Application of the Thin Flat-Plate Photo-Bioreactor to the Removal of Nitrate and Phosphate Using Marine *Nannochloropsis oculata*

Pei-Fen Wu, Sz-Chwun John Hwang, Guan-You Lin, Jiunn-Tzong Wu, and Cynthia Chun-Yu Hsieh

Abstract—**Many environmental issues of marine pollution and its causes and consequences were often learned from News. Algae in the ocean play the major role in the conversion of carbon dioxide into oxygen. This study used $NaHCO_3$ as a main carbon source to replace the two-percent-carbon-dioxide gas mixture that are often used in a large-scale algal field. The results show that the addition of 7.6 g/L $NaHCO_3$ obtains the best algal productivity and yield of about 4 g/L and 0.52 g/L/day, respectively. The shake-flask test shows that the cheap and easy-handling $NaHCO_3$ can be used as an alternative carbon source for replacement of CO_2 gas mixture in cultivation of microalgae and maintain the culture of effectiveness. In the thin flat-plate photo-bioreactor (FPPBR), designed to reduce the distance of the light pass, can solve the traditional drawback in the limit of the effective transmittance of light when cultured concentration increased, thereby inhibiting the growth of algae. The fed-batch FPPBR operated during 432 hr could reach a maximum algal concentration of 7.1 g/L in association with the periodical removal of substrate and nutrients (nitrate and phosphate) every three days. Its capacity for nitrate and phosphate were 0.22 g/m^2/day and 0.15 g/m^2/day, respectively referred to about 0.5-1.0 acre required for one-day spill for using FPPBR in the sea or in the adjacent coast area for treatment of an accidentally emitted domestic wastewater.**

Index Terms—**Estuary pollution, *Nannochloropsis oculata*, flat-plate photobioreactor.**

I. Introduction

The marine pollution is often ignored because of the misconception that the ocean is large enough to provide an infinite assimilative capacity for pollutants or because the marine pollutants would go away to other countries. Many environmental issues of marine pollution and its causes and consequences were learned from the Magazines or News. In Taiwan, not only the Environmental Protection Agency but also the local Environmental Protection Bureau (EPB) of the City or County has taken an action on the cleaning of the sea shore and coastal area. Many projects working on the auditing of the marine pollutants were executed for many years. The results can be found in the website of every local Environmental Protection Bureau, for example, the website of the EPB in Hsinchu County [1].

In the ocean algae play the major role in the conversion of carbon dioxide into oxygen. In rivers and reservoir, the eutrophication such as algae bloom is caused by the high load of nitrogen and phosphorus into the surface water. Consequently, algae have the capability to treat nitrogen and phosphorus with the oxygen produced through the algal growth, if they can be adequately utilized with continuously removal of the accumulated biomass. Therefore, in this study, *Nannochloropsis oculata* was chosen and associated with a high efficient photobioreactor.

Nannochloropsis oculata grows on temperate waters at 10-35 ^oC (the maximum growth rate at 25-31 ^oC). It can tolerate the high salinity between 5-77 ppt (the maximum growth rate at 20-35 ppt) and the strong light intensity from 12000 lux to 30000 lux (the most efficient at 12000 lux).

The algal photobioreactors have been studied for a long period of time. The commercial large-scale cultivation prefers the autotrophic mode using bicarbonate for the algal growth, requires a large surface area for capture of the light, and prevents the contamination of microorganisms [2]. Therefore, the carbon source using $NaHCO_3$ was considered in this study. Reference [3] reviewed many large-scale photobioreactor and classified them according to their efficiencies in mass transfer or light transmission. For example, (1) Open Pond is widely used because of its simple structure, but its major backs are on the poor mass transfer efficiency and the often-occurred interference by the weather [4]-[6]. (2) Flat-plate photobioreactor (FPPBR) was studied by Milner earlier in 1953. The major benefit is the high light utilization rate and mass transfer rate [7], [8]. (3) Tubular photobioreactor can be made with many modifications, such as horizontal [9], [10], spiral [11], vertical [12], Cone-shaped pipe [13], and inclined pipeline type [14], [15]. It has a very good mass transfer efficiency but poor light transmission, once the diameter of the pipe becomes large. (4) Vertical-column photobioreactor is designed to capture more light into the water phase, but light transmission becomes less when the scale in association with the diameter of column goes up [16]-[19]. (5) Internally-illuminated photobioreactor is designed to solve the problem of poor light transmission. However, it is only suitable for small scale of photobioreactor [20]. It becomes too complicated for set-up of light sources once the scale goes

Manuscript received February 3, 2015; revised May 5, 2015. This work was fully supported by the National Science Council under Grant NSC 100-2221-E-216 -002 and NSC 101-2221-E-216-017-MY1, 2&3 and in part by Green Energy and Environment Research Laboratories, Industrial Technology Research Institute.

Pei-Fen Wu is with the Green Energy and Environment Research Laboratories, Industrial Technology Research Institute, Hsinchu 310, Taiwan, ROC (e-mail: wpf@ itri.org.tw).

Sz-Chwun John Hwang and Cynthia Chun-Yu Hsieh are with the Department of Industrial Product Design, Chung Hua University, Hsinchu 300, Taiwan, ROC (e-mail: sjh@ chu.edu.tw, ch0315@ arch.nctu.edu.tw).

Guan-You Lin was with the Department of Civil Engineering, Chung Hua University, Hsinchu 300, Taiwan, ROC (e-mail: b09504072@chu.edu.tw).

Jiunn-Tzong Wu is with the Biodiversity Research Center, Academia Sinica, Taipei 115, Taiwan, ROC (e-mail: jtwu@gate.sinica.edu.tw).

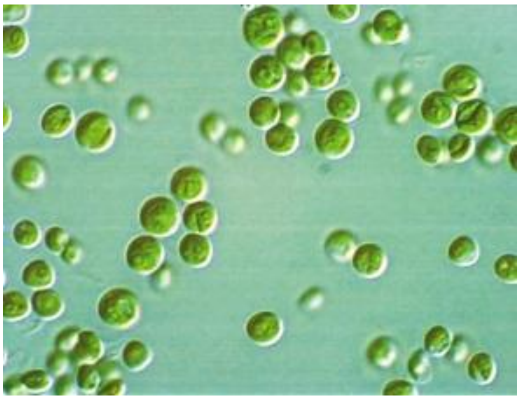
up.

The purpose of this study was to determine the characteristics of the pre-chosen FPPBR under the autotrophic mode feeding $NaHCO_3$ as carbon source. The resulting nitrogen and phosphorus removal were expected for cleaning the marine pollution in the sea, coastal area, or estuary.

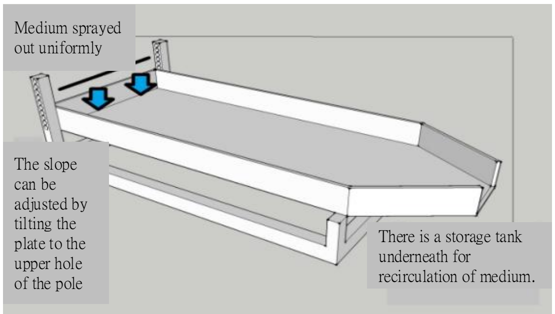
II. Materials and Methods

A. Microbe

The culture of marine *Nannochloropsis oculata* was obtained from the Dr. Su, Huei-Meei at Tungkang Marine Laboratory, Taiwan Fisheries Research Institute. The microscopical examination was shown in Fig. 1 a).



a)



b)

Fig. 1. *Nannochloropsis oculata*: a) the microscopical examination with a 200 × magnification, b) the schematic diagram of FPPBR.

B. Culture Medium

The F/2 medium shown in Table I was chosen for growth of marine *Nannochloropsis oculata* [21]. It contained sterilized seawater which was made with 20 g/L of NaCl diluted into R.O. water and then sterilized at 121 °C and 1.2 kg_f/cm^2 for 20 min. The stock solution of F/2 medium was normally stored in a 4 °C refrigerator and wrapped with aluminum foil before use. The Vit solution must be placed in an amber bottle. The trace metal solution and Vit solution were also stored in a 4 °C refrigerator.

C. The Flat-Plate Photobioreactor

The steel-made FPPBR (30 cm × 100 cm) was arranged with a slope of 3 % (Fig. 1b). There was a 20-L plastic tank underneath for storage of the circulation medium. The circulation of fluid was conveyed through a submersed water pump in the tank. The flowrate were set at 4 or 8.5 L/min.

D. Analysis

The algal concentration was obtained through the conversion of the algal optical density (O.D.) at 685 nm with the inversed calibration equation described by equation (1). The analysis of nitrate and phosphate was based on the methods of NIEA W436.51C and NIEA W427.53B, respectively, based on the Water Quality Standard Analysis Protocols announced by Environmental Analysis Laboratory, Environmental Protection Agency, Taiwan.

$$\begin{gathered} Biomass\ Conc.\ (\mathrm{g/L}) = 0.517 \times OD_{685} + 0.0156 \\ R^2 = 0.995 \end{gathered} \quad (1)$$

III. Results and Discussion

A. Microbial Characteristics

The environmental influencing factors were investigated through a series of shake-flask cultivation. They were optimal at pH of 8, at the initial substrate concentration of 7.6 g/L as $NaHCO_3$, and at the aeration rate of 0.15 L/min to keep algae suspended in a 20-L storage tank. Table II shows the comparisons of different carbon sources such as adding a 2% CO_2 or 7.6-g/L $NaHCO_3$ after 7-day cultivation. Both of them were validated to be the optimal concentrations for their own. According to the Table II, the results of microbial characteristics are comparable. Therefore, adding $NaHCO_3$ of 7.6 g/L was selected for the following experiment to make sure the light intensity is a dominant operating factor without the interference of the mass transfer efficiency for CO_2.

TABLE I: The Composition of F/2 Medium (Per Liter)

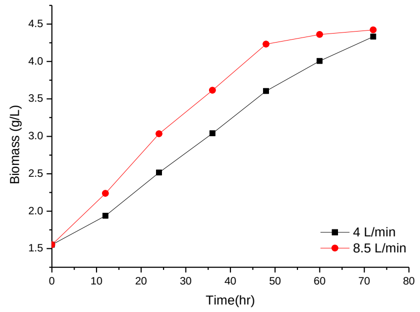
Composition	Amount	*Trace metal solution	Amount, g/L
KNO_3	0.075 g	EDTA Na_2	4.16
$NaH_2PO_4 \cdot 2H_2O$	0.00565 g	$FeCl_3 \cdot 6H_2O$	3.15
*Trace metal solution	1 c.c.	$CuSO_4 \cdot 5H_2O$	0.01
**Vit solution	1 c.c.	$ZnSO_4 \cdot 7H_2O$	0.022
****Vit solution**	Amount, g/L	$CoCl_2 \cdot 6H_2O$	0.01
Cyanobalamin (B_{12})	0.0005	$Na_2MoO_4 \cdot 6H_2O$	0.006
Thiamine HCl	0.1	$MnCl_2 \cdot 4H_2O$	0.18
Biotin	0.0005		

TABLE II: The Comparisons of the Algal Growth between Adding 2% CO_2 and Adding 7.6-g/L $NaHCO_3$

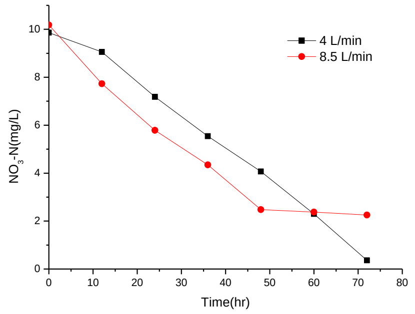
Carbon Source	μ (day^{-1})	The maximum algal concentration (g/L)	The average algal productivity (g/L/day)
CO_2	0.301	4.23	0.55
$NaHCO_3$	0.348	4.08	0.52

B. The Effect of the Flow Depth or the Water Circulation Rate on the Growth of *Nannochloropsis oculata*

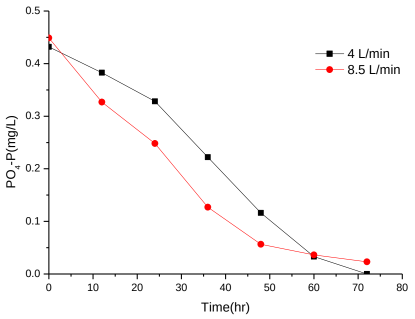
The experiments for different flow depths (0.2 cm and 0.5 cm) on the surface of the FPPBR under the light intensity of 15000 lux were performed by adjusting the water circulation rate to 4 and 8.5 L/min, respectively. If the nutrient supply is limited due to a high demand in algal growth, the higher water circulation rate will provide more nutrient per time to improve the growth condition. However, the thicker flow depth caused by the higher water circulation rate will have a less light absorbance efficiency if the algal concentration is kept the same. The results are shown in Fig. 2. Obviously, in this case, the higher algal concentration of 4.42 g/L was achieved at the water circulation rate of 8.5 L/min (Fig. 2 a)), due to the nutrient limitation occurred at the lower water circulation rate of 4 L/min (Fig. 2 b) and Fig. 2 c)).



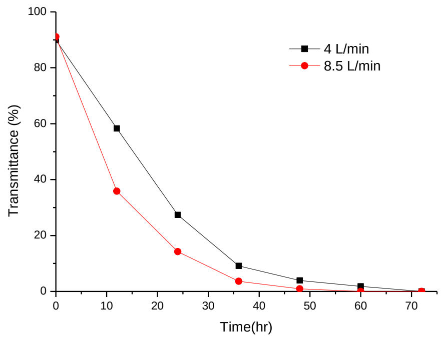
a)



b)



c)



d)

Fig. 2. The time courses of the performance of FPPBR under different water circulation rates between 4 and 8.5 L/min: a) the growth of *Nannochloropsis oculata*, b) the nitrate concentration, and c) the phosphate concentration, d) the transmittance of light passing through the water.

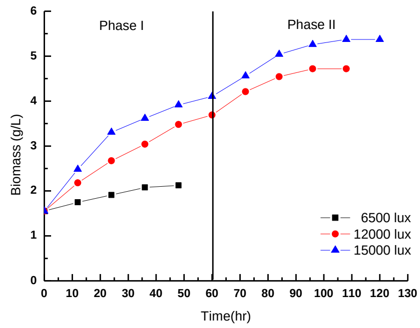
For both of them, before nutrients were completely consumed, the algal concentration increased faster during the period between the first 12 to 48 hr with the specific growth rate of 0.414 and 0.424 day^{-1} for the water circulation rate of 4 and 8.5 L/min, respectively (Table III). In the end of the experiment, algal concentration stopped increasing earlier at the water circulation rate of 8.5 L/min, indicating the higher algal biomass blocked the light traveling path through the water. There is an evidence from Fig. 2 d). The transmittance decreased immediately after the experiment started for the water circulation rate of 8.5 L/min.

TABLE III: THE PERFORMANCE IN THE GROWTH OF *NANNOCHLOROPSIS OCULATA* UNDER VARIOUS WATER CIRCULATION RATES

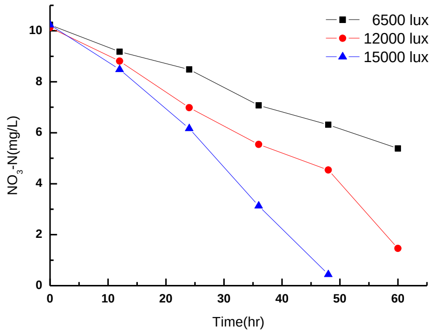
The medium recirculation rate (L/min)	μ (day^{-1})	The maximum algal concentration (g/L)	The average algal biomass productivity (g/L/day)
4	0.414	4.33	0.93
8.5	0.424	4.42	0.96

C. Effect of the Light Intensity on the Growth of *Nannochloropsis oculata*

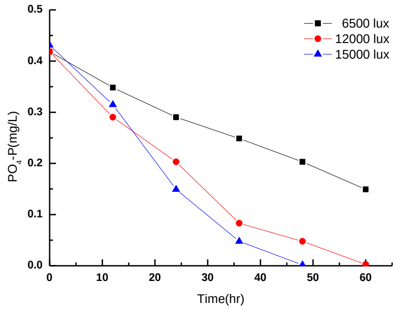
Experiments were also done in the FPPBR under the water circulation rate of 4 L/min. The light intensity was regulated by adjusting the distance of the light source, for example, 5 cm for 15000 lux, 15 cm for 12000 lux, and 45 cm for 6500 lux on the surface of the FPPBR. The initial algal biomass was 1.5±0.03 g/L. The growth of *Nannochloropsis oculata*, and the removal of nitrate and phosphate nutrients are shown in the Fig. 3. The higher the light intensity, the higher the algal concentration was obtained (Fig. 3 a)). However, the more algal biomass, the higher the demand on the nutrients of nitrate and phosphate. According to the Fig. 3b and 3c, the nitrate and phosphate were used up in 48 hr for the highest light intensity of 15000 lux. This is the reason why the biomass was accumulated slowly in the end of experiment. It is also proved by the following addition of the nutrients to the system in 60 hr. The algal concentration for the light intensity of 15000 lux increased again from the first plateau of 4.1 g/L to 5.4 g/L. On the opposite side, the maximum algal concentration for light intensity of 6500 lux was only 2 g/L. Much more nutrients were remained in 60 hr. It indicates that the light intensity is a key factor on the removal of the nutrient of nitrate and phosphate.



a)



b)



c)

Fig. 3. The time courses of the performance of FPPBR under various light intensity values from 6500 lux to 15000 lux: a) the growth of *Nannochloropsis oculata*, b) the nitrate concentration, and c) the phosphate concentration.

The algal concentration and biomass productivity was calculated in Table IV. It indicates that the light intensity of 12000 lux was more efficient and comparable to the light intensity of 15000 lux. In addition, the transmittance of light in the FPPBR was zero (Table IV) for the light intensity of 15000 lux, indicating the algal growth in the flow depth of 0.2 cm was limited by the amount of light absorbance when the incident light intensity was above 12000 lux.

TABLE IV: THE PERFORMANCE IN THE GROWTH OF *NANNOCHLOROPSIS OCULATA* UNDER VARIOUS INCIDENT LIGHT INTENSITY VALUES

The incident light intensity (lux)	μ (day^{-1})	The maximum algal concentration (g/L)	The average algal biomass productivity (g/L/day)	The transmittance of light in the FPPBR during 120 hr (%)
15000	0.376	5.37	0.76	0
12000	0.332	4.72	0.7	6.1
6500	0.173	2.12	0.29	28.9

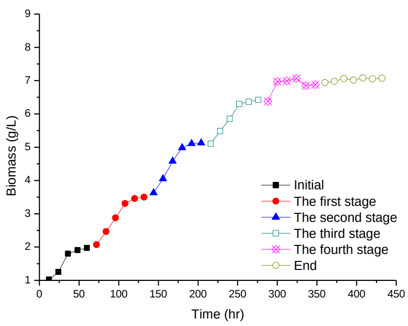
TABLE V: THE ESTIMATED REQUIRED AREA FOR FPPBR TO TREAT AN EFFLUENT OF DOMESTIC WASTE WATER TO MEET THE STANDARD OF EFFLUENT WATER QUALITY IN TAIWAN[#1]

Target Pollutants	Concentration to be removed (mg/L)	Flowrate (CMD)	Mass flow rate (g/day)	Capacity[#2] of FPPBR ($g/m^2/day$)	Estimated area for one day spill (m^2)
NO_3-N	30	250	7500	0.22	11364
PO_4	6	250	1500	0.15	5000

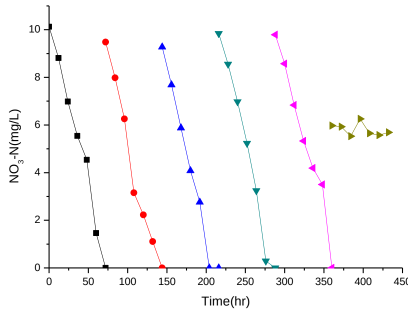
[#1]The standard of effluent water quality in Taiwan is 50 mg/L for NO_3-N and 4 mg/L for ortho-phosphate.
[#2]Capacity for nitrate = 10 mg/L*20 L/3 days/(0.3 m×1.0 m) and Capacity for ortho-phosphate = 1.5 mg/L*20 L/2 days/0.3 m^2*(31+64)/31

D. The Fed-Batch Cultivation of Nannochloropsis oculata Using FPPBR

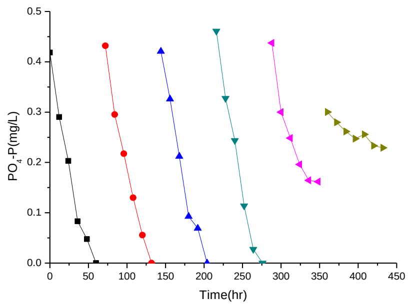
The FPPBR was designed for improvement of the conventional photobioreactor that has the major drawback on penetration of light into the deeper place of the reactor when the algal biomass was significantly accumulated. Although, the operating conditions of the incident light intensity and the water circulation rate were tuned already for the FPPBR, the nutrients were always insufficient. Nevertheless, there is a place that can provide the adequate substrate and nutrients periodically. That is the estuary of a river. The better way to simulate the cleaning process in the estuary of the river is doing the fed-batch reaction in FPPBR. The substrate of $NaHCO_3$ was provided again whenever the biomass concentration increased slowly and maintained at least for 12 hr, and the F/2 medium was replaced constantly every 60 hr. Since *Nannochloropsis oculata* was kept suspended in the medium, it was centrifuged twice at 1800 rpm for 5 min in 50-mL Eppendorf tubes using a High Speed Refrigerated Centrifuge, and then the supernatant was replaced with the new F/2 medium.



a)



b)



c)

Fig. 4. The time course of the performance of the fed-batch FPPBR under the light intensity of 12000 lux and the water circulation rate of 4 L/min: (a) the concentration of *Nannochloropsis oculat*, (b) the removal of nitrate, and (c) the removal of phosphate.

The performance of FPPBR in a fed-batch mode were resulted in the accumulation of algal biomass reaching a maximum algal concentration of 7.1 g/L in association with the periodical removal of substrate and nutrients (nitrate and phosphate) every three days (Fig. 4). It demonstrated that the algal system can maintain functioning in the FPPBR during 432 hr, almost for a half month. The amount of nitrate and phosphate in F/2 medium was consumed efficiently at the first two days in a three-day cycle, indicating the cycle time might be increased more if the concentration of pollutants was higher. The limitation of operating time was believed to be caused by no light penetration into the concentrated algal cells. Nevertheless, the maximum algal concentration of 7.1 g/L was more than twice as many as the tubular column reactor had in our laboratory.

The capacity of the FPPBR for nitrate and phosphate are 0.22 g/m^2/day and 0.15 $g/m^{2/}$day, respectively (Table V), indicating the estimated required area of FPPBR is about 0.1-0.5 acre in the sea or in the adjacent coastal area for treatment of an accidentally emitted domestic wastewater.

IV. Conclusions

The shake-flask test shows that the cheap and easy-handling $NaHCO_3$ can be used as an alternative carbon source for replacement of CO_2 gas mixture in cultivation of microalgae and maintain the culture of effectiveness. The optimal operating factors of FPPBR were at 4 L/min and 12000 lux. The fed-batch FPPBR operated during 432 hr could reach a maximum algal concentration of 7.1 g/L in association with the periodical removal of substrate and nutrients (nitrate and phosphate) every three days. Its capacity for nitrate and phosphate were 0.22 g/m^2/day and 0.15 g/m^2/day, respectively referred to about 0.5-1.0 acre required for using FPPBR in the sea or in the adjacent coast area for treatment of an accidentally emitted domestic wastewater.

References

[1] The Environmental Protection Bureau (EPB) of Hsinchu County, Taiwan, ROC. (January 2015). Water Pollution Control Section: Sea water quality monitoring results for the 4th quarter of 2014. *The website of EPB in Hsinchu County*. [Online]. Available: http://www.hcepb.gov.tw/ct/index.php?option=com_content&view=article&id=1161:2014-11-14-14-23-21&catid=60&Itemid=162

[2] K. L. Terry and L. P. Raymond, "System design for the autotrophic production of microalgae," *Enzyme and Microbial Technology*, vol. 7, no. 10, pp. 474–487, 1985.

[3] C. U. Ugwu, H. Aoyagi, and H. Uchiyama, "Photobioreactors for mass cultivation of algae," *Bioresource Technology*, vol. 99, no. 10, pp. 4021–4028, 2008.

[4] S. Boussiba, E. Sandbank, G. Shelef, Z. Cohen, A. Vonshak, A. Ben-Amotz, S. Arad, and A. Richmond, "Outdoor cultivation of the marine microalga *Isochrysis galbana* in open reactors," *Aquaculture*, vol. 72, no. 3–4, pp. 247–253, 1988.

[5] M. R. Tredici and R. Materassi, "From open ponds to vertical alveolar panels: The Italian experience in the development of reactors for the mass cultivation of photoautotrophic microorganisms," *Journal of Applied Phycology*, vol. 4, no. 3, pp. 221–231, 1992.

[6] R. Hase, H. Oikawa, C. Sasao, M. Morita, and Y. Watanabe, "Photosynthetic production of microalgal biomass in a raceway system under greenhouse conditions in Sendai City," *Journal of Bioscience and Bioengineering*, vol. 89, pp. 157–163, 2000.

[7] Q. Hu, H. Guterman, and A. Richmond, "A flat inclined modular photobioreactor for outdoor mass cultivation of Phototrophs," *Biotechnology and Bioengineering*, vol. 51, no. 1, pp. 51–60, 1996.

[8] A. Richmond, "Microalgal biotechnology at the turn of the millennium: A personal view," *Journal of Applied Phycology*, vol. 12, no. 3, pp. 441–451, 2000.

[9] D. Chaumont, C. Thepenier, and C. Gudin, "Scaling up a tubular photobioreactor for continuous culture of *Porphyridium cruentum*–from laboratory to pilot plant," in *Algal Biotechnology*, T. Stadler, J. Morillon, M. S. Verdus, W. Karamanos, H. Morvan, and D. Christiaen, Eds. London: Elsevier Applied Science, 1988, pp. 199-208.

[10] E. Molina, J. Fernández, F. G. Acién, and Y. Chisti, "Tubular photobioreactor design for algal cultures," *Journal of Biotechnology*, vol. 92, no. 2, pp. 113–131, 2001.

[11] S. J. Pirt, Y. K. Lee, M. R. Walach, M. W. Pirt, H. H. M. Balyuzi, and M. J. Bazin, "A tubular photobioreactor for photosynthetic production of biomass from carbon dioxide: Design and performance," *Journal of Chemical Technology and Biotechnology*, vol. 33B, pp. 35–38, 1983.

[12] M. R. Tredici and G. C. Zitelli, "Efficiency of sunlight utilization: Tubular versus flat photobioreactors," *Biotechnology and Bioengineering*, vol. 57, no. 2, pp. 187–197, 1998.

[13] Y. Watanabe and H. Saiki, "Development of photobioreactor incorporating *Chlorella* sp. for removal of CO_2 in stack gas," *Energy Conversion and Management*, vol. 38, pp. 499–503, 1997.

[14] Y. K. Lee and C. S. Low, "Effect of photobioreactor inclination on the biomass productivity of an outdoor algal culture," *Biotechnology and Bioengineering*, vol. 38, no. 9, pp. 995–1000, 1991.

[15] C. U. Ugwu, J. C. Ogbonna, and H. Tanaka, "Improvement of mass transfer characteristics and productivities of inclined tubular photobioreactors by installation of internal static mixers," *Applied Microbiology and Biotechnology*, vol. 58, no. 5, pp. 600–607, 2002.

[16] S. L. Choi, I. S. Suh, and C. G. Lee, "Lumostatic operation of bubble column photobioreactors for *Haematococcus pluvialis* cultures using a specific light uptake rate as a control parameter," *Enzyme and Microbial Technology*, vol. 33, pp. 403–409, 2003.

[17] J. Vega-Estrada, M. C. Montes-Horcasitas, A. R. Dominıguez-Bocanegra, and R. O. Canizares-Villanueva, "*Haematococcus pluvialis* cultivation in split-cylinder internal-loop airlift photobioreactor under aeration conditions avoiding cell damage," *Applied Microbiology and Biotechnology*, vol. 68, no. 1, pp. 31–35, 2005.

[18] M. C. García-Malea López, E. Del Rio, J. L. Casas López, F. G. Acién J. M. Fernández Sevilla, J. Rivas, M. G. Guerrero, and E. Molina-Grima, "Comparative analysis of the outdoor culture of *Haematococcus pluvialis* in tubular and bubble column photobioreactors," *Journal of Biotechnology*, vol. 123, no. 3, pp. 329–342, 2006.

[19] K. Kaewpintong, A. Shotipruk, S. Powtongsook, and P. Pavasant, "Photoautotrophic high-density cultivation of vegetative cells of *Haematococcus pluvialis* in airlift bioreactor," *Bioresource Technology*, vol. 98, pp. 288–295, 2007.

[20] J. C. Ogbonna, T. Soejima, and H. Tanaka, "An integrated solar and artificial light system for internal illumination of photobioreactors," *Journal of Biotechnology*, vol. 70, no. 1–3, pp. 289–297, 1999.

[21] P. F. Wu, J. C. Teng, Y. H. Lin, and S. C. J. Hwang, "Increasing algal biofuel production using *Nannocholropsis oculata* cultivated with anaerobically and aerobically treated swine wastewater," *Bioresource Technology*, vol. 133, pp. 102–108, April 2013.

Pei-Fen Wu was born in Yunlin, Taiwan (R.O.C.) in 1963. She graduated from the Department of Environmental Science, Feng Chia University (Taichung, Taiwan, R.O.C.) in 1986. During the period of the in-service training, she had the M.S. degree from the Department of Environmental Engineering, Feng Chia University (Taichung, Taiwan, R.O.C.) in 2006. Her major is biotechnology and microbiology.

She entered the Industrial Technology Research Institute, Chung Tung, Hsinchu County, Taiwan, R.O.C. in 1989. She is now a researcher and has primarily engaged in research of renewable energy and related works for nearly a decade, including refuse derived fuel (RDF) and production of biodiesel made from microalgae.

Sz-Chwun John Hwang was born in Taipei, Taiwan (R.O.C.) in 1959. He had his undergraduate degree from the Department of Chemical Engineering, Tunghai University (Taichung, Taiwan, R.O.C.) in 1981, and then had his M.S. degree from the Graduate Institute of Environmental Engineering, National Taiwan University (Taipei, Taiwan, R.O.C.) in 1986. Finally, he had the Ph.D. degree from the Department of Civil and Environmental Engineering, University of Iowa (Iowa City, U.S.A) in 1990. He became a memberof ACS and AWMA during the period in the States, and maintained the membership of AWMA for a several years after came back to his home Country. His major is biotechnology and biochemical engineering.

He was a lieutenant during serving the artillery troops in the army (1981-1983). Being a researcher, he had four-year working experience in Industrial Technology Research Institute (ITRI), Hsinchu City, Taiwan, R.O.C. (1990-1995). He had taught in the Department of Civil Engineering in Chung Hua University for 18 years (1995-2013), and then transferred to the Industrial Product Design Department. Recently, his research field focuses on the Green Design, Green Building, and Smart Products Devices wherever it is applying biotechnology.

In this project, he plays as a coordinator between the Science people and the Design people. He is trying to integrate the inter-discipline knowledge into the production of products designed for the environmental protection.

Guan-You Lin was born in Kaohsiung, Taiwan (R.O.C.) in 1988. He had his undergraduate degree from the Department of Civil Engineering, Chung Hua University (Hsinchu, Taiwan, R.O.C.) in 2010, and then had his M.S. degree from the same department of this University in 2014.

He had two-year internship in ITRI under Ms. Wu's guidance. He came back to the university to continue the same project for his thesis under the Prof. Hwang's guidance (2012-2014). He has gone to the army as a soldier after graduation until now.

Jiunn-Tzong Wu was born in Yilan, Taiwan (R.O.C.) in 1949. He had his undergraduate degree from the Department of Plant Biology, National Taiwan University (Taipei, Taiwan, R.O.C.) in 1971, and then had his M.S. degree from the Graduate Institute of Plant Biology, National Taiwan University (Taipei, Taiwan, R.O.C.) in 1973. Finally, he had the Ph.D. degree from Göttingen University, Germany in 1980. His major is phycology, limnology, and eco-physiology.

He is a research fellow and also the deputy director of Biodiversity Research Center in Academia Sonica. Recently, the research field focuses on the bioindicator of water pollution and eutrophication, allelopathy and active compounds of phytoplankton, and ecophysiology of algae.

Cynthia Chun-Yu Hsieh was born in Taoyuan, Taiwan (R.O.C.) in 1976. She had her undergraduate degree from the Department of Interior Design, Chung Yuan Christian University (Taoyuan, Taiwan, R.O.C.) in 1998, and then had her M.A. degree from the Graduate Institute of Architecture, National Chiao Tung University in 2004, and then had the Ph.D. degree from the Department of Civil Engineering, National Chiao Tung University (Hsinchu, Taiwan, R.O.C.) in 2010 under the same program. In addition, she also had M.A. degree from History and theory program, the Architectural Association School of Architecture, London, U.K in 2007. Her major is creativity study, architectural history, interior design, digital architecture.

She had four-year working experience as a chief editor of an Interior Design Magazine, before she pursued the Ph.D. degree. She has taught in the Department of Industrial Product Design, Chung Hua University for 4 years (2010-2015), and became the chairman of this department when it was established in 2012. Recently, her research field focuses on the Green Design, Green Building, and Tectonics.