	7.69	3.27	4.12	3.82	0.75	0.33
15/3/2557	73	3.0	1.97	1.21	0.02	0.02	2.25	0.08	0.07	0.03
16/3/2557	96	4.0	0.97	0.28	0.01	0.02	1.76	0.21	0.02	0.01
17/3/2557	114	4.8	0.97	0.52	0.00	0.00	1.49	0.22	0.02	0.01
18/3/2557*	142	5.9	2.10	1.74	0.00	0.00	1.94	0.13	0.03	0.01
19/3/2557	166	6.9	0.38	0.09	0.00	0.01	2.39	0.49	0.09	0.04
20/3/2557*	192	8.0	1.73	1.67	0.00	0.01	2.51	0.06	0.06	0.01
21/3/2557	212	8.8	0.91	0.51	0.00	0.00	2.39	0.24	0.21	0.34
22/3/2557*	240	10.0	1.67	0.67	0.00	0.00	2.39	0.15	0.02	0.01
23/3/2557	262	10.9	2.34	0.61	0.01	0.01	2.07	0.53	0.01	0.00
24/3/2557*	286	11.9	2.24	1.09	0.00	0.00	2.46	0.04	0.03	0.01
25/3/2557	312	13.0	2.35	0.86	0.00	0.00	2.54	0.05	0.04	0.01
27/3/2557	354	14.8	0.19	0.21	0.12	0.06	2.14	0.62	0.73	0.32
28/3/2557	384	16.0	0.33	0.18	0.02	0.01	3.00	0.20	1.03	0.22
29/3/2557	408	17.0	0.06	0.02	0.01	0.00	2.55	0.24	1.09	0.48

Appendix Table C32 Total nitrogen and total phosphorus during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 3.

Total Nitrogen (mg N/L)										
Day	T3-1 (Continuous aeration)					T3-2 (External CO₂ supplement during daytime)				
	Average	SD	1	2	3	Average	SD	1	2	3
Initial	82.90	0.82	82.02	83.03	83.64	82.90	0.82	82.02	83.03	83.64
Final	23.41	9.59	23.17	13.95	33.12	41.29	5.02	37.37	46.95	39.55

Total Soluble Nitrogen (mg N/L)										
Day	T3-1 (Continuous aeration)					T3-2 (External CO₂ supplement during daytime)				
	Average	SD	1	2	3	Average	SD	1	2	3
Initial	44.28	0.71	44.14	45.05	43.64	44.28	0.71	44.14	45.05	43.64
Final	9.26	4.57	7.85	5.57	14.37	7.70	1.40	8.10	8.86	6.14

Total Phosphorus (mg P/L)										
Day	T3-1 (Continuous aeration)					T3-2 (External CO₂ supplement during daytime)				
	Average	SD	1	2	3	Average	SD	1	2	3
Initial	32.18	1.60	30.45	33.62	32.47	32.18	1.60	30.45	33.62	32.47
Final	6.77	1.80	6.34	8.74	5.22	9.29	1.78	11.34	8.17	8.36

Appendix Table C32 (Continued)

Total Soluble phosphorus (mg P/L)										
Day	T3-1 (Continuous aeration)					T3-2 (External CO ₂ supplement during daytime)				
	Average	SD	1	2	3	Average	SD	1	2	3
Initial	4.63	0.12	4.50	4.70	4.70	4.63	0.12	4.50	4.70	4.70
Final	5.45	0.09	5.45	5.37	5.54	0.37	0.92	0.10	0.29	0.73

Appendix Table C33 COD during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 3.

Treatment	Total COD (mg/L)														
	Initial					Final					Reduction (%)				
	AV	SD	1	2	3	AV	SD	1	2	3	AV	SD	1	2	3
T3-1 (Continuous aeration)	2758.62	421.39	2666.67	3218.39	2390.80	1624.52	530.90	1931.03	1011.49	1931.03	38.46	26.41	27.59	68.57	19.23
T3-2 (External CO ₂ supplement during daytime)	2758.62	421.39	2666.67	3218.39	2390.80	1716.48	231.41	1747.13	1471.26	1931.03	36.00	17.58	34.48	54.29	19.23
Treatment	Soluble COD (mg/L)														
	Initial					Final					Reduction (%)				
	AV	SD	1	2	3	AV	SD	1	2	3	AV	SD	1	2	3
T3-1 (Continuous aeration)	496.55	31.85	478.16	533.33	478.16	275.86	73.56	275.86	349.43	202.30	44.83	11.81	42.31	34.48	57.69
T3-2 (External CO ₂ supplement during daytime)	496.55	31.85	478.16	533.33	478.16	257.47	48.66	312.64	239.08	220.69	47.88	11.50	34.62	55.17	53.85

Appendix Table C34 pH profile during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor semi continuous experiment in trial 3

Date	Days	pH				Replicate					
		T3-1		T3-2		T3-1			T3-2		
		AV	SD	AV	SD	1	2	3	1	2	3
12/3/2557	0.0	7.13	0.06	7.07	0.09	7.07	7.15	7.18	6.97	7.09	7.14
13/3/2557	1.0	8.27	0.02	7.17	0.05	8.27	8.29	8.26	7.13	7.17	7.22
14/3/2557	1.8	7.92	0.05	7.36	0.14	7.88	7.91	7.98	7.48	7.39	7.20
15/3/2557	3.0	8.57	0.05	7.29	0.13	8.61	8.58	8.51	7.43	7.28	7.17
16/3/2557	4.0	8.16	0.13	7.49	0.11	8.04	8.29	8.15	7.39	7.49	7.60
17/3/2557	4.8	7.78	0.13	7.04	0.04	7.63	7.88	7.84	7.09	7.03	7.01
18/3/2557*	5.9	8.40	0.10	7.54	0.10	8.50	8.40	8.31	7.65	7.50	7.46
19/3/2557	6.9	8.41	0.07	7.52	0.11	8.46	8.45	8.33	7.62	7.52	7.41
20/3/2557*	8.0	8.51	0.02	7.33	0.05	8.53	8.49	8.51	7.38	7.32	7.29
21/3/2557	8.8	8.16	0.14	7.21	0.17	8.01	8.19	8.28	7.34	7.28	7.02
22/3/2557*	10.0	7.97	0.20	7.36	0.15	7.78	7.97	8.17	7.50	7.37	7.21
24/3/2557*	11.9	8.43	0.06	7.48	0.14	8.43	8.38	8.49	7.34	7.48	7.62
25/3/2557	13.0	8.18	0.11	7.32	0.08	8.30	8.16	8.08	7.24	7.33	7.39
27/3/2557	14.8	8.06	0.09	7.43	0.07	7.96	8.13	8.09	7.50	7.43	7.37
28/3/2557	16.0	8.47	0.01	7.35	0.04	8.48	8.46	8.47	7.30	7.36	7.38
29/3/2557	17.0	8.26	0.11	7.29	0.02	8.28	8.15	8.36	7.29	7.31	7.28

Appendix Table C35 Cell density of microalgae cultivated in wastewater under outdoor continuous culture experiment.

Cell Density of <i>Scenedesmus</i> sp. (10^4 cell/ml)						
Date	Days	AV	SD	1	2	3
29/4/2557	0.0	23.14	6.05	19.14	30.09	20.19
30/4/2557	0.9	10.51	3.70	14.63	7.47	9.44
1/5/2557	1.9	20.25	2.19	18.89	22.78	19.07
2/5/2557	3.0	74.81	13.17	62.78	72.78	88.89
3/5/2557	3.8	111.85	26.25	82.22	121.11	132.22
5/5/2557	5.9	210.83	75.59	154.17	181.67	296.67
6/6/2557	6.9	291.36	39.37	336.11	262.04	275.93
7/5/2557	8.0	259.88	118.44	396.30	200.00	183.33
8/5/2557	8.9	182.72	27.69	207.41	187.96	152.78
9/5/2557	10.0	154.63	48.68	210.19	134.26	119.44
10/5/2557	10.8	123.46	9.32	133.33	122.22	114.81
11/5/2557	11.9	111.42	5.27	112.96	115.74	105.56
12/5/2557	12.9	114.20	38.56	158.33	97.22	87.04
13/5/2557	14.0	141.36	43.52	185.19	140.74	98.15
14/5/2557	14.9	121.91	19.97	130.56	136.11	99.07
15/5/2557	16.0	115.74	9.04	125.00	106.94	115.28
16/5/2557	17.0	95.37	10.68	107.41	87.04	91.67
17/5/2557	17.8	92.28	21.32	74.07	87.04	115.74
18/5/2557	18.8	81.23	48.76	113.89	104.63	25.19
19/5/2557	19.9	60.68	42.93	105.56	56.48	20.00
20/5/2557	21.0	87.35	21.80	108.33	88.89	64.81
21/5/2557	21.9	96.60	17.18	78.70	98.15	112.96
22/5/2557	22.7	90.74	12.83	105.56	83.33	83.33
23/5/2557	23.8	82.41	13.98	69.44	80.56	97.22
24/5/2557	25.0	105.86	46.37	88.89	158.33	70.37
25/5/2557	25.9	109.26	19.33	122.22	87.04	118.52
26/5/2557	27.0	104.63	18.91	119.44	83.33	111.11
27/5/2557	28.0	96.91	30.80	120.37	62.04	108.33

Appendix Table C35 (Continued)

Cell Density of <i>Scenedesmus</i> sp. (10^4 cell/ml)						
Date	Days	AV	SD	1	2	3
28/5/2557	28.9	109.26	29.59	142.59	86.11	99.07
29/5/2557	30.0	109.26	16.97	105.56	94.44	127.78
30/5/2557	30.9	91.67	10.02	88.89	83.33	102.78
31/5/2557	31.7	99.69	8.40	109.26	96.30	93.52
1/6/2557	32.9	99.69	8.40	109.26	96.30	93.52
2/6/2557	33.7	103.70	20.48	111.11	80.56	119.44
3/6/2557	35.0	107.41	11.23	113.89	94.44	113.89
4/6/2557	36.0	107.41	6.99	113.89	108.33	100.00
5/6/2557	37.0	102.78	10.02	100.00	113.89	94.44
6/6/2557	38.0	93.52	13.13	88.89	108.33	83.33

Appendix Table C36 Biomass of microalgae cultivated in wastewater under outdoor continuous culture experiment.

Biomass of <i>Scenedesmus</i> sp. (mg/L)						
Date	Days	AV	SD	1	2	3
29/4/2557	0.0	103.14	20.53	89.56	126.76	93.12
30/4/2557	0.9	60.28	12.56	74.25	49.94	56.65
1/5/2557	1.9	93.33	7.45	88.72	101.92	89.35
2/5/2557	3.0	278.62	44.73	237.75	271.70	326.41
3/5/2557	3.8	404.38	89.15	303.77	435.82	473.55
5/5/2557	5.9	740.48	256.69	548.06	641.44	1031.94
6/6/2557	6.9	1013.91	133.70	1165.87	914.35	961.51
7/5/2557	8.0	907.01	402.16	1370.24	703.70	647.10
8/5/2557	8.9	645.01	94.02	728.85	662.82	543.35
9/5/2557	10.0	549.64	165.30	738.28	480.47	430.16
10/5/2557	10.8	443.79	31.65	477.32	439.59	414.44
11/5/2557	11.9	402.91	17.88	408.15	417.59	383.00
12/5/2557	12.9	412.35	130.94	562.21	354.70	320.12
13/5/2557	14.0	504.57	147.78	653.39	502.48	357.85
14/5/2557	14.9	438.55	67.82	467.89	486.76	360.99
15/5/2557	16.0	417.59	30.68	449.03	387.72	416.01
16/5/2557	17.0	348.42	36.26	389.29	320.12	335.84
17/5/2557	17.8	337.94	72.40	276.10	320.12	417.59
18/5/2557	18.8	300.42	165.57	411.30	379.86	110.10
19/5/2557	19.9	230.62	145.78	383.00	216.37	92.49
20/5/2557	21.0	321.17	74.02	392.43	326.41	244.66
21/5/2557	21.9	352.61	58.34	291.82	357.85	408.15
22/5/2557	22.7	332.70	43.57	383.00	307.54	307.54
23/5/2557	23.8	304.40	47.47	260.38	298.11	354.70
24/5/2557	25.0	384.05	157.46	326.41	562.21	263.53
25/5/2557	25.9	395.58	65.65	439.59	320.12	427.02
26/5/2557	27.0	379.86	64.20	430.16	307.54	401.87

Appendix Table C36 (Continued)

Biomass of <i>Scenedesmus</i> sp. (mg/L)						
Date	Days	AV	SD	1	2	3
27/5/2557	28.0	353.66	104.58	433.31	235.23	392.43
28/5/2557	28.9	395.58	100.46	508.76	316.98	360.99
29/5/2557	30.0	395.58	57.63	383.00	345.27	458.46
30/5/2557	30.9	335.84	34.01	326.41	307.54	373.57
31/5/2557	31.7	363.09	28.53	395.58	351.56	342.13
1/6/2557	32.9	363.09	28.53	395.58	351.56	342.13
2/6/2557	33.7	376.71	69.53	401.87	298.11	430.16
3/6/2557	35.0	389.29	38.12	411.30	345.27	411.30
4/6/2557	36.0	389.29	23.74	411.30	392.43	364.14
5/6/2557	37.0	373.57	34.01	364.14	411.30	345.27
6/6/2557	38.0	342.13	44.57	326.41	392.43	307.54

Appendix Table C37 Dilution rate of microalgae cultivated in wastewater under outdoor continuous culture experiment.

Dilution rate (day ⁻¹)						
Date	Days	AV	SD	1	2	3
29/4/2557	0.0	0.00	0.00	0.00	0.00	0.00
30/4/2557	0.9	0.00	0.00	0.00	0.00	0.00
1/5/2557	1.9	0.00	0.00	0.00	0.00	0.00
2/5/2557	3.0	0.00	0.00	0.00	0.00	0.00
3/5/2557	3.8	0.00	0.00	0.00	0.00	0.00
5/5/2557	5.9	0.00	0.00	0.00	0.00	0.00
6/6/2557	6.9	0.00	0.00	0.00	0.00	0.00
7/5/2557	8.0	0.39	0.01	0.40	0.38	0.40
8/5/2557	8.9	0.37	0.04	0.33	0.42	0.35
9/5/2557	10.0	0.53	0.06	0.54	0.46	0.58
10/5/2557	10.8	0.46	0.04	0.46	0.42	0.50
11/5/2557	11.9	0.39	0.05	0.42	0.33	0.42
12/5/2557	12.9	0.54	0.04	0.54	0.58	0.50
13/5/2557	14.0	0.44	0.05	0.42	0.50	0.42
14/5/2557	14.9	0.53	0.04	0.52	0.58	0.50
15/5/2557	16.0	0.65	0.06	0.58	0.67	0.71
16/5/2557	17.0	0.74	0.10	0.63	0.83	0.75
17/5/2557	17.8	0.42	0.00	0.42	0.42	0.42
18/5/2557	18.8	0.00	0.00	0.00	0.00	0.00
19/5/2557	19.9	0.00	0.00	0.00	0.00	0.00
20/5/2557	21.0	0.52	0.02	0.50	0.53	0.52
21/5/2557	21.9	0.46	0.01	0.45	0.46	0.47
22/5/2557	22.7	0.54	0.04	0.54	0.50	0.58
23/5/2557	23.8	0.43	0.03	0.42	0.47	0.42
24/5/2557	25.0	0.44	0.05	0.42	0.50	0.42
25/5/2557	25.9	0.38	0.04	0.33	0.38	0.42
26/5/2557	27.0	0.42	0.14	0.33	0.33	0.58
27/5/2557	28.0	0.39	0.05	0.42	0.33	0.43

Appendix Table C37 (Continued)

Date	Days	Dilution rate (day ⁻¹)				
		AV	SD	1	2	3
28/5/2557	28.9	0.49	0.03	0.50	0.52	0.46
29/5/2557	30.0	0.49	0.03	0.50	0.52	0.46
30/5/2557	30.9	0.56	0.10	0.50	0.50	0.67
31/5/2557	31.7	0.49	0.02	0.50	0.50	0.46
1/6/2557	32.9	0.74	0.23	0.58	0.63	1.00
2/6/2557	33.7	0.49	0.06	0.42	0.50	0.54
3/6/2557	35.0	0.44	0.07	0.37	0.46	0.50
4/6/2557	36.0	0.50	0.04	0.50	0.46	0.54
5/6/2557	37.0	0.53	0.05	0.50	0.50	0.58
6/6/2557	38.0	0.38	0.05	0.33	0.38	0.43

Appendix Table C38 Volumetric biomass productivity of microalgae cultivated in wastewater under outdoor continuous culture experiment.

Volumetric Productivity (mg/L/day)						
Date	Days	AV	SD	1	2	3
29/4/2557	0.0	0.00	0.00	0.00	0.00	0.00
30/4/2557	0.9	0.00	0.00	0.00	0.00	0.00
1/5/2557	1.9	0.00	0.00	0.00	0.00	0.00
2/5/2557	3.0	0.00	0.00	0.00	0.00	0.00
3/5/2557	3.8	0.00	0.00	0.00	0.00	0.00
5/5/2557	5.9	0.00	0.00	0.00	0.00	0.00
6/6/2557	6.9	0.00	0.00	0.00	0.00	0.00
7/5/2557	8.0	44.35	19.90	67.30	33.54	32.19
8/5/2557	8.9	270.21	49.57	277.66	315.63	217.34
9/5/2557	10.0	268.01	88.72	369.14	203.27	231.63
10/5/2557	10.8	256.49	22.95	276.34	231.37	261.75
11/5/2557	11.9	138.92	13.95	151.17	123.73	141.85
12/5/2557	12.9	223.83	73.71	304.53	206.91	160.06
13/5/2557	14.0	206.95	60.81	251.30	231.91	137.63
14/5/2557	14.9	256.79	56.74	263.72	309.75	196.91
15/5/2557	16.0	241.51	17.76	232.83	229.76	261.93
16/5/2557	17.0	277.07	12.95	265.42	291.02	274.78
17/5/2557	17.8	168.97	36.20	138.05	160.06	208.79
18/5/2557	18.8	0.00	0.00	0.00	0.00	0.00
19/5/2557	19.9	0.00	0.00	0.00	0.00	0.00
20/5/2557	21.0	152.83	32.93	181.12	160.69	116.69
21/5/2557	21.9	165.38	30.26	134.11	167.50	194.52
22/5/2557	22.7	233.79	34.84	269.14	199.49	232.74
23/5/2557	23.8	121.66	19.06	100.15	128.42	136.42
24/5/2557	25.0	150.55	79.09	116.57	240.95	94.12
25/5/2557	25.9	154.61	30.23	152.90	125.26	185.66
26/5/2557	27.0	178.05	17.88	198.54	165.60	170.02
27/5/2557	28.0	150.59	75.44	144.44	78.41	228.92

Appendix Table C38 (Continued)

Volumetric Productivity (mg/L/day)						
Date	Days	AV	SD	1	2	3
28/5/2557	28.9	172.39	58.02	231.26	115.26	170.65
29/5/2557	30.0	178.47	14.72	176.77	164.67	193.96
30/5/2557	30.9	205.83	57.27	178.04	167.75	271.69
31/5/2557	31.7	223.32	25.91	249.84	222.04	198.07
1/6/2557	32.9	218.65	56.04	190.97	181.84	283.14
2/6/2557	33.7	183.17	44.13	167.44	149.06	233.00
3/6/2557	35.0	171.57	29.75	150.81	158.25	205.65
4/6/2557	36.0	194.25	13.15	205.65	179.87	197.24
5/6/2557	37.0	196.38	12.57	182.07	205.65	201.41
6/6/2557	38.0	129.74	19.42	108.80	147.16	133.27

Appendix Table C39 Areal biomass productivity of microalgae cultivated in wastewater under outdoor continuous culture experiment.

Areal Productivity (g/m ² /day)						
Date	Days	AV	SD	1	2	3
29/4/2557	0.0	0.00	0.00	0.00	0.00	0.00
30/4/2557	0.9	0.00	0.00	0.00	0.00	0.00
1/5/2557	1.9	0.00	0.00	0.00	0.00	0.00
2/5/2557	3.0	0.00	0.00	0.00	0.00	0.00
3/5/2557	3.8	0.00	0.00	0.00	0.00	0.00
5/5/2557	5.9	0.00	0.00	0.00	0.00	0.00
6/6/2557	6.9	0.00	0.00	0.00	0.00	0.00
7/5/2557	8.0	8.47	3.80	12.86	6.41	6.15
8/5/2557	8.9	51.63	9.47	53.06	60.31	41.53
9/5/2557	10.0	51.21	16.95	70.54	38.84	44.26
10/5/2557	10.8	49.01	4.38	52.80	44.21	50.02
11/5/2557	11.9	26.54	2.67	28.89	23.64	27.11
12/5/2557	12.9	42.77	14.08	58.19	39.54	30.58
13/5/2557	14.0	39.54	11.62	48.02	44.31	26.30
14/5/2557	14.9	49.07	10.84	50.39	59.19	37.63
15/5/2557	16.0	46.15	3.39	44.49	43.90	50.05
16/5/2557	17.0	52.94	2.47	50.72	55.61	52.51
17/5/2557	17.8	32.29	6.92	26.38	30.58	39.90
18/5/2557	18.8	0.00	0.00	0.00	0.00	0.00
19/5/2557	19.9	0.00	0.00	0.00	0.00	0.00
20/5/2557	21.0	29.20	6.29	34.61	30.71	22.30
21/5/2557	21.9	31.60	5.78	25.63	32.01	37.17
22/5/2557	22.7	44.67	6.66	51.43	38.12	44.47
23/5/2557	23.8	23.25	3.64	19.14	24.54	26.07
24/5/2557	25.0	28.77	15.11	22.28	46.04	17.98
25/5/2557	25.9	29.54	5.78	29.22	23.94	35.48
26/5/2557	27.0	34.02	3.42	37.94	31.64	32.49
27/5/2557	28.0	28.77	14.42	27.60	14.98	43.74

Appendix Table C39 (Continued)

Areal Productivity (g/m ² /day)						
Date	Days	AV	SD	1	2	3
28/5/2557	28.9	32.94	11.09	44.19	22.02	32.61
29/5/2557	30.0	34.10	2.81	33.78	31.47	37.06
30/5/2557	30.9	39.33	10.94	34.02	32.05	51.91
31/5/2557	31.7	42.67	4.95	47.74	42.43	37.85
1/6/2557	32.9	41.78	10.71	36.49	34.75	54.10
2/6/2557	33.7	46.67	11.24	42.66	37.98	59.36
3/6/2557	35.0	24.59	4.26	21.61	22.68	29.47
4/6/2557	36.0	37.12	2.51	39.30	34.37	37.69
5/6/2557	37.0	37.52	2.40	34.79	39.30	38.49
6/6/2557	38.0	24.79	3.71	20.79	28.12	25.47

Appendix Table C40 Inorganic nitrogen and inorganic phosphorus during *Scenedesmus* sp. cultivation in 6 L vertical column photobioreactor under outdoor continuous culture experiment.

Date	Day	Treatment								Initial Wastewater							
		TAN (mg N/L)		Nitrite (mg N/L)		Nitrate (mg N/L)		Phosphate (mg P/L)		TAN (mg N/L)		Nitrite (mg N/L)		Nitrate (mg N/L)		Phosphate (mg P/L)	
		Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD
29/4/2557	0.0	20.62	1.36	0.16	0.04	32.17	2.28	7.36	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30/4/2557	0.9	16.26	2.28	11.75	0.40	7.70	4.30	5.06	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1/5/2557	1.9	19.32	1.34	6.46	4.79	5.01	1.36	5.92	1.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2/5/2557	3.0	19.61	1.24	5.01	4.47	2.68	0.16	4.53	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3/5/2557	3.8	17.63	3.40	1.43	1.91	2.52	0.67	4.29	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5/5/2557	5.9	6.85	1.90	0.02	0.03	2.59	0.14	3.68	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6/6/2557	6.9	4.37	0.40	0.04	0.07	2.51	0.35	3.30	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/5/2557	8.0	3.43	1.50	0.10	0.03	0.27	0.05	3.73	0.19	30.09	5.18	0.07	0.01	8.96	0.37	9.25	0.10
8/5/2557	8.9	4.92	0.73	0.04	0.01	0.23	0.04	3.03	0.44	14.20	0.71	0.04	0.01	9.22	0.21	8.85	0.07
9/5/2557	10.0	9.09	1.94	0.06	0.01	0.34	0.06	4.85	0.83	11.28	1.21	0.05	0.01	8.45	0.18	9.25	0.06
10/5/2557	10.8	10.90	0.89	0.02	0.01	2.61	0.03	5.36	0.54	15.15	1.27	0.02	0.01	7.08	0.06	7.99	0.09
11/5/2557	11.9	11.61	1.35	0.01	0.01	2.65	0.03	5.71	0.52	19.85	0.42	0.00	0.01	6.78	0.06	7.81	0.07
12/5/2557	12.9	11.22	3.28	0.01	0.01	2.67	0.10	5.50	0.72	20.67	0.28	0.00	0.00	8.09	0.11	8.03	0.34
13/5/2557	14.0	16.18	4.25	0.00	0.01	2.58	0.43	5.45	1.69	14.10	0.76	0.02	0.00	5.56	0.09	6.48	0.47
14/5/2557	14.9	18.02	3.91	0.00	0.00	2.79	0.19	5.47	0.46	17.51	2.86	0.00	0.00	8.68	0.04	8.65	0.25

Appendix Table C40 (Continued)

Date	Day	Treatment								Initial Wastewater							
		TAN (mg N/L)		Nitrite (mg N/L)		Nitrate (mg N/L)		Phosphate (mg P/L)		TAN (mg N/L)		Nitrite (mg N/L)		Nitrate (mg N/L)		Phosphate (mg P/L)	
		Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD
21/5/2557	21.9	5.70	2.67	0.04	0.02	1.80	0.17	3.73	1.58	4.11	1.10	0.07	0.01	3.04	0.09	3.94	0.06
22/5/2557	22.7	3.28	2.39	0.02	0.01	1.74	0.11	3.78	1.28	8.14	0.74	0.03	0.00	2.62	0.05	13.18	0.47
23/5/2557	23.8	4.04	1.48	0.03	0.03	1.77	0.09	3.50	0.23	20.72	0.65	0.03	0.01	4.04	0.22	4.98	0.22
24/5/2557	25.0	16.75	3.05	0.04	0.02	2.08	0.29	4.69	0.94	7.38	1.76	0.07	0.01	7.42	0.05	6.75	0.12
25/5/2557	25.9	13.32	2.13	0.04	0.03	2.32	0.46	5.58	0.95	9.25	2.47	0.07	0.01	5.99	0.21	6.69	0.09
27/5/2557	28.0	12.49	1.24	0.16	0.12	2.24	0.27	8.10	4.45	13.88	0.79	0.01	0.02	8.18	0.08	7.94	0.51
29/5/2557	30.0	15.32	3.56	0.04	0.05	2.94	0.46	6.11	0.77	61.49	1.96	0.08	0.01	10.73	0.13	9.34	0.22
30/5/2557	30.9	25.06	9.31	0.00	0.00	5.39	5.32	6.90	0.51	52.90	0.91	0.02	0.00	11.51	0.01	8.53	1.70
31/5/2557	31.7	20.38	12.26	0.07	0.01	13.65	0.33	10.13	4.92	5.26	1.00	0.03	0.02	2.17	0.15	1.63	0.08
1/6/2557	32.9	7.86	2.51	0.15	0.08	4.05	0.56	2.85	1.10	1.92	0.86	0.03	0.01	2.41	0.04	1.50	0.05
2/6/2557	33.7	6.27	3.13	0.33	0.24	5.41	1.41	2.43	0.74	3.51	0.97	0.06	0.01	2.34	0.06	1.05	0.02
3/6/2557	35.0	4.41	1.73	0.14	0.15	1.94	0.27	1.68	0.64	15.04	1.78	0.01	0.01	4.83	0.07	1.24	0.03
4/6/2557	36.0	4.55	0.58	0.00	0.00	2.40	0.22	1.37	0.37	16.30	0.33	0.02	0.01	5.24	0.16	1.37	0.02
5/6/2557	37.0	3.26	0.70	0.00	0.00	1.56	0.10	1.13	0.37	13.81	0.32	0.02	0.01	4.56	0.22	1.44	0.02
6/6/2557	38.0	1.92	1.20	0.00	0.01	1.43	0.03	0.91	0.62	14.64	0.97	0.02	0.00	6.13	0.09	1.31	0.05

Appendix Table C41 Total COD changing during *Scenedesmus* sp. cultivation in 6L vertical column photobioreactor under outdoor continuous culture experiment.

Total COD (mg/L)							
Date	Day	Treatment					initial wastewater
		Average	SD	1	2	3	
7/5/2557	8.0	888.89	171.07	790.12	1086.42	790.12	4790.12
8/5/2557	8.9	987.65	452.60	1382.72	1086.42	493.83	4641.98
9/5/2557	10.0	790.12	592.59	1382.72	197.53	790.12	4493.83
10/5/2557	10.8	888.89	153.96	800.00	800.00	1066.67	3111.11
11/5/2557	11.9	711.11	153.96	800.00	800.00	533.33	2666.67
12/5/2557	12.9	533.33	266.67	800.00	533.33	266.67	4000.00
13/5/2557	14.0	1047.62	329.91	1428.57	857.14	857.14	7857.14
14/5/2557	14.9	952.38	436.44	857.14	1428.57	571.43	9285.71
15/5/2557	16.0	666.67	436.44	1142.86	571.43	285.71	9285.71
16/5/2557	17.0	711.11	153.96	800.00	533.33	800.00	8765.43
17/5/2557	17.8	815.99	258.47	790.12	1086.42	571.43	9285.71
18/5/2557	18.8	888.89	153.96	800.00	1066.67	800.00	8765.43
19/5/2557	19.9	736.51	285.93	1066.67	571.43	571.43	7857.14
21/5/2557	21.9	888.89	153.96	800.00	1066.67	800.00	7857.14
22/5/2557	22.7	882.30	159.67	790.12	1066.67	790.12	6000.00
23/5/2557	23.8	647.62	131.96	571.43	571.43	800.00	6000.00
24/5/2557	25.0	888.89	153.96	800.00	1066.67	800.00	7857.14
25/5/2557	25.9	618.93	148.26	790.12	533.33	533.33	8765.43
27/5/2557	28.0	885.60	156.89	790.12	1066.67	800.00	8765.43
29/5/2557	30.0	711.11	153.96	800.00	533.33	800.00	6000.00
30/5/2557	30.9	882.30	159.67	790.12	1066.67	790.12	6000.00
31/5/2557	31.7	723.81	297.54	533.33	571.43	1066.67	7857.14
1/6/2557	32.9	800.00	266.67	800.00	1066.67	533.33	9285.71
2/6/2557	33.7	888.89	153.96	1066.67	800.00	800.00	9285.71
3/6/2557	35.0	707.82	151.19	790.12	533.33	800.00	6000.00
4/6/2557	36.0	885.60	156.89	800.00	1066.67	790.12	7857.14
5/6/2557	37.0	723.81	131.96	800.00	800.00	571.43	7857.14
6/6/2557	38.0	634.92	144.23	571.43	533.33	800.00	6000.00

Appendix Table C42 Soluble COD changing during *Scenedesmus* sp. cultivation in 6L vertical column photobioreactor under outdoor continuous culture experiment.

Soluble COD (mg/L)							
Date	Day	Treatment					initial wastewater
		Average	SD	1	2	3	
7/5/2557	8.0	138.27	34.21	158.02	98.77	158.02	908.64
8/5/2557	8.9	118.52	34.21	98.77	158.02	98.77	572.84
9/5/2557	10.0	158.02	102.64	217.28	39.51	217.28	750.62
10/5/2557	10.8	177.78	101.84	66.67	200.00	266.67	866.67
11/5/2557	11.9	244.44	38.49	200.00	266.67	266.67	933.33
12/5/2557	12.9	266.67	66.67	266.67	200.00	333.33	866.67
13/5/2557	14.0	166.67	109.11	71.43	142.86	285.71	642.86
14/5/2557	14.9	309.52	41.24	285.71	285.71	357.14	1000.00
15/5/2557	16.0	500.00	257.54	428.57	785.71	285.71	1000.00
16/5/2557	17.0	333.33	41.24	357.14	357.14	285.71	866.67
17/5/2557	17.8	380.95	41.24	357.14	428.57	357.14	933.33
18/5/2557	18.8	333.33	41.24	357.14	285.71	357.14	1000.00
19/5/2557	19.9	309.52	41.24	285.71	357.14	285.71	866.67
21/5/2557	21.9	333.33	82.48	428.57	285.71	285.71	866.67
22/5/2557	22.7	357.14	71.43	285.71	357.14	428.57	1000.00
23/5/2557	23.8	333.33	41.24	357.14	357.14	285.71	866.67
24/5/2557	25.0	333.33	41.24	357.14	285.71	357.14	933.33
25/5/2557	25.9	309.52	41.24	285.71	357.14	285.71	866.67
27/5/2557	28.0	333.33	82.48	285.71	428.57	285.71	866.67
29/5/2557	30.0	357.14	71.43	357.14	285.71	428.57	933.33
30/5/2557	30.9	452.38	288.68	785.71	285.71	285.71	866.67
31/5/2557	31.7	357.14	0.00	357.14	357.14	357.14	1000.00
1/6/2557	32.9	309.52	41.24	285.71	285.71	357.14	866.67
2/6/2557	33.7	500.00	257.54	785.71	428.57	285.71	933.33
3/6/2557	35.0	452.38	288.68	285.71	285.71	785.71	933.33
4/6/2557	36.0	333.33	41.24	357.14	285.71	357.14	933.33
5/6/2557	37.0	309.52	41.24	285.71	357.14	285.71	866.67
6/6/2557	38.0	380.95	41.24	428.57	357.14	357.14	1000.00

Appendix Table C43 pH profile during *Scenedesmus* sp. cultivation in 6L vertical column photobioreactor under outdoor continuous culture experiment.

Date	Days	pH		Replicate		
		T3-1		T3-1		
		AV	SD	1	2	3
29/4/2557	0.0	6.97	0.03	6.94	6.97	6.99
30/4/2557	0.9	6.97	0.08	6.88	7.02	7.02
1/5/2557	1.9	7.03	0.07	6.96	7.10	7.02
2/5/2557	3.0	7.33	0.14	7.44	7.39	7.17
3/5/2557	3.8	7.03	0.06	6.96	7.07	7.05
5/5/2557	5.9	7.14	0.03	7.10	7.15	7.16
6/6/2557	6.9	7.13	0.05	7.07	7.14	7.17
7/5/2557	8.0	7.11	0.02	7.09	7.11	7.13
8/5/2557	8.9	7.25	0.07	7.18	7.31	7.27
10/5/2557	10.8	7.14	0.02	7.13	7.16	7.14
11/5/2557	11.9	7.12	0.03	7.08	7.14	7.14
12/5/2557	12.9	7.11	0.08	7.04	7.11	7.19
14/5/2557	14.9	7.09	0.04	7.05	7.10	7.13
15/5/2557	16.0	7.03	0.01	7.02	7.04	7.03
17/5/2557	17.8	7.03	0.01	7.03	7.02	7.03
19/5/2557	19.9	7.02	0.00	7.02	7.02	7.02
20/5/2557	21.0	7.02	0.01	7.03	7.03	7.01
22/5/2557	22.7	7.02	0.01	7.02	7.02	7.03
23/5/2557	23.8	7.02	0.01	7.02	7.02	7.03
26/5/2557	27.0	7.03	0.01	7.03	7.03	7.02
27/5/2557	28.0	7.06	0.03	7.05	7.04	7.10
30/5/2557	30.9	7.03	0.01	7.04	7.03	7.02
31/5/2557	31.7	7.02	0.01	7.03	7.02	7.01
2/6/2557	33.7	7.02	0.01	7.02	7.03	7.02
5/6/2557	37.0	7.03	0.01	7.02	7.04	7.03
6/6/2557	38.0	7.02	0.01	7.02	7.02	7.03
Average (staedy state)		7.03	0.00	7.03	7.03	7.03

Appendix Table C44 CHN content in *Scenedesmus* cell and wastewater sludge.

Sample	CHN component (%)														
	C		H		N		C			H			N		
	AV	SD	AV	SD	AV	SD	1	2	3	1	2	3	1	2	3
Initial sludge	33.47	0.02	6.09	0.06	6.17	0.09	33.45	33.49	33.47	6.07	6.15	6.04	6.10	6.28	6.14
Sludge after <i>Scenedesmus</i> sp. cultivated in photobioreactor	31.67	0.01	5.79	0.09	5.15	0.04	31.68	31.66	31.66	5.89	5.73	5.74	5.11	5.16	5.19
<i>Scenedesmus</i> sp. cultivated in photobioreactor using MLSS	14.35	0.76	2.68	0.11	2.48	0.14	15.00	14.52	13.52	2.76	2.56	2.72	2.61	2.50	2.34

Appendix Table C45 Total lipid content in microalgae.

Microalgae	% Total lipid				
	AV	SD	1	2	3
<i>Scenedesmus</i> sp.	7.13	1.78	5.43	8.98	6.99

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