



UNIVERSITI PUTRA MALAYSIA

***PRODUCTIVITY AND PROXIMATE ANALYSES OF SPIRULINA
(ARTHROSPIRA PLATENSIS) IN DIFFERENT FLOATING
WATER-BASED PHOTOBIOREACTOR DESIGNS***

MOHAMED AMAR NAQQUDDIN BIN ABDUL KADER

FS 2016 6



**PRODUCTIVITY AND PROXIMATE ANALYSES OF SPIRULINA
(*ARTHROSPIRA PLATENSIS*) IN DIFFERENT FLOATING
WATER-BASED PHOTOBIOREACTOR DESIGNS**

By

MOHAMED AMAR NAQQIUDDIN BIN ABDUL KADER

**Thesis Submitted to the School of Graduate Studies, Universiti Putra
Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of
Philosophy**

July 2016

COPYRIGHT

All material contained within the thesis, including without limitation text, logos, icons, photographs, and all other artwork, is copyright material of Universiti Putra Malaysia unless otherwise stated. Use may be made of any material contained within the thesis for non-commercial purposes from the copyright holder. Commercial use of material may only be made with the express, prior, written permission of Universiti Putra Malaysia.

Copyright © Universiti Putra Malaysia



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

**PRODUCTIVITY AND PROXIMATE ANALYSES OF SPIRULINA
(*ARTHROSPIRA PLATENSIS*) IN DIFFERENT FLOATING
WATER-BASED PHOTOBIOREACTOR DESIGNS**

By

MOHAMED AMAR NAQIUDDIN BIN ABDUL KADER

July 2016

Chairman : Hishamuddin Omar, PhD
Faculty : Science

Various concepts of photobioreactor (PBR) have been discovered by scientists around the world. Though, only definite photobioreactor designs would be suitable for growing microalgae in a certain geographical climate outdoor condition. This study focused on developing simple floating water-based photobioreactor (PBR) without any computerized controlled systems. The aim of this study was to identify the chronology in developing best design overall for a photobioreactor. Major part of the design involved the aspect of the structure materials, shape and rigidity, whereas minor parts of the photobioreactors design includes the aeration placement, agitation or mixing, coloration corresponding to the high light intensity, temperature control, the size of the openings for the free exchange of gas and support for stable float on the water. Experiments performed would indicate these simple floating photobioreactors whether there are either significant or insignificant effects on the productivity of *Arthrospira platensis* (*Spirulina*) compared to the simple land based PBR especially under tropical climate.

In outdoor condition in Malaysia, the weather patterns are extremely unexpected. Weather patterns that usually occurs can be categorized into three namely, first, humid or wet weather that have a high frequency of rain; mixed weather which has average frequency of rain occurrence, overcast with thick cloud layer and also relatively have high light intensity; finally, dry weather having less rain, often exposed to high temperatures and bright sunlight.

Floating photobioreactor (PBR) has been designed in two distinct rigid shapes (Octagonal and Cylindrical) built using recycled water bottles, Polyethylene terephthalate (PET). While another form of simple floating PBR was designed more flexible as floating enclosure and was custom made from

High Density Polyethylene (HDPE) materials. Simple land based PBR was prepared with High-density Polyethylene (HDPE) plastic bag, (25cm x 50cm). For every minor modification, 10 days of *A. platensis* cultivation inside all PBRs were conducted with daily monitoring of growth parameters. The expected outcome from this experiment shall anticipate that floating PBRs would give higher yield in term of biomass dry weight and specific growth rate of cultured *A. platensis* in comparison of land based PBR. In any case, developing and third world countries could use simple floating PBRs for commercial applications instead of investing on impractical and complicated photobioreactor designs.

For proximate analyses, the average total protein content (%) of *A. platensis* cultured in Cylindrical and Octagonal PBR under dry weather condition was higher significantly ($p < 0.05$) at 61.18 ± 0.45 and 60.58 ± 0.62 than other PBRs respectively. Total carbohydrate content (%) of *A. platensis* cultured in Cylindrical PBR (dry weather condition) was significantly ($p < 0.05$) higher at 26.71 ± 1.43 . While the lowest lipid content recorded in Flexible PBR, $0.66 \pm 0.579\%$ respectively. Highest scored by Cylindrical PBR, 7.883 ± 0.28 under mix weather condition.

The study indicated simple floating photobioreactor system for practical commercial cultivation system. Water based cultivation system has been seen promising compared to land based cultivation system. Several advantages were determined as more dry biomass and productivity of *Spirulina* were achieved compared to common practice of land based cultivation system. Moreover, this simple enclosed floating photobioreactor system may be an economical starter approach for modern farmers in order to maintain high quality, cleanliness and purity of *Spirulina*.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**PRODUKTIVITI DAN ANALISIS PROKSIMA SPIRULINA (*ARTHROSPIRA
PLATENSIS*) YANG DIKULTUR DALAM PELBAGAI REKA BENTUK
FOTOBIOREAKTOR YANG TERAPUNG BERASASKAN AIR**

Oleh

MOHAMED AMAR NAQIUDDIN BIN ABDUL KADER

Julai 2016

Pengerusi : Hishamuddin Omar, PhD
Fakulti : Sains

Pelbagai konsep fotobioreaktor (PBR) telah ditemui ahli-ahli sains di seluruh dunia. Akan tetapi, reka bentuk fotobioreaktor yang sesuai sahaja dapat meningkatkan pertumbuhan mikroalga dalam keadaan iklim geografi tertentu. Kertas kerja ini memberi tumpuan kepada pembangunan fotobioreaktor (PBR) terapung berasaskan air yang mudah tanpa memerlukan sistem berkomputer yang rumit untuk mengawalinya. Tujuan kajian ini adalah untuk mengenalpasti susur galur reka bentuk yang paling ringkas dan terbaik secara keseluruhan bagi sesebuah fotobioreaktor. Reka bentuk sesebuah fotobioreaktor majoritinya melibatkan aspek struktur, bentuk fizikal dan ketegarannya, manakala aspek-aspek yang lain yang perlu ditekankan termasuk peredaran kultur yang konsisten, warna yang sesuai untuk reflex cahaya pada tahap yang tinggi, kawalan suhu kultur, saiz bukaan bagi pertukaran bebas gas dan sokongan bagi pengapungan stabil atas air. Ujian yang telah dilaksanakan akan member sedikit sebanyak pendedahan bahawa fotobioreaktor terapung dengan ringkas berasaskan air ini sama ada memberi impak yang jelas atau kurang kepada produktiviti *Arthrospira platensis* (Spirulina) berbanding dengan sistem pengkulturan mudah berasaskan darat terutamanya yang diuji sepenuhnya di bawah iklim tropika.

Corak cuaca kawasan lapangan di Malaysia pada kebiasaannya tidak dapat dijangkakan. Corak cuaca yang kebiasaannya berlaku boleh dikategorikan kepada tiga iaitu pertamanya, cuaca yang lembap yang mempunyai kekerapan yang tinggi turunnya hujan; keduanya cuaca yang bercampur yang mempunyai kekerapan kejadian hujan, mendung dengan lapisan awan yang tebal dan juga mempunyai limpahan cahaya matahari yang agak tinggi dan; akhirnya, cuaca kering yang kurang turunnya hujan, menghadapi kenaikan suhu yang tinggi dan mempunyai keamatan cahaya matahari yang terang.

Fotobioreaktor terapung (PBR) yang ringkas telah direka dalam dua bentuk tegar yang berbeza (PBR yang bersegi dan yang mempunyai bentuk silinder) dibina menggunakan bekas botol air, Polyethylene terephthalate (PET). Manakala satu lagi bentuk PBR terapung yang ringkas direka lebih fleksibel seperti bentuknya sampulan plastik terapung yang mana bahannya diperbuat dari Polyethylene Berketumpatan Tinggi (HDPE). Pengkulturan berasaskan darat pula menggunakan PBR yang telah direka ringkas dengan hanya menggunakan beg plastik Polyethylene yang berkepadatan tinggi (HDPE), (25cm x 50cm). Untuk setiap eksperimen yang dijalankan, *A. platensis* melalui pengkulturan selama 10 hari dalam semua fotobioreaktor dengan pemantauan parameter pertumbuhan harian secara teliti. Hasil yang diharapkan dari eksperimen ini akan memberi ilmu pengetahuan yang lebih mendalam sama ada system fotobioreaktor terapung yang ringkas ini dapat membuahkan hasil yang lebih atau kurang dalam jangkaan berat kering dan bagaimanakah jangkaan seterusnya pula pada kadar pertumbuhan bagi *A. platensis* jika dibandingkan dengan sistem pengkulturan berasaskan darat. Sehubungan dengan itu, negara-negara membangun dan negara dunia ketiga perlu mengambil peluang yang sedia ada menggunakan sistem fotobioreaktor terapung yang ringkas ini untuk aplikasi komersial dan juga perlu berhenti melaburkan masa dan wang untuk mereka bentuk fotobioreaktor yang tidak praktikal dan terlalu rumit.

Untuk analisis proksima, purata jumlah kandungan protein (%) daripada *A. platensis* yang dikulturkan dalam PBR berbentuk silinder dan oktagon di bawah keadaan cuaca kering adalah lebih tinggi dengan ketara ($p < 0.05$) masing-masing pada 61.18 ± 0.45 dan 60.58 ± 0.62 daripada PBR yang lain. Jumlah kandungan karbohidrat (%) daripada *A. platensis* yang dikulturkan dalam PBR yang berbentuk silinder (keadaan cuaca kering) adalah ketara ($p < 0.05$) lebih tinggi pada 26.71 ± 1.43 . Manakala kandungan lipid (%) yang paling rendah telah dicatatkan melalui PBR fleksibel iaitu 0.66 ± 0.579 . PBR berbentuk silinder pula telah merekodkan bacaan lipid yang tertinggi, 7.883 ± 0.28 di bawah keadaan cuaca yang bercampur.

Kajian menunjukkan sistem fotobioreaktor terapung ringkas ini menepati ciri-ciri praktikal untuk digunakan sebagai sistem pengkulturan moden yang komersial. Sistem pengkulturan berasaskan air dilihat lebih berpotensi berbanding dengan sistem pengkulturan yang berasaskan darat. Beberapa kelebihan telah dapat dikenalpasti daripada analisis berat kering dan produktiviti *Spirulina* tersebut yang dilihat telah meningkat pencapaiannya berbanding dengan sistem biasa pengkulturan berasaskan darat. Selain itu, sistem tertutup fotobioreaktor terapung yang ringkas ini adalah satu-satunya permulaan sebagai satu pendekatan ekonomi yang baru bagi petani moden supaya dapat mengekalkan kualiti dan kebersihan *Spirulina* yang tinggi.

ACKNOWLEDGEMENTS

From the very beginning, this thesis report has been wonderfully transformed me and my writings throughout tough difficult experiences. Nothing can be given to return the favors from numerous important people worth to be mentioned here for their great contribution supporting me in finishing this thesis writings.

Firstly thanks to my parent, Abdul Kader Bin Hj. Mohamed and Zohra Beebe Binti Abdul Kader. My younger sisters, Nurfatimatul Sairah, Nur An Umillah and Nurhalimatus Saadiah for believing in me. Million thanks to all of you and to my close friends and relatives that have been continuously pushing me and always be part of my journey creating my own life from the inside out. A special thanks to my beloved wife, Maifuzatul Shafiqah Binti Muhammad Yusof for being by my side regardless of quite a lot moments of hard times, keeping me focused on what truly matters. Not to mention the supports and courage from my father and mother-in-law, Muhammad Yusof Bin Marakar, Fatimah Binti Ismail; the younger sibling-in-law, Khatib, Hafifah and Uwais. Your strengths and smiles have kept me with positive energy coming from your eyes and the answer is always clear. In shaa Allah.

I would like to take this opportunity to acknowledge the advice and guidance of Dr. Hishamuddin B. Omar, my main supervisor for this project. He managed to supervise my dissertation and generally kept me on track. Your gentle spirits and willingness to guide me so completely, contributed mightily to creating the space, time, energy essential in completing this project. I also thank the lab staffs for their guidance and suggestions, friends under same supervision in this lab, Norsalwani and Hafidh Ali Almahrouqi for all their advice and encouragement. A word of thanks also goes to the Head of Department, Prof Ahmad Ismail, Dr. Rusimah Nulit, Dr. Shahrizim Zulkifly, Dr. Syaizwan Zahmir Zulkifli and to all other department lecturers and members. Without their encouragements, I would not have finished the degree. Thank you.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor Philosophy.

Members of the Supervisory Committee were as follows:

Hishamuddin Omar, PhD

Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Shahrizim Zulkifly, PhD

Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Member)

Syaizwan Zahmir Zulkifli, PhD

Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Member)

BUJANG BIN KIM HUAT, PhD

Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work
- quotations, illustrations and citations have been duly referenced
- the thesis has not been submitted previously or concurrently for any other degree at any institutions
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be owned from supervisor and deputy vice – chancellor (Research and innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software

Signature: _____ Date: _____

Name and Matric No: Mohamed Amar Naqqiuddin Bin Abdul Kader,GS35352

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

Signature: _____
Name of
Chairman of
Supervisory
Committee: Dr. Hishamuddin Omar

Signature: _____
Name of
Member of
Supervisory
Committee: Dr. Shahrizim Zulkifly

Signature: _____
Name of
Member of
Supervisory
Committee: Dr. Syaizwan Zahmir Zulkifli

TABLE OF CONTENTS

ABSTRACT	Page
ABSTRAK	i
ACKNOWLEDGEMENT	iii
APPROVAL	v
DECLARATION	vi
LIST OF TABLES	viii
LIST OF FIGURES	xiv
LIST OF ABBREVIATIONS	xv
	xix

CHAPTER

1.	INTRODUCTION	1
	1.1 Introduction	1
	1.2 Objectives	3
	1.2.1 General objective	3
	1.2.2 Specific objectives	3
2.	LITERATURE REVIEW	4
	2.1 About microalgae	4
	2.2 Microalgae uses and functions	4
	2.2.1 Research on microalgae production	4
	2.2.2 Nutritional values	5
	2.2.3 Medicinal values and food supplement	6
	2.2.4 Microalgae as renewable fuel source	7
	2.2.5 Microalgae as bioremediation agent	7
	2.3 Microalgae as potential solution for present and future world crisis	8
	2.4 Brief history of microalgae cultivation	9
	2.5 Present microalgae cultivation	10
	2.5.1 <i>Arthrospira platensis</i> (Spirulina)	10
	2.6 Cultivation conditions	11
	2.6.1 Weather pattern	11
	2.6.2 Microclimate	14
	2.7 Factors affecting growth	15
	2.7.1 Light intensity	15
	2.7.2 Temperature	16
	2.7.3 pH	16
	2.7.4 Nutrients	17
	2.8 Cultivation method	17
	2.8.1 Open system – open ponds	17
	2.8.2 Closed system – enclosed photobioreactor designs	18
	2.8.3 Different photobioreactor system currently in used	19
	2.9 Photobioreactor limitations	19
	2.9.1 Mixing and aeration	20
	2.9.2 Materials	21

2.9.3	Light	27
2.9.4	Gases exchange	32
2.9.5	System management	33
2.10	Research and commercial algae cultivation in Malaysia	34
3.	GENERAL METHODOLOGY	35
3.1	Experimental site	35
3.2	Experimental design	35
3.3	Weather classification and study duration	35
3.3.1	Weather condition scale	37
3.4	Source of <i>Arthrospira platensis</i>	37
3.5	Maintenance of Stock Culture	37
3.6	Culture media	38
3.6.1	Kosaric medium	38
3.7	Culture monitoring of <i>Arthrospira platensis</i>	38
3.7.1	Physico-chemical parameters and weather conditions	38
3.7.2	Determination of biomass concentration by optical density	39
3.7.3	Cell dry weight determination	39
3.7.4	Chlorophyll a content	39
3.8	Productivity and Specific Growth Rate	40
3.9	Photobioreactor preparation (major design)	41
3.9.1	Land based photobioreactor (mixing variation)	41
3.9.2	Water-based octagonal and cylindrical floating photobioreactor (Rigid)	42
3.9.3	Water-based flexible floating enclosure photobioreactor	42
3.9.4	Design inspection	43
3.10	Proximate analyses	43
3.10.1	Total protein	44
3.10.2	Total lipid	44
3.10.3	Total carbohydrate	44
3.11	Harvesting and sample handling	45
3.12	Samples preservation	45
3.13	Data analysis	45
4.	PRELIMINARY OBSERVATION AND DEVELOPMENT OF	47
4.1	Introduction	47
4.2	Materials and Methods	48
4.2.1	Setting up simple floating photobioreactor	48
4.2.2	Quality and specific criteria assessment	49
4.2.3	Methods of buoyant attachment	50
4.2.4	Methods of fabricating simple floating photobioreactor	52
4.2.5	Methods of positioning simple floating photobioreactor	53
4.2.6	Methods of installing simple gases exchange outlet	54
4.3	Results	56

4.3.1	Preliminary testing	56
4.3.2	Behavior observation	58
4.3.3	Quality scores based on behavior	60
4.4	Discussion	62
5.	GROWTH PERFORMANCE OF SPIRULINA IN DIFFERENT SIMPLE FLOATING PHOTOBIOREACTORS	66
5.1	Introduction	66
5.2	Materials and Methods	68
5.2.1	Simple mixing application	69
5.2.2	Simple rigid and flexible floating photobioreactor Designs	71
5.2.3	The effect of color on rigid photobioreactor design	72
5.2.4	Simple gases exchange outlet sizes application	73
5.2.5	Other applications	74
5.3	Results	75
5.3.1	Simple mixing variations	75
5.3.2	Growth performance in rigid and flexible simple floating photobioreactor designs under different weather conditions	82
5.3.3	Effect of different colorations on rigid simple floating photobioreactors (Octagonal and Cylindrical)	91
5.3.4	Sizes of gases exchange outlet variations	97
5.4	Discussion	103
6.	PRODUCTIVITY AND BIOECONOMIC OF SPIRULINA GROWN IN SIMPLE FLOATING PHOTOBIOREACTOR	108
6.1	Introduction	108
6.2	Materials and Methods	110
6.2.1	Cost analysis calculation	110
6.3	Results	111
6.3.1	Productivity and specific growth rate	111
6.3.2	Bioeconomic evaluation of simple floating photobioreactors	112
6.3.3	The estimation of production cost and the forecast	113
6.3.4	Break-even point	116
6.4	Discussion	119
7.	PROXIMATE COMPOSITION OF SPIRULINA GROWN IN DIFFERENT PHOTOBIOREACTORS AND DIFFERENT WEATHER CONDITIONS	123
7.1	Introduction	123
7.2	Materials and Methods	124
7.3	Results	124
7.3.1	Total protein content (%) of cultured Spirulina in different simple floating photobioreactor design under different weather conditions	124

7.3.2	Total carbohydrate content (%) of cultured Spirulina in different simple floating photobioreactor design under different weather conditions	125
7.3.3	Total lipid content (%) of cultured Spirulina in different simple floating photobioreactor design under different weather conditions	126
7.4	Discussion	127
8.	GENERAL DISCUSSION	130
8.1	Introduction	130
8.2	Important factors in developing photobioreactor system	132
9.	SUMMARY, CONCLUSION AND RECOMMENDATIONS	136
	BIBLIOGRAPHY	139
	APPENDICES	162
	BIODATA OF STUDENT	165
	LIST OF PUBLICATIONS	166

LIST OF TABLES

Table		Page
1	Temperature recorded highest, lowest and daily based variation in Malaysia.	16
2	Weather conditions (wet, mix and dry) described in scales (1-10).	37
3	Specific criteria description for quality assessment of simple floating photobioreactor.	49
4	Major issues on the simple floating photobioreactor were described with the suggested solutions during the trial sessions.	57
5	Quality scores assessed with final methods applied for all designed simple floating photobioreactor based on actual experiment.	61
6	Materials used for photobioreactor designs.	63
7	Highest productivity ($\text{g L}^{-1} \text{d}^{-1}$) in different simple photobioreactors: Octagonal, Cylindrical, Land, and Flexible floating photobioreactors (PBR) during wet, mix and dry weather condition.	111
8	Photobioreactor Capacity (Scaled Up Estimation).	113
9	Major Equipment Cost (MEC).	113
10	Total estimated production costs for the conceptually designed photobioreactor system.	114
11	The estimation of cost-benefit analysis for Octagonal PBR.	117
12	Comparative estimation of cost benefits analyses.	118
13	Contrast comparison of reactor cost.	120
14	Proximate composition of <i>A. platensis</i> (% dry weight) in different climate conditions.	129

LIST OF FIGURES

Figure		Page
1	Average precipitation in depth (mm per year) from year 2011 to 2015.	12
2	Northeast monsoon and southwest monsoon season current flow.	13
3	Photobioreactors made of DURAN® glass tubing, Borosilicate (Pyrex) glass.	22
4	Low Density Polyethylene (LDPE) films.	23
5	Flexible plastic film photobioreactor.	24
6	Clear acrylic plastic.	25
7	Clear polyvinyl chloride (PVC).	26
8	Large scale fluorescent lamps fitted photobioreactor.	29
9	LED based lighting system for photobioreactor.	30
10	Optical fiber supplied for photobioreactor.	31
11	Prepared land based photobioreactor design.	42
12	Simple flexible enclosure floating photobioreactor (PBR) design.	43
13	Buoyant attachments using A) iron wire, B) only with rafia strings.	51
14	Buoyant attachments using A) hard iron wire, B) small diameter thin iron wire to tie altogether.	52
15	Joining two parts of PET bottle (5 L).	53
16	Positioning the photobioreactor. A: Top tied. B: Bottom tied to heavy rocks.	54
17	Installing two PET bottles (500 mL) for gases exchange outlet on the floating photobioreactor.	55
18	Biomass dry weight of <i>Arthrospira platensis</i> during 10 cultivation days in Octagonal PBR (R1, R2, R3, R4) and Cylindrical PBR (T1, T2, T3).	58

19	Joining two parts of PET bottles using (A) hot glue, (B) normal epoxy glue.	59
20	Joining two parts of PET bottles using (A) epoxy and mosquito net; (B) epoxy and clothes.	59
21	Joining two parts of PET bottles using (A) plastic wrapper and epoxy; (B) clear silicone glue, white coating and polyurethane epoxy.	59
22	Cross sectional diagram of aeration/mixing flows positioned for bottom aeration.	70
23	Cross sectional diagram of aeration/mixing flows positioned for top aeration.	71
24	Prepared flexible enclosure floating photobioreactor (PBR).	72
25	Prepared rigid water based floating photobioreactors	72
26	Prepared colored floating photobioreactors	73
27	Prepared gases exchange outlets	74
28	Light intensity and absorbance of <i>A. platensis</i> grown with bottom bubble aeration supplied using (AS-air stone & WAS-without air stone) in different simple photobioreactors	76
29	Light intensity and absorbance of <i>A. platensis</i> grown with top bubble aeration supplied using (AS-air stone & WAS-without air stone) in different simple photobioreactors	77
30	Light intensity and dry weight (g L^{-1}) of <i>A. platensis</i> grown with bottom bubble aeration supplied using (AS-air stone & WAS-without air stone) in different simple photobioreactors	78
31	Light intensity and dry weight (g L^{-1}) of <i>A. platensis</i> grown with top bubble aeration supplied using (AS-air stone & WAS-without air stone) in different simple photobioreactors	79
32	pH of grown <i>A. platensis</i> with bottom bubble aeration supplied using (AS-air stone & WAS-without air stone) in different simple photobioreactors (PBR)	81

33	pH of grown <i>A. platensis</i> with top bubble aeration supplied using (AS-air stone & WAS-without air stone) in different simple photobioreactors	81
34	Light intensity ($\mu\text{mol m}^{-2} \text{s}^{-1}$) and temperature ($^{\circ}\text{C}$); Morning (8-11am), Afternoon (11-2pm), Evening (2-5pm) for the 10 days of <i>A. platensis</i> cultivation with bottom and top aeration of (AS-air stone & WAS-without air stone) in different simple photobioreactors	82
35	Light intensity and absorbance of <i>A. platensis</i> grown in different simple floating photobioreactors (PBR) (O-Octagonal; C-Cylindrical; F-Flexible) for 10 days in three different weather conditions (Wet, Mixed and Dry).	84
36	Light intensity and dry weight (g L^{-1}) of <i>A. platensis</i> grown in different simple photobioreactors (PBR) (O-Octagonal; C-Cylindrical; F-Flexible) for 10 days in different weather condition (wet, mixed and dry).	86
37	Light intensity and chlorophyll <i>a</i> of <i>A. platensis</i> grown in different simple floating photobioreactors (PBR) (O-Octagonal; C-Cylindrical; F-Flexible) for 10 days in different weather conditions (wet, mixed and dry).	88
38	pH of grown <i>A. platensis</i> in different simple floating photobioreactors (PBR) (O-Octagonal; C-Cylindrical; F-Flexible) for 10 days under different weather conditions (Wet, Mixed and Dry).	90
39	Light intensity and absorbance of <i>A. platensis</i> grown with different colorations (B- Black; S- Silver; W- White; Control) in simple floating photobioreactors (PBR) (O-Octagonal and C-Cylindrical) for 10 days.	92
40	Light intensity and biomass dry weight (g L^{-1}) collected of <i>A. platensis</i> grown in different colored (B- Black; S- Silver; W- White; Control) simple floating photobioreactors (PBR) (O-Octagonal and C-Cylindrical) for 10 days.	93
41	Light intensity and chlorophyll <i>a</i> of <i>A. platensis</i> grown in different colored (B- Black; S- Silver; W- White; Control) simple floating photobioreactors (PBR) (O-Octagonal and C-Cylindrical).	94
42	pH of grown <i>A. platensis</i> in different colored (B- Black; S- Silver; W- White; Control) simple floating photobioreactors (PBR) (O-Octagonal; C-Cylindrical) for 10 days.	95

43	Light intensity ($\mu\text{mol m}^{-2} \text{s}^{-1}$) and temperature ($^{\circ}\text{C}$); Morning (8-11am), Afternoon (11-2pm), Evening (2-5pm) for the 10 days of <i>A. platensis</i> cultivation in different colored (B- Black; S- Silver; W- White; Control-uncolored PBR) simple floating photobioreactors (PBR) (O-Octagonal; C-Cylindrical).	96
44	Light intensity and absorbance of <i>A. platensis</i> grown in different size of gaseous exchange area (A: $> 500 \text{ cm}^3$; B: $< 500 \text{ cm}^3$; C: 0 cm^3) of simple Octagonal floating photobioreactors (PBR) for 10 cultivation days.	98
45	Light intensity and biomass dry weight (g L^{-1}) of <i>A. platensis</i> grown in different size of gaseous exchange area (A: $> 500 \text{ cm}^3$; B: $< 500 \text{ cm}^3$; C: 0 cm^3) in simple Octagonal floating photobioreactors (PBR) for 10 days.	99
46	Light intensity and chlorophyll <i>a</i> of <i>A. platensis</i> grown in different size of gaseous exchange area (A: $> 500 \text{ cm}^3$; B: $< 500 \text{ cm}^3$; C: 0 cm^3) of simple Octagonal floating photobioreactors (PBR) for 10 days of cultivation.	100
47	Dissolved oxygen (mg L^{-1}) of <i>A. platensis</i> grown in different gaseous exchange area sizes (A: $> 500 \text{ cm}^3$; B: $< 500 \text{ cm}^3$; C: 0 cm^3) of simple Octagonal floating photobioreactors (PBR) for 10 cultivation days.	101
48	pH values of <i>A. platensis</i> grown in different gaseous exchange area sizes (A: $> 500 \text{ cm}^3$; B: $< 500 \text{ cm}^3$; C: 0 cm^3) of simple Octagonal floating photobioreactors (PBR) for 10 days of cultivation.	102
49	Total protein content (%) gained from different designed simple floating photobioreactors (F: Flexible; O: Octagonal; C: Cylindrical; Land based as reference) under wet, mix and dry weather conditions.	125
50	Total carbohydrate content (%) gained from different designed simple floating photobioreactors (F: Flexible; O: Octagonal; C: Cylindrical; Land based as reference) under wet, mix and dry weather conditions.	126
51	Total lipid content (%) gained from different designed simple floating photobioreactors (F: Flexible; O: Octagonal; C: Cylindrical; Land based as reference) under wet, mix and dry weather conditions.	127
52	Flow diagram showing general description of the study.	131

LIST OF ABBREVIATIONS

%	Percentage
°C	Degree
µg	Microgram
µg day ⁻¹	Microgram per day
µg g ⁻¹	Microgram per gram
µl	Microlitre
µm	Micrometre
µmol L ⁻¹	Micromolar per litre
µmol m ⁻² s ⁻¹	Micromolar per second metre square
ANOVA	Analysis of variance
Ca	Calcium
CHCl ₃	Chloroform
cm	Centimetre
CO ₂	Carbon dioxide
Cr	Chromium
Cr (III)	Trivalent chromium
Cr (VI)	Hexavalent chromium
CrO ₄ ²⁻	Chromate
CrO ₇ ²⁺	Dichromate
Cu	Copper
DW	Dry weight
H ₂ O ₂	Hydrogen peroxide
g L ⁻¹	gram per litre

KCl	Potassium chloride
L	Litre
M	Molar
MeOH	Methanol
Mg	Magnesium
mg L ⁻¹	Milligram per litre
mg mL ⁻¹	Milligram per millilitre
mL	Millilitre
mm	Millimetre
mM	Millimolar
N	Nitrogen
Na ₂ CO ₃	Sodium carbonate
nm	Nanometre
P	Phosphate
PBR	photobioreactor
ppm	Part per million
rpm	Round per minute
SD	Standard deviation
SE	Standard error
Se	Selenium
SPSS	Statistical Package for Science Social
UV	Ultraviolet
v/v	volume/volume

CHAPTER 1

INTRODUCTION

1.1 Introduction

Numerous studies have shown that microalgae benefit the environment by sequestering CO₂ and producing more O₂ while utilizing less water than normal crops (Kargupta *et al.*, 2015). Microalgae have higher productivity compared to terrestrial crop per size of production in long term. Due to great diversity and simplicity of its form, the evolution and performance of microalgae is beyond prospect than the same process from terrestrial crops which may take some years (Hannon *et al.*, 2010). From thousands of microalgae species existed, few hundred have been successfully cultured in laboratories and less than 100 species have been commercialized. The most common microalgae commercially produced are *Chlorella vulgaris*, *Dunaliella salina* and *Spirulina* (Spolaore *et al.*, 2006). Of all the species cultured, *Spirulina* (*A. platensis*) is widely cultured in many geographical regions of the world because it lives in alkaline medium which make it less susceptible to contamination. Most *Spirulina* producing regions lies in semi arid area where climate are stable, less cloud cover, ample sunshine and receiving less rain (Vonshak *et al.*, 1982). Malaysia on the other hand lies in the equator where it is believed to be less suitable for microalgae cultivation due to indistinct weather, frequent cloud covers and high precipitation which dilute growth medium.

Scientists have suggested cultivating microalgae as one of proficient ways to encounter escalating issues such as global warming and climate change which are among the most debated issues in the world presently. The magnitudes of these occurrences have profound effect to the global flora and fauna diversity whereby it could cause hundreds or thousands of species extinction. Global warming can alter atmospheric air and water circulation patterns which influence the weather patterns of air exchanges, rainfall distributions, wind speed, wind directions, precipitation, cloud covers and other variables (Barry and Chorley, 2009). Industrialization, forest destruction and other human activities are the major producer CO₂ and CH₄ which led to the formation of greenhouses gases causing global warming. The consequences of global warming are climate change producing phenomena like extreme weathers: tornadoes, huge typhoons, thunderstorms, flash floods, drought, acid rain, raising sea levels and more. Mitigation of global warming requires concerted efforts from major producer of greenhouse gas nation (Cop21paris, 2015). Although many nations have pledge to reduce greenhouse production, this will take time. Meanwhile scientific communities worldwide have provided numerous evidences pertaining to global warming

including declining results caused by the atmosphere disturbance towards productivity of agriculture (Smith *et al.*, 2015).

Published reports on cultivation in outdoor condition especially in Malaysia are scanty. Small scale culture studies of *Spirulina* in outdoor conditions in Malaysia have shown that *Spirulina* can be grown successfully despite of those limitations. *A. platensis* can be grown successfully in sheltered outdoor conditions achieving dry weight of 0.8 g L⁻¹ in 8 days (Sukumaran *et al.*, 2014). With suitable rain shelter, production of microalgae can commence successfully without any contamination from the surrounding and frequent rainfalls. Using conventional mode of cultivation, a Malaysian company, Algae International Sdn. Bhd. have patented a culturing system of *Spirulina* floating bed method (FBM) photobioreactor. However, the information on its performance was not published.

Discovery of floating photobioreactor (PBR) offered better alternative in culturing microalgae rather than using land base culture system with rain sheltering. Most invented photobioreactor (PBR) for microalgae cultivation are designed to be land-based system. Land-based photobioreactor often designed to have bigger surface area for light exchange for photosynthetic process compared to water based. Scaling up land based photobioreactor would be very costly and have higher risk of contamination. The concept of floating photobioreactor in water area, such as big lakes, pools, ponds or reservoirs was later recommended alternatively for better production economically (Wiley *et al.*, 2013). Large water bodies have thermal stability as such that the range of water temperature for open pond or sheltered raceway pond may not fluctuate extremely. Vast volume of water could act as a regulator to maintain temperature. However for land-based photobioreactor, additional cooling systems are incorporated in the design of photobioreactor system. Radiated heat from land surface and radiant heat absorbed by the PBR structures during daylight increased the temperature inside the PBR, therefore it is necessary to have cooling system or shelters covering land based PBR to balance the temperature back to optimal condition (Mehlitz, 2009). Every cultivation system design has different aspects to be reviewed in terms of maintenance, culture managements and suitability of the growing microalgae species with the system. Thus, the growth of microalgae differs depends to the design of the cultivation system. Types of mixing or aeration, sunlight illumination intensity, temperature regulations, air exchanges, coloration, transparency, buoyancy and structure materials are important variables that require serious consideration. Culture conditions inside PBR are one of the important factors for the microalgae growth and intracellular substance accumulation (Yoon *et al.*, 2008). According to Teresa *et al.* (2010) these factors are divided into biotic, abiotic and operational factors. The examples of biotic factors are pathogens and competition by other microalgae. Meanwhile, abiotic factors are dissolved oxygen, CO₂, pH, salinity, light intensity, temperature, nutrient concentration and toxic chemical buildup by the microalgae itself. Next, the operational

factors are described as energy to produce mixing, dilution rate, depth, harvest frequency and additions of fertilizer and bicarbonate. Enhancement of the basic requirements for *Spirulina* (*A. platensis*) such as nutrient assessment, salinity, and pH should be done to maximize the productivity.

Outdoor cultivation in foreign countries usually has high initial installation cost excluding the maintenance and management cost. The most familiar system, open channel raceway ponds were being used for microalgae cultivation in commercial scale. Although it is easy to construct and operate, open system have low productivity, require large space area and has high risk of contamination. Open channel raceway ponds are not practical in Malaysia because lands are limited, expensive plus frequent rains will cause dilution and contamination. Lack of capitals and technical expertise will make conventional PBR less viable proposition. However the discovery of simple floating photobioreactor/floating bed method is an attractive proposition because of its design simplicity, cheap to operate, scalable and can operate in any sheltered water bodies. Nevertheless information on most aspect of this simple floating photobioreactor in Malaysian perspectives is lacking.

1.2 Objectives

1.2.1 General Objective

This paper will focus on finding suitable design of floating photobioreactor system which is simple, practical, low maintenance cost, handy and scalable.

1.2.2 Specific Objectives

1. To explore different design of simple floating photobioreactor in term of durability: size, shape, coloration, rigidity and flexibility; buoyancy, long lasting and tough materials; mixing, aeration; and the opening sizes of gases exchange area.
2. To determine the growth performance of *Arthrospira platensis* in terms of cell density, biomass dry weight and chlorophyll *a* content in different floating photobioreactor designs.
3. To measure the productivity rate of *A. platensis* and the bioeconomic of different floating photobioreactor designs.
4. To analyze the proximate analyses composition of grown *A. platensis* in different floating photobioreactor designs.

BIBLIOGRAPHY

- Acien, F.G., Sevilla, J.M.F., Perez, J.A.S., Molina Grima, E. and Chisti, Y. (2001). Airlift driven external-loop tubular photobioreactors for outdoor production of microalgae: assessment of design and performance. *Chemical Engineering Science*, 56: 2721-2732.
- Acien, F.G., Fernández, J.M., Magán, J.J. and Molina, E. (2012). Production cost of a real microalgae production plant and strategies to reduce it. *Biotechnology Advances*, 30:1344-1353.
- Almahrouqi, H., Naqqiuddin, M.A., Achankunju, J., Omar, H. and Ismail, A. (2015a). Different salinity effects on the mass cultivation of *Spirulina* (*Arthrospira platensis*) under sheltered outdoor conditions in Oman and Malaysia. *Journal of Algal Biomass Utilization*, 6(1): 1-14.
- Almahrouqi, H., Sukumaran, P., Naqqiuddin, M.A., Alsabahi, J., Omar, H. and Ismail, A. (2015b). The effect of salinity on growth, biochemical composition and fatty acid profile of *Spirulina* (*Arthrospira platensis*) grown in sheltered outdoor conditions in Oman. *Journal of Algal Biomass Utilization*, 6(2): 61-67.
- Al-Abdul-elah, K.M., Almatar, S., Abu-Rezq, T. and James, C.M. (2001). Development of Hatchery Technology for the Silver Pomfret *Pampus argenteus* (Euphrasen): Effect of Microalgal Species on Larval Survival. *Aquaculture Research*, 32(10): 849-860.
- Algae Biomass, (2012). Retrieved from <http://www.algaebiomass.org/wp-content/gallery/2012-algae-biomass-summit/2010/06/Miller-Harlan1.pdf>
- Algae International Sdn. Bhd., (2013). Retrieved from <http://www.algaeinternational.biz/index.htm>
- Algaerocksmybox, (2008). Retrieved from <http://algaerocksmybox.blogspot.com/2008/02/thinking-simply-green-about.html>
- Algaetech International Sdn. Bhd., (2012). Retrieved from <http://algaetech.com.my/v1/category/press-release/>
- An J.Y. and Kim B.W. (2000). Biological desulfurization in an optical-fiber photobioreactor using an automatic sunlight collection system. *Journal of Biotechnology*, 80(1): 35-44.
- Anderson J. (2009). Determining manufacturing costs. *Chemical Engineering Progress*, 105: 27-31.
- Asenjo J.A. and Merchuk J.C. (1994). *Bioreactor system design*. (pp. 139–555). Marcel Dekker, New York.
- Asha, P., Nira, K.S., Ashok, P., Edgard, G. and Datta, M., (2011). Cyanobacteria and microalgae: a positive prospect for biofuels. *Bioresource Technology*, 102: 10163–10172.
- Ashokkumar, V., Salam, Z., Tiwari, O. N., Chinnasamy, S., Mohammed, S. and Ani, F. N. (2015). An integrated approach for biodiesel and bioethanol production from *Scenedesmus bijugatus* cultivated in a vertical tubular photobioreactor. *Energy Conversion and Management*, 101: 778-786.
- Avila-Leon, I., Chuei Matsudo, M., Sato, S. and De Carvalho, J. C. M. (2012). *Arthrospira platensis* biomass with high protein content cultivated in

- continuous process using urea as nitrogen source. *Journal of Applied Microbiology*, 112(6): 1086-1094.
- Babcock, R. W., Malda, J. and Radway, J. C. (2002). Hydrodynamics and mass transfer in a tubular airlift photobioreactor. *Journal of Applied Phycology*, 14(3): 169-184.
- Bamba, B., Yu, X., Lozano, P., Ouattara, A., Vian, M.A. and Lozano, Y. (2014). Photobioreactor based procedures for reproducible small-scale production of microalgal biomasses. *Journal of Algal Biomass Utilization*, 5(1): 1-14.
- Barry, R.G. and Chorley, R.J. (2009). Atmosphere, weather and climate. Routledge.
- Basniwal, R.K. and Kaushik, P. (2014). Biofuel production from microalgae for energy applications. *Journal of Algal Biomass Utilization*, 5(4): 50-54.
- Becker, E.W. (1986). Nutritional Properties of Microalgae: Potentials and Constraints. In: A. Richmond (Ed.). *CRC Handbook of Microalgal Mass Culture* (pp. 339-420). CRC Press, Inc. Florida.
- Becker, E.W. (1994). Microalgae — Biotechnology and Microbiology. Cambridge: Cambridge University Press.
- Becker, E.W. (2007). Review: Microalgae as a source of protein. *Biotechnology Advances*, 25: 207–210.
- Becker, E.W. and Venkataraman L.V. (1980). Production and Processing of Algae in Pilot Plant Scale Experience of the Indo-German Project. In: G. Shelef and C.J. Soeder (Ed.), *Algae Biomass*. (pp. 35-50). Elsevier/North-Holland Biomedical Press. Amsterdam.
- Belay, A., Ota, Y., Miyakawa, K. and Shimamatsu, H. (1993). Current knowledge on potential health benefits of *Spirulina*. *Journal of Applied Phycology*, 5: 235-241.
- Belay, A. (1997). Mass culture of *Spirulina* outdoors—the Earthrise Farms experience. In: A. Vonshak (Ed.). *Spirulina platensis (Arthrospira) Physiology, Cell Biology and Biotechnology* (pp. 131-158). Taylor and Francis, London.
- Berberoglu, H., Jay, J. and Pilon, L. (2008). Effect of nutrient medium on hydrogen production of *A. variabilis* in a flat panel photobioreactor. *International Journal of Hydrogen Energy*, 3: 1172 – 1184.
- Bertling, K., Hurse, T.J., Kappler, U. and Rakic, A.D. (2006). Lasers - an effective artificial source of radiation for the cultivation of anoxygenic photosynthetic bacteria. *Biotechnology Bioengineering*, 94: 337– 345.
- Bezerra, R.P., Matsudo, M.C., Coverti, A., Sato, S. and Carvalho, J.C.M. de (2007). Influence of Ammonium Chloride feeding time and light intensity on the cultivation of *Spirulina (Arthrospira) platensis*. *Biotechnology and Bioengineering*, 100(2): 297-305.
- Bhatia, S., Othman, Z. and Ahmad, A.L. (2007). Pretreatment of palm oil mill effluent (POME) using *Moringa oleifera* seeds as natural coagulant. *Journal of Hazardous Materials*, 145: 120-126.
- BiofuelsDigest, (2014, September 28). Retrieved from <http://www.biofuelsdigest.com/bdigest/2014/09/28/schott-algatech-find-that-thin-glass-walls-for-improve-algae-cultivation-efficiency-in-photobioreactors/>.

- Black, J. (1997). Oxford Dictionary of Economics. Oxford University Press. New York.
- Blaga, A. (1980). Plastics in glazing lighting applications. Canadian Building Digest Report CBD-213.
- Borowitzka, L.J. (1991). Development of western biotechnology's algal β -carotene plant. *Bioresource technology*, 38(2), 251-252.
- Borowitzka, M.A. (1992). Algal Biotechnology Products and Processes-Matching Science and Economies. *Journal of Applied Phycology*, 4:267-279.
- Borowitzka, M.A. (1998). Limits to growth, in Wastewater treatment with algae, Y.-S. Wong and N.F.Y. Tam, (Ed.), (pp. 203–226). Springer Verlag.
- Borowitzka, M.A. (1999). Commercial production of microalgae: ponds, tanks, tubes, and fermenters. *Journal of Biotechnology*, 70: 313-321.
- Borowitzka, M.A. (2006). Biotechnological and Environmental Applications of Microalgae.
- Borowitzka, M.A. (2005). Culturing of Microalgae in Outdoor Ponds. In: R.A. Andersen (Ed.), *Algal Culturing Techniques*. London: Elsevier, 14.
- Boustead, I. (2005). Eco-profiles of the European Plastics Industry, Plastics Europe, March, www.plasticseurope.org
- Brown, N. (1993). The implications of climate and gap microclimate for seedling growth conditions in a Bornean low land rain forest. *Journal of tropical ecology*, 9(02), 153-168.
- Brown, M.R., Jeffrey, S.W., Volkman, J.K. and Dunstan. G.A. (1997). Nutritional properties of microalgae for mariculture. *Aquaculture*, 151: 315-331.
- Burgess, G., Fernandez-Velasco, J.G. and Lovegrove, K. (2007). Materials, geometry, and net energy ratio of tubular photobioreactors for microalgal hydrogen production. *International Journal of Hydrogen Energy*, 32(9): 1225-1234.
- Burlew, J.S. (1953). Algal Culture from Laboratory to Pilot Plant. (pp. 357). Carnegie Institution of Washington, Washington, DC.,
- Burns, A. (2014). Photobioreactor Design for Improved Energy Efficiency of Microalgae Production.
- Buyukkamaci, N. and Koken, E. (2010). Economic evaluation of alternative wastewater treatment plant options for pulp and paper industry. *Science of The Total Environment*, 408(24): 6070-6078.
- Camacho Rubio, F., Ación Fernández, F.G., Sánchez Pérez, J.A., García Camacho, F., and Molina Grima, E. (1999). Prediction of dissolved oxygen and carbon dioxide concentration profiles in tubular photobioreactors for microalgal culture. *Biotechnology Bioengineering*, 62: 71-86.
- Capelli, B. and Cysewski, G.R. (2010). Potential health benefits of Spirulina microalgae*. *Nutrafoods*, 9(2): 19-26.
- Carvalho, A.P., Meireles, L.A. and Malcata, F.X. (2006). Microalgae reactors: a review of enclosed system designs and performances. *Biotechnology Progress*, 22: 1490-1506.

- Carvalho, A.P., Silva, S.O. and Baptista, J.M. (2011). Light requirements in microalgal photobioreactors: an overview of biophotonic aspects. *Applied Microbiology Biotechnology*, 89: 1275-1288.
- Carvalho, J. C. M., Francisco, F. R., Almeida, K. A., Sato, S., & Converti, A. (2004). Cultivation of *Arthrospira (Spirulina) platensis* (Cyanophyceae) by fed-batch addition of ammonium chloride at exponentially increasing feeding rates. *Journal of Phycology*, 40(3): 589-597.
- Chameides, W.L., Yu, H., Liu, S.C., Bergin, M., Zhou, X., Mearns, L., Wang, G., Kiang, C.S., Saylor, R.D., Luo, C., Huang, Y., Steiner, A. and Giorgi, F. (Eds.). (1999). Case study of the effects of atmospheric aerosols and regional haze on agriculture: An opportunity to enhance crop yields in China through emission controls? Proceedings of the National Academy of Sciences of the United States of America, 96(24):13626–13633.
- Chemicals-technology, (2015) Retrieved from <http://www.chemicals-technology.com/projects/algenol-biofuels-integrated-bio-refinery-florida/>.
- Chen, C.Y., Lee, C.M. and Chang, J.S. (2006). Feasibility study on bioreactor strategies for enhanced photohydrogen production from *Rhodospseudomonas palustris* WP3-5 using optical fiber assisted illumination systems. *International Journal of Hydrogen Energy*, 31(15): 2345-2355.
- Chen, C.Y., Yeh, K.L., Aisyah, R., Lee, D.J. and Chang, J.S. (2011). Cultivation, photobioreactor design and harvesting of microalgae for biodiesel production: A critical review. *Bioresources Technology*, 102: 71-81.
- Cheng-Wu, Z., Zmora, O., Kopel, R. and Richmond, A. (2001). An industrial-size flat plate glass reactor for mass production of *Nannochloropsis* sp. (Eustigmatophyceae). *Aquaculture* 195: 35-49.
- Chetsumon, A., Umeda, F., Maeda, I., Yagi, K., Mizoguchi, T. and Miura, Y. (1998). Broad spectrum and mode of action of an antibiotic produced by *Scytonema* sp. TISTR 8208 in a seaweed-type bioreactor. *Applied Biochemistry and Biotechnology*, 70-72: 249-256.
- Chiaromonti, D., Prussi, M., Casini, D., Tredici, M.R., Rodolfi, L., Bassi, N., Zittelli, G.C. and Bondioli, P. (2013). Review of energy balance in raceway ponds for microalgae cultivation: Re-thinking a traditional system is possible. *Applied Energy*, 102: 101-111.
- ChiniZitelli, G., Lavista, F., Bastianini, A., Rodolfi, L. Vicenzini, M. and Tredici, M.R. (1999). Production of eicosapentaenoic acid by *Nannochloropsis* sp. cultures in outdoor tubular photobioreactors. *Journal of Biotechnology*, 70: 299-312.
- ChiniZitelli, G., Rodolfi, L. and Tredici, M.R. (2003). Mass cultivation of *Nannochloropsis* sp. in annular reactor. *Journal of Applied Phycology*, 15: 107-114.
- ChiniZitelli, G., Rodolfi, L., Biondi, N. and Tredici, M.R. (2006). Productivity and photosynthetic efficiency of outdoor cultures of *Tetraselmis suecica* in annular columns. *Aquaculture*, 261: 932-943.
- Chisti, Y. and Moo-Young, M. (1989). On the calculation of shear rate and apparent viscosity in airlift and bubble column bioreactors. *Biotechnology and Bioengineering*, 34: 1391–1392.

- Choi, S.L., Suh, I.S. and Lee, C.G. (2003). Lumostatic operation of bubble column photobioreactors for *Haematococcus pluvialis* cultures using a specific light uptake rate as a control parameter. *Enzyme Microbiology Technology*, 33: 403–409.
- Clarens A.F., Resurreccion E., White M. and Colosi A. (2010). Environmental life cycle comparison of algae to other bioenergy feedstocks. *Environmental Science Technology*, 44:1813–1819.
- ClearFlo, (2015). Retrieved from <http://www.newageindustries.com/clearflo-clear-pvc-tubing.asp>.
- Clement, G. and Van Landeghem, H. (1971). Spirulina: eingunstigesobjekt fur die massen kultur von mikoalgen. *Berichte der Deutschen Botanischen Gesellschaft*, 83: 559-561.
- Cogne, G., Cornet, J.F. and Gross, J.B. (2005). Design, operation, and modelling of a membrane photobioreactor to study the growth of the cyanobacterium *Arthrospira platensis* in space conditions. *Biotechnology Progress*, 21: 741-750.
- Converti, A., Lodi, A., Del Borghi, A. and Solisio, C. (2006). Cultivation of *Spirulina platensis* in a combined airlift-tubular reactor system. *Biochemical Engineering Journal*, 32: 13–18.
- Cop21paris, (2015). Retrieved from <http://www.cop21paris.org>.
- Cornet, J.F. (1992). Etude cinétique et énergétique d'un photobioréacteur- Etablissement d'un modèle structuré. Applications à un écosystème clos artificiel. PhD Thesis. Université de Paris-Sud, centre d'Orsay.
- Costas, E., Flores-Moya, A. and López-Rodas, V., (2008). Rapid adaptation of algae to extreme environments (geothermal waters) by single mutation allows Noah's Arks for photosynthesizers during the Neoproterozoic Snowball Earth? *New Phytologist*, 189: 922–932.
- Danesi, E.D.G., Rangel-Yagui, C.O., Carvalho, J.C.M. and Sato, S. (2002). An investigation of effect of replacing nitrate by urea in the growth and production of chlorophyll by *Spirulina platensis*. *Biomass Bioenergy*, 23: 261–269.
- Danesi, E.D.G., Rangel-Yagui, C.O., Carvalho, J.C.M. and Sato, S. (2004). Effect of reducing the light intensity on the growth and production of chlorophyll by *Spirulina platensis*. *Biomass and Bioenergy*, 26: 329-335.
- Danesi, E.D.G., Rangel-Yagui, C.O., Sato, S. and Carvalho, J.C.M.D. (2011). Growth and content of *Spirulina platensis* biomass chlorophyll cultivated at different values of light intensity and temperature using different nitrogen sources. *Brazilian Journal of Microbiology*, 42 (1): 362-373.
- De Baere, L. (2000). Anaerobic digestion of solid waste: state-of-the-art. *Water Science Technology*, 41(3): 283 –290.
- Degen, J., Uebele, A., Retze, A., Schmidt-Staigar, U. and Trosch, W.A. (2001). A novel airlift photobioreactor with baffles from improved light utilization through flashing light effect. *Journal of Biotechnology*, 92: 89-94.
- Desai, T., Dutt, V. and Srivastava, S. (2015). Systems Biology and Metabolic Engineering of Marine Algae and Cyanobacteria for Biofuel Production. *Marine Bioenergy: Trends and Developments*, 163.

- Devi M.A. and Venkataraman L.V. (1983) Hypocholesteremic effect of blue green algae *Spirulina platensis* in albino rats. *Nutrition Reports International*, 28: 519-530.
- Dunstan, G.A., Volkman J.K., Barrett S.M. and Garland C.D. (1993). Changes in the lipid composition and maximization of the polyunsaturated fatty acid content of three microalgae grown in mass culture. *Journal of Applied Phycology*, 5: 71-83.
- Dynalabcorp, (2015). Retrieved from <http://www.dynalabcorp.com/images/610855.jpg>.
- Elsayedllham, S.M. (2012). Mitigation of urban heat island of the city of Kuala Lumpur, Malaysia. *Middle-East Journal of Scientific Research*, 11(11): 1602-1613.
- Engel-Cox J.A., Nair N.L. and Ford J.L. (2012). Evaluation of solar and meteorological data relevant to solar energy technology performance in Malaysia. *Journal of Sustainable Energy and Environment*, 3: 115-124.
- Enright, C.T., Newkirk G.F., Craigie J.S. and Castell. J.D. (1986). Evaluation of Phytoplankton as Diets for Juvenile *Ostrea edulis* L. *Journal of Experimental Marine Biology and Ecology*, 96: 1-13.
- EnviroKingUV, (2015). Retrieved from <http://www.envirokinguv.com/>.
- Erickson, L.E. and Lee, H.Y. (1986). Process analysis and design of algal growth systems. In W., Barclay, and R.P. McIntosh, (Ed.), *Algal Biomass Technologies: An Interdisciplinary Perspective*. (pp. 197). Nova Hedwigia, Berlin.
- Ethanol Producer Magazine, (2014). Retrieved from ethanolproducer.com/articles/10766/proterro-receives-patent-on-unique-photobioreactor.
- Fedler ,C.B., Pulluoglu, M.A. and Parker, N.C. (1993). Integrating livestock waste recycling with production of microalgae. In Techniques for Modern Aquaculture, American society of Agricultural Engineers, Publication 02-93.
- Feng, Y., Li C. and Zhang, D. (2011). Lipid production of *Chlorella vulgaris* cultured in artificial wastewater medium. *Bioresource Technology*, 102: 101-105.
- Fischer, D., Schlösser, U. G. and Pohl, P. (1997). Exopolysaccharide production by cyanobacteria grown in closed photobioreactors and immobilized using white cotton towelling. *Journal of Applied Phycology*, 9(3): 205-213.
- Fleck-Schneider, P., Lehr, F. and Posten, C. (2007). Modelling of growth and product formation of *Porphyridium purpureum*. *Journal of Biotechnology*, 32: 134–141,
- Frohlich, B.T., Webster, I.A., Atai, M.M. and Shuler, M.L. (1983). Photobioreactors: models for interaction of light intensity, reactor design and algal physiology. In: *Biotechnology Bioengineering Symposium, (United States)* (Vol. 13, pp. 331–350, No. CONF-830567-). Cornell Univ., Ithaca, NY.
- Fu, C.-C., Lu, S.-Y., Hsu, Y.-J., Chen, G.-C., Lin, Y.-R. and Wu, W.-T. (2004). Superior mixing performance for airlift reactor with a net draft tube. *Chemical Engineering Science*, 59: 3021-3028.

- Fu, C.-C., Wu, W.-T. and Lu, S.-Y. (2003). Performance of airlift bioreactors with net draft tube. *Enzyme and Microbial Technology*, 33: 332–342.
- Fuentes, M.M.R., Sanchez, J.L.G., Sevilla, J.M.F., Fernandez, F.G.A., Perez, J.A.S. and Grima, E.M. (1999). Outdoor continuous culture of *Porphyridinium cruentum* in a tubular photobioreactor: quantitative analysis of the daily cyclic variation of culture parameters. *Journal of Biotechnology*, 70: 271-288.
- García-Malea López, M.C., Del Río Sánchez E., Casas López J.L., Acie'n Fernández F.G., Fernández Sevilla J.M., Rivas J., Guerrero M.G. and Molina Grima E. (2006). Comparative analysis of the outdoor culture of *Haematococcus pluvialis* in tubular and bubble column photobioreactors. *Journal of Biotechnology*, 123: 329–342.
- Garcia-Balboa, C., Baselga-Cervera B., Garcia-Sanchez A., Igual J.M., Lopez-Rodas V. and Costas E. (2013). Rapid adaptation of microalgae to bodies of water with extreme pollution from uranium mining: An explanation of how mesophilic organisms can rapidly colonise extremely toxic environments. *Aquatic Toxicology*, 144-145: 116-123.
- Garcia-Gozalet,, M., Moreno, J., Canavate, J.P., Anguis, V., Preto, A., Manzano, C., Florencio, F.J. and Guerrero, M.G. (2003). Conditions for open-air outdoor culture of *Dunaliella salina* in southern Spain. *Journal of Applied Phycology*, 15: 177-184.
- Gavrilescu, M. and Tudose, R. Z. (1998). Modelling of liquid circulation velocity in concentric-tube airlift reactors. *Chemical Engineering Journal*, 69: 85-91.
- Ghosh, T., Paliwal, C., Maurya, R. and Mishra, S. (2015). Microalgal rainbow colours for nutraceutical and pharmaceutical applications. In: B. Bahadur, M.V. Rajam, L. Sahijram and K.V. Krishnamurthy (Ed.) *Plant Biology and Biotechnology* (pp. 777-791). Springer India.
- Gilbert, P.M., Landsberg, J.H., Evans, J.J., Al-Sarawi, M.A., Faraj, M., Al-Jarallah, M.A., Haywood, A., Ibrahim, S., Klesius, P., Powell, C. and Shoemaker, C. (2002). A fish kill of massive proportion in Kuwait Bay, Arabian Gulf, 2001: the role of bacteria disease, harmful algae and eutrophication. *Harmful Algae*, 1: 215-231.
- Gong, N., Shao, K., Feng, W., Lin, Z., Liang, C. and Sun, Y. (2011). Biototoxicity of nickel oxide nanoparticles and bioremediation by microalgae *Chlorella vulgaris*. *Chemosphere*, 83(4): 510-516.
- Gouveia, L., Batista, A.P., Sousa, I., Raymundo, A. and Bandarra, N.M. (2008). Microalgae in novel food products. In: K.N. Papadopoulos (Ed.), *Food chemistry research developments*, vol 2. (pp. 1–37). Nova Science Publishers, Inc.
- Grobbelaar, J.U. (1991). The influence of light/dark cycles in mixed algal cultures on their productivity. *Bioresource Technology*, 38: 189-194.
- Grobbelaar, J.U. (2000). Physiological and technological considerations for optimizing mass algal cultures. *Journal of Applied Phycology*, 12: 201–20.
- Guang Ming Daily, (2012). Retrieved from <http://www.guangming.com.my/node/142893?tid=23>

- Guangxiong, P., Jing, L., Yunhao, C., Norizan, A.P. and Tay, L. (2006). High-resolution surface relative humidity computation using MODIS image in Peninsular Malaysia. *Chinese Geographical Science*, 16(3): 250-264.
- Gudin, C. and Chaumont, D. (1991). Cell fragility - the key problem of microalgae mass production in closed photobioreactors. *Bioresource Technology*, 38: 145-151.
- Guil-Guerrero, J.L. (2007). Stearidonic acid (18:4n-3): Metabolism, nutritional importance, medical uses and natural sources. *European Journal of Lipid Science and Technology*, 109: 1226-1236.
- Haas, M.J., Scott, K.M., Alleman, T.L. and McCormick, R.L. (2001). Engine Performance of Biodiesel Fuel Prepared from Soybean Soap stock: A High Quality Renewable Fuel Produced from Waste Feedstock. *Energy and Fuels*, 15: 1207-1212.
- Habib, M.A.B., Yusoff, F.M., Phang, S.M., Ang, K.J. and Mohamed, S. (1997). Nutritional values of chironomid larvae grown in palm oil mill effluent and algal culture. *Aquaculture*, 158: 95-105.
- Hall, D.O., Fernandez, F.G.A., Guerrero, E.C., Rao, K.K. and Grima, E.M. (2003). Outdoor helical tubular photobioreactors for microalgal production: modelling of fluid-dynamics and mass transfer and assessment of biomass productivity. *Biotechnology Bioengineering*, 82: 62-73.
- Hallegraeff, G.M. (2015). Transport of Harmful Marine Microalgae via Ship's Ballast Water: Management and Mitigation with Special Reference to the Arabian Gulf Region. *Aquatic Ecosystem Health and Management*, 18(3): 290-298.
- Hannon, M., Gimpel, J., Tran, M., Rasala, B. and Mayfield, S. (2010). Biofuels from algae: challenges and potential. *Biofuels*, 1(5): 763-784.
- Hansmann E. (1979) Growth media-freshwater. In Handbook of Phycological Methods, Culture Methods and Growth Measurements, ed. J. R. Stein. Cambridge University Press, Cambridge, pp. 359-368.
- Harker, M., Tsavalos, A.J., and Young, A.J. (1996). Autotrophic growth and carotenoid production of *Haematococcus pluvialis* in a 30 liter airlift photobioreactor. *Journal of Fermentation Bioengineering*, 82: 113-118.
- Hase, R., Oikawa, H., Sasao, C., Morita, M., and Watanabe, Y. (2000). Photosynthetic production of microalgal biomass in a raceway system under greenhouse conditions in Sendai City. *Journal of Bioscience Bioengineering*, 89: 157-163.
- Hemming, M.L. (1977). The treatment of effluents from the production of palm oil. D. A., Earp and W. Newall (Ed.), International Development in Palm Oil, Incorporated Society of Planters, Kuala Lumpur (1977), pp. 79-101.
- Henrard, A.A., de Morais M.G. and Costa J.A.V. (2011). Vertical tubular photo-bioreactor for semicontinuous culture of *Cyanobium* sp. *Bioresource Technology*, 102: 4897-4900.
- Henrikson, R. (1989). Earth food Spirulina. Laguna Beach, CA: Ronore Enterprises, Inc.
- Henrikson, R. (2009). Earth Food Spirulina: How This Remarkable Blue-Green Algae Can Transform Your Health and Our Planet. Hana: Ronore Enterprises, Inc.

- Hogan, C. (2012). Microclimate. Retrieved from <http://www.eoearth.org/view/article/160653>
- Holland, D. L., & Gabbott, P. A. (1971). A micro-analytical scheme for the determination of protein, carbohydrate, lipid and RNA levels in marine invertebrate larvae. *Journal of the Marine Biological Association of the United Kingdom*, 51(03), 659-668.
- Hu, Q. and Richmond, A. (1996). Productivity and photosynthetic efficiency of *Spirulina platensis* as affected by light intensity, algal density and rate of mixing in a flat plate photobioreactor. *Journal of Applied Phycology*, 8: 139-145.
- Hu, Q., Guterman, H. and Richmond, A. (1996). A flat inclined modular photobioreactor for outdoor mass cultivation of phototrophs. *Biotechnology Bioengineering*, 51: 51-60.
- Hu, Q., Kurano, N., Kawachi, M., Iwasaki, I. and Miyachi, S. (1998). Ultrahigh-cell-density culture of marine green alga *Chlorococcum littorale* in a flat panel photobioreactor. *Applied Microbial Biotechnology*, 49: 655-662.
- Huang, G.H., Chen, F., Wei, D., Zhang, X.W. and Chen, G. (2010). Biodiesel production by microalgal biotechnology. *Applied Energy*, 87: 38-46.
- Hulatt, C.J. and Thomas D.N. (2011). Energy efficiency of an outdoor microalgal photobioreactor sited at mid-temperate latitude. *Bioresource Technology*, 102: 6687-6695.
- Hussain I. and Hamid H. (2004). Plastics in Agriculture. In: A.L., Andrady (Ed.) *Plastics and the Environment*, (pp.185-209). John Wiley and Sons.
- Ibrahim, A.H., Dahlan, I., Adlan, M.N. and Dasti, A.F. (2012). Comparative study on characterization of Malaysian palm oil mill effluent (POME). *Research Journal of Chemical Science*, 2(12): 1-5.
- INO, (2015). Retrieved from <http://www.ino.ca/en/examples/artificial-lighting-system-optimizing-photosynthesis-for-microalgae-cultivation/>.
- Insureon, (2015). Retrieved from <http://www.insureon.com/insureonu/costs/workers-compensation>.
- Jacob-Lopes, E. (2015). Why does the photobioreactors fail? *Journal of Bioprocessing and Biotechniques*, 5(7).
- Jalal, K.C.A., Alam, M.Z., Matin, W.A., Kamaruzzaman, B.Y., Akbar, J. and Hossain, T. (2011). Removal of nitrate and phosphate from municipal wastewater sludge by *Chlorella vulgaris*, *Spirulina platensis* and *Scenedesmus quadricauda*. *IJUM Engineering Journal*, 12(4): 125-132.
- Janssen, M., Tramper, J., Mur, L. and Wijffels, R. (2003). Enclosed outdoor photobioreactor: Light regime, photosynthetic efficiency, scale-up, and future prospects. *Biotechnology and Bioengineering*, 81: 193-210.
- Jernelov, A. (1970). Release of methyl mercury from sediments with layers containing inorganic mercury at different depths. *Limnology and Oceanography*, 15: 958.
- Jiménez, C., Cossio, B.R. and Niell, F.X. (2003). Relationship between physiochemical variables and productivity in open ponds for the production of *Spirulina*: a predictive model of algal yield. *Aquaculture*, 221: 331-345.
- Jorquera, O., Kiperstok, A., Sales, E.A., Embirucu, M. and Ghirardi, M.L. (2010). Comparative energy life-cycle analyses of microalgal biomass

- production in open ponds and photobioreactors. *Bioresource Technology*, 101: 1406-1413.
- Jourdan, J.P. (2003). Grow your own Spirulina. http://www.antenna.ch/en/documents/Jourdan_UK.pdf
- Kaewpintong, K., Shotipruk, A., Powtongsook, S. and Pavasant, P. (2007). Photoautotrophic high-density cultivation of vegetative cells of *Haematococcus pluvialis* in airlift bioreactor. *Bioresource Technology*, 98: 288–295.
- Kargupta, W., Ganesh, A. and Mukherji, S. (2015). Estimation of carbon dioxide sequestration potential of microalgae grown in a batch photobioreactor. *Bioresource Technology*, 180: 370-375.
- Kemker, C. (2014). "Water Temperature." *Fundamentals of Environmental Measurements*. Fondriest Environmental, Inc. Web: <http://www.fondriest.com/environmental-measurements/parameters/water-quality/water-temperature/>.
- Kennedy, A.A. (2003). Mass culture of *Arthrospira platensis* utilizing aerobically digested palm oil mill effluent (ADPOME). Master Thesis. University Putra Malaysia, Serdang.
- Koc, C., Anderson, G.A. and Kommareddy, A. (2013). Use of red and blue Light-Emitting Diodes (LED) and fluorescent lamps to grow microalgae in a photobioreactor. *The Israeli Journal of Aquaculture – Bamidgeh*, 65: 1-8.
- Koc, C., Vatandas, M. and Koc, A.B. (2009). LED lighting technology and using in agriculture. In: 25th National Congress on Mechanization and Energy in Agriculture. (pp. 153-158). Isparta, Turkey.
- Kochert G (1978) Carbohydrate determination by the phenol-sulphuric acid method. In: J.A. Hellebust and J.S. Craigie (Ed.), *Handbook of phycological methods: physiological and biochemical methods*. (pp. 95–97). Cambridge University Press, Cambridge.
- Kommareddy, A. and Anderson, G. (2003). Study of light as a parameter in the growth of algae in a Photo-Bio-Reactor (PBR). ASAE Annual International Meeting Presentation 034057, Las Vegas, USA.
- Kondyurin, A., Kondyurina, I. and Bilek, M. (2013). Radiation damage of polyethylene exposed in the stratosphere at an altitude of 40 km. *Polymer Degradation and Stability*, 98(8): 1526-1536.
- Konopacki, S. and Akbari, H. (2001). Measured energy savings and demand reduction from a reflective roof membrane on a large retail store in Austin. Lawrence Berkley Laboratory Report No. LBNL-47149, CA.
- Kumar, K., Dasgupta, C.N., Nayak, B., Lindblad, P. and Das, D. (2011). Development of suitable photobioreactors for CO₂ sequestration addressing global warming using green algae and cyanobacteria. *Bioresource Technology*, 102: 4945-4953.
- Kumar, K., Mishra, S.K., Shrivastav, A., Park, M.S. and Yang, J.W. (2015). Recent trends in the mass cultivation of algae in raceway ponds. *Renewable and Sustainable Energy Reviews*, 51: 875-885.
- KWSP, (2015). Retrieved from <http://www.kwsp.gov.my/portal/employers/employers-responsibility/contribution/contribution-rate/>.

- Lai, J.I., Yusoff, F.M. and Shariff, M. (2012). Large-scale culture of a tropical marine microalga *Chaetoceros calcitrans* (Paulsen) Takano 1968 at different temperatures using annular photobioreactors. *Pakistan Journal of Biological Sciences*, 15(13): 635.
- Laliberte G., Olguin E.J. and Noue J.D.L. (1997). Mass cultivation and wastewater treatment using *Spirulina*. *Spirulina platensis* (Arthrospira). *Physiology, Cell-biology and Biotechnology*, 9: 159-173.
- Laws, E.A., Terry, K.L., Wickman, J. and Chalup, M.S. (1983). A simple algal production systems designed to utilize the flashing light effect. *Biotechnology Bioengineering*, 25: 2319-2335.
- Lee, Y.K. and Low, C.S. (1991). Effect of photobioreactor inclination on the biomass productivity of an outdoor algal culture. *Biotechnology Bioengineering*, 38: 995–1000.
- Lee, C.G. and Palsson, B.Ø. (1994). High-Density algal photobioreactors using light-emitting diodes. *Biotechnology and Bioengineering*, 44: 1161-1167.
- Lee, C.G. and Palsson, B.Ø. (1996). Photoacclimation of *Chlorella vulgaris* to red light from light-emitting diodes leads to autospore release following each cellular division. *Biotechnology Progress*, 12: 249–256.
- Lee, C.G. (1999). Calculation of light penetration depth in photobioreactors. *Biotechnology Bioengineering*, 4: 78-81.
- Lee, J.S.H., Jaafar, Z., Tan, A.K.J., Carrasco, L.R., Ewing, J.J., Bickford, D.P., and Koh, L.P. (2016). Toward clearer skies: Challenges in regulating transboundary haze in Southeast Asia. *Environmental Science and Policy*, 55: 87-95.
- Lee, K.H. and Kim, B.W. (1998). Enhanced microbial removal of H₂S using chlorobium in an optical fiber bioreactor. *Biotechnology Letters*, 20: 525–529.
- Lee, Y.K. (1986). Enclosed bioreactors for the mass cultivation of photosynthetic microorganisms: the future trend. *Trends in Biotechnology*, 4: 186–189.
- Lee, Y.K. (1997). Commercial production of microalgae in the Asia Pacific rim. *Journal of Applied Phycology*, 9: 403–411.
- Lee, Y.K. (2001). Microalgal mass culture systems and methods: Their limitation and potential. *Journal of Applied Phycology*, 13: 307-315.
- Lee, Y.K., Ding, S.Y., Low, C.S., Chang, Y.C., Forday W.L. and Chew, P.C. (1995). Design and performance of an α-type tubular photobioreactor for mass cultivation of microalgae. *Journal of Applied Phycology*, 7: 47–51.
- Lee, Y.K. and Low, C.S. (1991). Effect of photobioreactor inclination on the biomass productivity of an outdoor algal culture. *Biotechnology Bioengineering*, 38: 995–1000.
- Levinson, R., Pan, H., Ban-Weiss, G., Rosado, P., Paolini, R., and Akbari, H. (2011). Potential benefits of solar reflective car shells: Cooler cabins, fuel savings and emission reductions. *Applied Energy*, 88(12): 4343-4357.
- Li, J., Zhu, D., Niu, J., Shen, S. and Wang, G. (2011). An economic assessment of astaxanthin production by large scale cultivation of *Haematococcus pluvialis*. *Biotechnology Advances*, 29(6): 568-574.

- Liang, I. and Millican, P.F. (1986). Relative growth and growth efficiency of *Ostrea edulis* L. spat fed various algal diets. *Aquaculture*, 54:245-262.
- Livansky, K. and Doucha, J. (1996). CO₂ and O₂ gas exchange in outdoor thin-layer high density microalgal cultures. *Journal of Applied Phycology*, 8: 353–358.
- Lorenz, R.T. and Cysewski, G.R. (2000). Commercial potential for *Haematococcus* microalgae as a natural source of astaxanthin. *Trends in Biotechnology*, 18: 160-167.
- Lowry, O.H., Rosebrough, N.J., Farr, A.L. and Randall, R.J. (1951). Protein measurement with the Folin phenol reagent. *The Journal of Biological Chemistry*, 193(1): 265-275.
- Lv, Y., Huang, Y., Yang, J., Kong, M., Yang, H., Zhao, J. and Li, G. (2015). Outdoor and accelerated laboratory weathering of polypropylene: A comparison and correlation study. *Polymer Degradation and Stability*, 112: 145-159.
- Mansor, H., Mat, J. and Tahir, W.P.A.W.M. (2011). Treatment of leachate using cultured *Spirulina platensis*. *International Journal of Engineering and Technology*, 8(2): 57-60.
- Markou, G., Chatzipavlidis, I. and Georgakakis, D. (2012). Effects of phosphorus concentration and light intensity on the biomass composition of *Arthrospira* (*Spirulina*) *platensis*. *World Journal of Microbiology and Biotechnology*, 28 (8): 2661-2670.
- Martinez, G. and Perez, H. (2003). Effect of different temperature regimes on reproductive conditioning in the Scallop *Argopecten purpuratus*. *Aquaculture*, 228(1-4):153-167.
- Martis, R.V., Singh, R., Ankita, K., Pathak, A.K. and Guria, C. (2013). Solubility of carbon dioxide using aqueous NPK 10:26:26 complex fertilizer culture medium and *Spirulina platensis* suspension. *Journal of Environmental Chemical Engineering*, 1: 1245–1251.
- Mata, T.M., Martins, A.A. and Caetano, N.S. (2010). Microalgae for biodiesel production and other applications: a review. *Renewable and Sustainable Energy Review*, 14(1): 217–232.
- Matsunaga, T., Takeyama, H., Suso, H., Oyama, N., Ariura, S., Takano, H., Hirano, M., Burgess, J.G., Sode, K. and Nakamura, N. (1981). Glutamate production from CO₂ by marine cyanobacterium *Synechococcus* sp. using a novel biosolar reactor employing light diffusing optical fibers. *Applied Biochemistry and Biotechnology*, 28:157–167.
- Matthijs, H.C.P., Balke, H. and Van Hes, U.M. (1996). Application of light-emitting diodes in bioreactors. *Biotechnology and Bioengineering*, 50: 98–107.
- Mehlitz, T.H. (2009). Temperature influence and heat management requirements of microalgae cultivation in PBRs. Master Thesis, San Luis Obispo: California Polytechnic State University. p. 149.
- Mei-Fen, S. and Jong-Yuh, C. (2005). Potential hypoglycemic effects of *Chlorella* in streptozotocin-induced diabetic mice. *Life Science*, 77: 980-990.
- Merchant, R.E., Carmack, C.A. and Wise, C.M. (2000). Nutritional supplementation with *Chlorella pyrenoidosa* for patients with

- Fibromyalgia Syndrome: A pilot study. *Phytotherapy Research*, 14: 167-173.
- Meseck, S.L., Alix, J.H. and Wikfors, G.H. (2005). Photoperiod and light intensity effects on growth and utilization of nutrients by the aquaculture feed microalga, *Tetraselmis chui* (PLY 429). *Aquaculture*, 246: 393-404.
- Miao X. and Wu Q. (2004). High yield bio-oil production from fast pyrolysis by metabolic controlling of *Chlorella protothecoides*. *Journal of Biotechnology*, 110: 85–93.
- Michalak, I. and Chojnacka, K. (2015). Algae as production systems of bioactive compounds. *Engineering in Life Sciences*, 15: 160-176.
- Mignot, L., Junter, G.A. and Labbe, M. (1989). A new type of immobilized cell photoreactor with internal illumination by optical fiber. *Biotechnology Techniques*, 3(5): 98-107.
- Milner, H.W. (1953). Rocking tray. In: J.S. Burlew, (Ed.), *Algal Culture from Laboratory to Pilot Plant* (pp. 108). Carnegie Institution, Washington, DC, No. 600.
- Miron, A.S., Gomez, A.C., Camacho, F.G., Grima, E.M. and Chisti, Y. (1999). Comparative evaluation of compact photobioreactors for large-scale monoculture of microalgae. *Journal of Biotechnology*, 70: 249–270.
- Mirón, A. S., Garcia, M. C. C., Camacho, F. G., Grima, E. M., & Chisti, Y. (2002). Growth and biochemical characterization of microalgal biomass produced in bubble column and airlift photobioreactors: studies in fed-batch culture. *Enzyme and Microbial Technology*, 31(7): 1015-1023.
- Mishan, E. J. and Quah, E. (2007). *Cost-benefit analysis*. Routledge. p. 8.
- MMD, (2013). Malaysian Meteorological Department. Retrieved from <http://www.met.gov.my/>
- Moheimani, N.R. and Borowitzka, M.A. (2006). The long-term culture of the coccolithophore *Pluerochrysis carterae* (Haptophyta) in outdoor raceway ponds. *Journal of Applied Phycology*, 18: 703-712.
- Molina-Grima, E., Acie'n Ferna'ndez, F.G., Garcí'a Camacho, F. and Chisti, Y. (1999). Photobioreactors: light regime, mass transfer and scale up. *Journal of Biotechnology*, 70: 231-247.
- Molina-Grima, E., Fernandez, J., Acien Ferna'ndez, F.G. and Chisti, Y. (2001). Tubular photobioreactor design for algal cultures. *Journal of Biotechnology*, 92(2): 113-131.
- Molina-Grima, E., Belarbi, E. H., Fernández, F. A., Medina, A. R. and Chisti, Y. (2003). Recovery of microalgal biomass and metabolites: process options and economics. *Biotechnology Advances*, 20(7): 491-515.
- Molina Grima, E. (2009). "Challenges in Microalgae Biofuels," In: Energy Manufacturing Workshop, National Science Foundation, Arlington, VA, pp. 1-34.
- Monkonsit, S., Powtongsook, S. and Pavasant, P. (2011). Comparison between airlift photobioreactor and bubble column for *Skeletonema costatum* cultivation. *Engineering Journal*, 15(4): 53-64.
- Morais De, M.G. and Costa, J.A.V. (2007). Biofixation of carbon dioxide by *Spirulina* sp. and *Scenedesmus obliquus* cultivated in a three-stage serial tubular photobioreactor. *Journal of Biotechnology*, 129(3): 439-445.

- Moreno, J., Vargas, M.A., Rodriguez, H., Rivas, J., and Guerrero, M.G. (2003). Outdoor cultivation of a nitrogen-fixing marine cyanobacterium, *Anabaena* sp. ATCC 33047. *Biomolecular Engineering*, 20: 191-197.
- Mori, K. (1985). Photoautotrophic bioreactor using visible solar rays condensed by fresnel lenses and transmitted through optical fibers. *Biotechnology and Bioengineering Symposium*, 15: 331–345.
- Morita, M., Watanabe, Y. and Saiki, H. (2000). Investigation of photobioreactor design for enhancing the photosynthetic productivity of microalgae. *Biotechnology and Bioengineering*, 69: 693–698.
- Morizane, T. (1991). A Review of Automation and Mechanization Used In The Production of Rotifer In Japan. In W. Fulks and K.L. Main (Ed.). *Rotifer and Microalgae Culture Systems* (pp. 79-89). Proceedings of A U.S.- Asia Workshop. Honolulu, Hi. The Oceanic Institute.
- Naqqiuddin M.A., Nor N.M., Omar H. and Ismail A. (2014). Development of simple floating photobioreactor design for mass culture of *Arthrospira platensis* in outdoor conditions: Effects of simple mixing variation. *Journal of Algal Biomass Utilization*, 5(3): 46-58.
- Nor, N. M., Naqqiuddin M.A., Mashor N., Zulkifly S., Omar H. and Ismail A. (2015). The effect of different nitrogen sources on continuous growth of *Arthrospira platensis* in simple floating photobioreactor design in outdoor conditions. *Journal of Algal Biomass Utilization*, 6(4): 1-11.
- Nuno, K., Villarruel-Lopez, A., Puebla-Perez, A.M., Romero-Velarde, E., Puebla-Mora, A.G. and Ascencio, F. (2013). Effects of the marine microalgae *Isochrysis galbana* and *Nannochloropsis oculata* in diabetic rats. *Journal of Functional Foods*, 5: 106-115.
- Ogbonda, K. H., Aminigo, R. E. and Abu, G. O. (2007). Influence of temperature and pH on biomass production and protein biosynthesis in a putative *Spirulina* sp. *Bioresource Technology*, 98(11): 2207-2211.
- Ogbonna, J.C., Ichige, E. and Tanaka, H. (2002). Interactions between photoautotrophic and heterotrophic metabolism in photoheterotrophic cultures of *Euglena gracilis*. *Applied Microbiology and Biotechnology*, 58: 532-538.
- Ogbonna, J.C., Soejima, T. and Tanaka, H. (1999). An integrated solar and artificial light system for internal illumination of photobioreactors. *Journal of Biotechnology*, 70: 289-297.
- Oh T.H. (2010). Carbon capture and storage potential in coal-fired plant in Malaysia – a review. *Renewable and Sustainable Energy Reviews*, 14: 2697–2709.
- Oilgae, (2015). Retrieved from <http://www.oilgae.com/ref/downloads/>.
- Olaizola, M. (2003). Commercial Development of Microalgae Biotechnology: From the Test tube to the Marketplace. *Biomolecular Engineering*, 20(4-6): 459-466.
- Oliveira, D.M.A.C.L., Monteiro, M.P.C., Robbs, P.G., & Leite, S.G.F. (1999). Growth and chemical composition of *Spirulina maxima* and *Spirulina platensis* biomass at different temperatures. *Aquaculture international*, 7(4): 261-275.
- Oliver, R.L. and Ganf, G.G. (2000). Freshwater blooms. In: B.A. Whitton and M. Potts (Ed.). *The ecology of cyanobacteria: their diversity in time and space* (pp. 149–194). Kluwer: Dordrecht.

- Oncel, S. and Vardar Sukan, F. (2008). Comparison of two different pneumatically mixed column photobioreactors for the cultivation of *Arthrospira platensis* (*Spirulina platensis*). *Bioresources Technology*, 99: 4755-4760.
- Pandey, J.P., Tiwari, A., Singh, S. and Tiwari, D. (2011). Potential of different light intensities on the productivity of *Spirulina maxima*. *Journal of Algal Biomass Utilization*, 2(3): 9-14.
- Paoletti, C., Pushparaj, B., & Tomaselli, L. (1975). Ricerche sulla nutrizione minerale di *Spirulina platensis*. *Attidel XVII Congresso Nazionale della Societa` Italiana di Microbiologia*, 2: 833-839.
- Park, K.H. and Lee, C.G. (2000). Optimization of algal photobioreactors using flashing lights. *Biotechnology and Bioprocess Engineering*, 5: 186-190.
- Parkavi, K., Kuppusamy, S., Yusop, H.M. and Alwi, S.I.S. (2011). POME treatment using *Spirulina platensis* Geitler. *International Journal of Current Science*, 1: 11-13.
- Pelizer, L.H., Danesi, E.D., Rangel, C.O., Sassano, C.E., Carvalho, J.C. and Sato, S. (2003). Influence of inoculum age and concentration in *Spirulina platensis* cultivation. *Journal of Food Engineering*, 56: 371-375.
- Perkeso, (2015). Retrieved from <http://www.perkeso.gov.my/my/perlindungan-keselamatan-sosial/kelayakan-majikan-dan-pekerja/kadar-caruman.html>.
- Peters, M.S. and Timmerhaus, K.D. (2003). Plant design and economics for chemical engineers. New York: McGraw-Hill.
- Phang, S.M., Miah, M.S., Yeoh, B.G. and Hashim, M.A. (2000). *Spirulina* cultivation in digested sago starch factory wastewater. *Journal of Applied Phycology*, 12: 395-400.
- Pirt, S.J., Lee, Y.K., Walach, M.R., Pirt, M.W., Balyuzi, H.H.M. and Bazin, M.J. (1983). A tubular bioreactor for photosynthetic production of biomass from carbon dioxide: design and performance. *Journal of Chemical Technology and Biotechnology*, 33B: 35-58.
- Plexiglas, (2015). Retrieved from <http://www.plexiglas.com/export/sites/plexiglas/>.
- Pruvost, J., Pottier, L. and Legrand, J. (2006). Numerical investigation of hydrodynamic and mixing conditions in a torus photobioreactor. *Chemical Engineering Science*, 61: 4476-4489.
- PSI, (2015). Retrieved from <http://psi.cz/products/photobioreactors/>.
- Pulz, O., Gerbsch, N. and Buchholz, R. (1995). Light energy supply in plate type and light diffusing optical fiber bioreactors. *Journal of Applied Phycology*, 7: 145-149.
- Pulz, O. (2001). Photobioreactors production systems for phototrophic microorganisms. *Applied Microbiology and Biotechnology*, 57: 287-293.
- Pulz, O. and Gross, W. (2004). Valuable products from biotechnology of microalgae. *Applied Microbiology and Biotechnology*, 65: 635-648.
- Pushparaj, B., Pelosi, E., Tredici, M.R., Pinzani, E. and Materassi, R. (1997). An integrated culture system for outdoor production of microalgae and cyanobacteria. *Journal of Applied Phycology*, 9: 113-119.

- Qubit Biology Inc., (2015). Retrieved from <http://www.qubitbiology.com/algae-and-bacteria/cultivation-monitoring-a-b/z150-photobioreactor/>.
- Radmann, E.M., Reinehr, C.O. and Costa, J.A.V. (2007). Optimization of the repeated batch cultivation of microalga *Spirulina platensis* in open raceway ponds. *Aquaculture*, 265: 118-126.
- Rafiqul, I. M., Hassan, A., Sulebele, G., Orosco, C. A., Roustaian, P. and Jalal, K. C. A. (2003). Salt stress culture of blue green algae *Spirulina fusiformis*. *Pakistan Journal of Biological Sciences*, 6(7): 648-650.
- Randall, H.K. (2010). HKR Communications and Marketing, Des Moines, Iowa. Retrieved from <http://www.extension.iastate.edu/agdm/wholefarm/html/c5-16.html/>.
- Rausser, G.C. and Hochman, E. (1979). Dynamic Agricultural Systems: Economic Prediction and Control. North Holland, New York. (No. 04; HD1411, R3.).
- Razon, L.F. and Tan, R.R. (2011). Net energy analysis of the production of biodiesel and biogas from the microalgae: *Haematococcus pluvialis* and *Nannochloropsis* sp. *Applied Energy*, 88(10): 3507-3514.
- Reboloso Fuentes, M.M., Garcia Sanchez, J.L., Fernandez Sevilla, J.M., Acien Fernandez, F.G., Sanchez Perez, J.A. and Molina Grima, E. (1999). Outdoor continuous culture of *Porphyridium cruentum* in a tubular photobioreactor: quantitative analysis of the daily cyclic variation of culture parameters. *Journal of Biotechnology*, 70: 271-288.
- Reboloso-Fuentes, M.M., Navarro-Pérez, A., García-Camacho, F., Ramos-Miras, J.J. and Guil-Guerrero, J. (2001). Biomass nutrient profiles of the microalga *Nannochloropsis*. *Journal of Agricultural and Food Chemistry*, 49: 2966-2972.
- Ree, G.Y. and Gotham, I.J. (1981). The effect of environmental factors on phytoplankton growth: Light and interaction of light with nitrate limitation. *Limnology and Oceanography*, 26: 649-659.
- Reynolds, C.S., and Allen, S.E. (1968). Changes in the phytoplankton of Oak Mere following the introduction of base rich water. *British Phycological Journal*, 451-458.
- Richmond, A. (1991). Large-Scale Microalgal Culture and Applications. In: R., Chapman (Ed.). *Progress in Phycological Research* (pp. 1-62). Biopress Ltd., Bristol, England,
- Richmond, A. (1992). Open systems for the mass-production of photoautotrophic microalgae outdoor-physiological principles. *Journal of Applied Phycology*, 4: 281-286.
- Richmond, A. (2004). Handbook of microalgal culture: biotechnology and applied phycology. Blackwell Publishing, Oxford, pp. 566.
- Richmond, A. and Cheng-Wu, Z. (2001). Optimization of a plate glass reactor for mass production of *Nannochloropsis* sp. outdoors. *Journal of Biotechnology*, 85: 259-269.
- Richmond, A., Boussibam, S., Vonshak, A. and Kopel, R. (1993). A new tubular reactor for mass production of microalgae outdoors. *Journal of Applied Phycology*, 5: 327-332.
- Richmond, A., Lichtenberg, E., Stahl, B. and Vonshak, A. (1990). Quantitative assessment of the major limitations on productivity of

- Spirulina platensis* in open raceways. *Journal of Applied Phycology*, 2: 195–206.
- Rivkin, R.B. (1989). Influence of irradiation and spectral quality on carbon metabolism of phytoplankton. I. Photosynthesis, chemical composition and growth. *Marine Ecology Progress Series*, 55: 291-304.
- Rodolfi, L., Chini Zittelli, G., Bassi, N., Padovani, G., Biondi, N., Bonini, G. and Tredici, M. (2009). Microalgae for oil: strain selection, induction of lipid synthesis and outdoor mass cultivation in a low-cost photobioreactor. *Biotechnology and Bioengineering*, 102: 100-112.
- Rosenberg, J.N., Oyler, G.A., Wilkinson, L. and Betenbaugh, M.J. (2008). A green light for engineered algae: redirecting metabolism to fuel a biotechnology revolution. *Current Opinion in Biotechnology*, 19 (5): 430-436.
- Roso, G.R., Queiroz, M.I., Streit, N.M., Menezes, C.R.D. and Zepka, L.Q. (2015). The Bioeconomy of Microalgal Carotenoid-Rich Oleoresins Produced in Agroindustrial Biorefineries. *Journal of Chemical Engineering Process Technology*, 6: 218. doi:10.4172/2157-7048.1000218
- Ryu, H.J., Oh, K.K. and Kim, Y.S. (2009). Optimization of the influential factors for the improvement of CO₂ utilization efficiency and CO₂ mass transfer rate. *Journal of Industrial and Engineering Chemistry*, 15: 471-475.
- Saeid, A. and Chojnacka, K. (2015). Toward production of microalgae in photobioreactors under temperate climate. *Chemical Engineering Research and Design*, 93: 377-391.
- Salihu, A. and Alam, M.Z. (2012). Palm oil mill effluent: a waste or a raw material? *Journal of Applied Sciences Research*, 8(1): 466-473.
- Samuel, G.S., Sofi, M.Y. and Masih, S. (2010). Potential of different light intensities on the productivity of *Spirulina platensis* under agra conditions. *Research Journal of Agriculture Science*, 1(4): 468-469.
- Schlösser, U.G. (1982). Sammlung von Algenkulturen. *Berichte der Deutschen Botanischen Gesellschaft*, 95: 181–276.
- Schmitz, P. M. and Kavallari, A. (2009). Crop plants versus energy plants: On the international food crisis. *Bioorganic and Medicinal Chemistry*, 17: 4020-4021.
- Schott, North America Inc., (2015). Retrieved from <http://www.us.schott.com/tubing/english/>.
- Schreiber, U. (1983). Chlorophyll fluorescence yield changes as a tool in plant physiology. 1. The measuring system. *Photosynthesis Research*, 4: 361-373.
- Schugerl, K. and Lucke, J. (1977). Bubble column bioreactors: tower bioreactor without mechanical agitation. *Advances in Biochemical Engineering*, 7: 1–84.
- Shamsudin, L. (1992). Lipid and fatty acid composition of microalgae used in Malaysian aquaculture as live food for the early stage of Penaeid larvae. *Journal of Applied Phycology*, 4: 371-378.
- Sheehan, J., Dunahay, T., Benemann, J. and Roessler, P., (1998). A look back at the US Department of Energy's aquatic species program: biodiesel from algae. *National Renewable Energy Laboratory*, 328.

- Sim, T.S. and Goh, A. (1988). Ecology of microalgae in a high rate pond for piggery effluent purification in Singapore. *MICREN Journal*, 4: 285-297.
- Singh, R.N. and Sharma, S. (2012). Development of suitable photobioreactor for algae production—a review. *Renewable and Sustainable Energy Reviews*, 16: 2347–2353.
- Small, E. (2011). 37. Spirulina—food for the universe. *Biodiversity*, 12(4): 255-265.
- Smith, S. J., Edmonds, J., Hartin, C. A., Mundra, A. and Calvin, K. (2015). Near-term acceleration in the rate of temperature change. *Nature Climate Change*, 5: 333-336.
- Soeder, C. and Stengel, E. (1974). Physio-chemical factor affecting metabolism and growth rate. In: W.D.P. Stewart (Ed.), *Algal Physiology and Biochemistry* (pp. 714). Blackwell Scientific Publications, Oxford.
- Spolaore, P., Joannis-Cassan, C., Duran, E. and Isambert, A. (2006). Commercial applications of microalgae—review. *Journal of Bioscience Bioengineering*, 101: 87–96.
- Su, H.M, Su M.S. and Liao. I.C. (1998). The culture and use of microalgae for larval rearing in Taiwan. In: I.C. Liao and J. Bakers (Eds.), *Conference Proceedings in Aquaculture and Fisheries Resources Management*. pp. 157-162.
- Subitec GmbH Company, (2013). Retrieved from <http://subitec.com/en/flat-panel-airlift-fpa-photobioreactor/>.
- Suh, I.S. and Lee, S.B. (2001). Cultivation of a cyanobacterium in an internally radiating air-lift photobioreactor. *Journal of Applied Phycology*, 13(4): 381-388.
- Suh, I.S. and Lee, C.G. (2003a). Photobioreactor engineering: design and performance. *Biotechnology and Bioprocess Engineering*, 8: 313–321.
- Suh, I.S. and Lee, S.B. (2003b). A light distribution model for an internally radiating photobioreactor. *Biotechnology and Bioengineering*, 82 (2): 180–189.
- Sukumaran, P., Nulit, R., Zulkifly, S., Halimoon, N., Omar, H. and Ismail, A. (2014). Potential of fresh POME as a growth medium in mass production of *Arthrospira platensis*. *International Journal of Current Microbiology and Applied Sciences*, 3(4): 235-250.
- Sung, K.D., Lee, J.S., Shin, C.S., Park, S.C. and Choi, M.J. (1999). CO₂ fixation by *Chlorella* sp. KR-1 and its cultural characteristics. *Bioresource Technology*, 68: 269–273.
- Super Olefins Private Limited, (2015). Retrieved from <http://www.indiamart.com/superolefins/ldpe-films.html/>.
- Syabas, (2015). Retrieved from <http://www.syabas.com.my/consumer/water-bill-water-tariff/>.
- Tabernero, A., Martin del Valle, E.M. and Galan, M.A. (2012). Evaluating the industrial potential of biodiesel from a microalgae heterotrophic culture: Scale-up and economics. *Biochemical Engineering Journal*, 63: 104-115.
- Talling, J. F. and Driver, D. 1963. Some problems in the estimation of chlorophyll a in phytoplankton. In: Proc. Conference on Primary Productivity Measurements, Marine and Freshwater. Doty. M. (ed.).

- United states atomic energy comm., division of technical information. (TID-7633) 237 pp.
- Tap Plastics, (2015). Retrieved from <http://www.tapplastics.com/info/acrylic.php/>.
- Tennessen, D.J., Bula, R.J. and Sharkey, T.D. (1995). Efficiency of photosynthesis in continuous and pulsed light emitting diode irradiation. *Photosynthesis Research*, 44: 261–269.
- Teresa, M.M., Antonio, A.M. and Nidia, S.C. (2010). Microalgae for biodiesel production and other applications: A review. *Renewable and Sustainable Energy Reviews*, 14: 217-232.
- ThaiSurfRaider.com. (2014). Retrieved from <http://www.thaisurfrider.com/resources/surf-guides/gulf-surf-guide/>.
- The Star Online, (2011). Retrieved from <http://www.thestar.com.my/story.aspx?file=%2f2011%2f4%2f12%2flifefocus%2f8327270andsec=lifefocus/>.
- The Star Online, (2012). Retrieved from <http://www.thestar.com.my/Lifestyle/Features/2012/12/18/Tenaga-Nasional-looks-at-algae-for-CO2reducing-efforts/>.
- The Star Online, (2013). Retrieved from <http://www.thestar.com.my/News/Nation/2013/06/27/Haze-Rain-helps-to-douse-raging-Sumatra-fires-hotspots-reduced-to-54/>.
- The World Bank. (2015). Retrieved from <http://data.worldbank.org/indicator/AG.LND.PRCP.MM/countries?display=map/>.
- Thitakamol, B., Veawab, A. and Aroonwilas, A. (2007). Environmental impacts of absorption based CO₂ capture unit for post-combustion treatment of flue gas from coal-fired power plant. *International Journal of Greenhouse Gas Control*, 1: 318–342.
- Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., and Howarth, R. (2001). Forcasting agriculture driven global environmental change. *Science*, 292: 281-284.
- TNB, (2015). Retrieved from <https://www.tnb.com.my/commercial-industrial/>.
- Tompkins, J. 1995 Culture collection of algae and protozoa. In M.M. De Ville, J.G. Day & M.F. Turner (Eds.), *Catalogue of Strains: Natural Environment Research Council*, pp. 144-173 Kendal, U.K: Titus Wilson and Sons Ltd.
- Torzillo, G., Pushparaj, B., Bocci, F., Balloni, F., Materassi, W. and Florenzano, G. (1986) Production of *Spirulina* biomass in closed photobioreactors. *Biomass*, 11: 61-64.
- Torzillo, G., Carlozzi, P., Pushparaj, B., Montaini, E. and Materassi, R. (1993). A two-plane tubular photobioreactor for outdoor culture of *Spirulina*. *Biotechnology and Bioengineering*, 42(7): 891-898.
- Torzillo, G. (1997). Tubular bioreactors. In: A. Vonshak (Ed.), *Spirulina platensis (Arthrospira): Physiology, Cell-biology and Biotechnology* (pp. 101–115). Taylor and Francis, London.
- Travieso, L., Hall, D. O., Rao, K. K., Benitez, F., Sánchez, E., & Borja, R. (2001). A helical tubular photobioreactor producing *Spirulina* in a semicontinuous mode. *International Biodeterioration & Biodegradation*, 47(3), 151-155.

- Tredici, M.R., Carlozzi, P., Zittelli, C.G. and Materassi, R. (1991). A vertical alveolar panel (VAP) for outdoor mass cultivation of microalgae and cyanobacteria. *Bioresource Technology*, 38: 153–159.
- Tredici, M.R. and Chini Zittelli, G. (1998). Efficiency of sunlight utilization: tubular versus flat photobioreactors. *Biotechnology and Bioengineering*, 57: 187-197.
- Tredici, M.R. and Materassi, R. (1992). From open ponds to vertical alveolar panels: the Italian experience in the development of reactors for the mass cultivation of phototrophic microorganisms. *Journal of Applied Phycology*, 4: 221–231.
- Tredici, M.R., Chini Zittelli, G. and Rodolfi, L. (2010). Photobioreactors. In: M.C. Flickinger and S. Anderson (Ed.), *Encyclopedia of Industrial Biotechnology: Bioprocess, Bioseparation, and Cell Technology*, vol. 6 (pp. 3821–3838). Wiley, Hoboken,
- Tredici, M.R., Bassi, N., Prussi, M., Biondi, N., Rodolfi, L., Zittelli, G.C. and Sampietro, G. (2015). Energy balance of algal biomass production in a 1-ha “Green Wall Panel” plant: How to produce algal biomass in a closed reactor achieving a high Net Energy Ratio. *Applied Energy*, 154: 1103-1111.
- Trusted Choice, Independent Insurance Agents. (2015). Retrieved from <https://www.trustedchoice.com/business-insurance/workers-compensation/industrial/>.
- Ugwu, C.U., Aoyagi, H. and Uchiyama, H. (2008). Review- Photobioreactors for mass cultivation of algae. *Bioresources Technology*, 99: 4021-4028.
- Ugwu, C.U., Ogbonna, J.C. and Tanaka, H. (2002). Improvement of mass transfer characteristics and productivities of inclined tubular photobioreactors by installation of internal static mixers. *Applied Microbiology and Biotechnology*, 58: 600–607.
- Ugwu, C.U., Ogbonna, J.C. and Tanaka, H. (2003). Design of static mixers for inclined tubular photobioreactors. *Journal of Applied Phycology*, 15: 217–223.
- Vanthoor-Koopmans, M., Cordoba-Matson, M.V., Arredondo-Vega, B.O., Lozano-Ramírez, C., Garcia-Trejo, J.F. and Rodriguez-Palacio, M.C. (2014). Chapter 8: Microalgae and Cyanobacteria Production for Feed and Food Supplement. In: R. Guevara-Gonzalez and I. Torres-Pacheco (Ed.), *Biosystems Engineering: Biofactories for Food Production in the Century XXI* (pp. 253). Switzerland.
- Vonshak, A. (1997). Outdoor Mass Production of Spirulina: the basic concept. In: A. Vonshak (Ed.), *Spirulina platensis (Arthrospira): Physiology, Cell-biology and Biotechnology* (pp. 79–99). Taylor and Francis, London.
- Vonshak, A. and Tomaselli, L. (2000). *Arthrospira* (Spirulina): Systematics and Ecophysiology. In: B.A. Whitton and M. Potts (Ed.), *Ecology of Cyanobacteria* (pp. 505 – 523). Kluwer, The Netherlands.
- Vonshak, A., Abeliovich, A., Boussiba, S., Arad, S. and Richmond, A. (1982). Production of Spirulina biomass: effects of environmental factors and population density. *Biomass*, 2(3): 175-185.

- Vonshak, A., Boussiba, S., Abeliovich, A. and Richmond, A. (1983). Production of *Spirulina* biomass: maintenance of monoalgal culture outdoors. *Biotechnology and Bioengineering*, 25(2): 341-349.
- Vonshak, A., Kancharaksa, N., Bunnag, B. and Tanticharoen, M. (1996). Role of light and photosynthesis on the acclimation process of the cyanobacterium *Spirulina platensis* to salinity stress. *Journal of Applied Phycology*, 8: 119-124.
- Vörösmarty, C.J., Green, P., Salisbury, J. and Lammers, R.B. (2000). Global water resources: vulnerability from climate change and population growth. *Science*, 289(5477): 284-288.
- Vunjak-Novakovic, G., Kim, Y., Wu, X., Berzin, I. and Merchuk, J.C. (2005). Air-lift bioreactors for algal growth on flue gas: mathematical modeling and pilot-plant studies. *Industrial and Engineering Chemical Research*, 44: 6154–6163.
- Wang, B., Lan, C.Q. and Horsman, M. (2012). Closed photobioreactors for production of microalgal biomasses. *Biotechnology Advances*, 30: 904-912.
- Wang, C. (2001). Atlantic climate variability and its associated atmospheric circulation cells. *Journal of Climate*, 15: 1516-1536.
- Watanabe, Y. and Saiki, H. (1997). Development of photobioreactor incorporating *Chlorella* sp. for removal of CO₂ in stack gas. *Energy Conversion and Management*, 38: 499-503.
- Watanabe, E., Wang, C. M., Utsunomiya, T. and Moan, T. (2004). Very large floating structures: applications, analysis and design. *CORE Report*, 2: 104-109.
- Weissman, J.C., Goebel, R.P. and Benemann, J.R. (1988). Photobioreactor design: Mixing, carbon utilization, and oxygen accumulation. *Biotechnology and Bioengineering*, 31: 336–344.
- Wiley, P., Harris, L., Reinsch, S., Tozzi, S., Embaye, T., Clark, K., McKuin, B., Kolber, Z., Adams, R., Kagawa, H., Richardson, T-M.J., Malinowski, J., Beal, C., Claxton, M.A., Geiger, E., Rask, J., Campbell, J.E. and Trent, J.D. (2013). Microalgae cultivation using offshore membrane enclosures for growing algae (OMEGA). *Journal of Sustainable Bioenergy Systems*, 3: 18-32.
- Wiley, P.E. (2013). Microalgae Cultivation using Offshore Membrane Enclosures for Growing Algae (OMEGA). UC Merced: Environmental Systems. Retrieved from: <http://escholarship.org/uc/item/0586c8p5/>.
- Wu, T.Y., Mohammad, A.W., Jahim, J.M. and Anuar, N. (2007). Palm Oil Mill Effluent (POME) treatment and bioresources recovery using ultrafiltration membrane: Effect of pressure on membrane fouling. *Biochemical Engineering Journal*, 35(3): 309-317.
- Wu, T.Y., Mohammad, A.W., Jahim, J.M. and Anuar, N. (2010). Pollution control technologies for the treatment of palm oil mill effluent (POME) through end-of-pipe processes. *Journal of Environmental Management*, 91(7): 1467-1490.
- Yamada, A., Takano, H., Burgess, J.G. and Matsunaga, T. (1996). Enhanced hydrogen production by a marine photosynthetic bacterium *Rhodobacter marinus* immobilized onto light diffusing optical fiber. *Journal of Marine Biotechnology*, 4: 23–27.

- Yamaguchi, K. (1997). Recent advances in microalgal bioscience in Japan, with special reference to utilization of biomass and metabolites: a review. *Journal of Applied Phycology*, 8: 487–502.
- Yamasaki, A. (2003). An overview of CO₂ mitigation options for global warming-emphasizing CO₂ sequestration options. *Journal of Chemical Engineering of Japan*, 36: 361–375.
- Yilmaz, H.K. (2012). The proximate composition and growth of *Spirulina platensis* biomass (*Arthrospira platensis*) at different temperatures. *Journal of Animal and Veterinary Advances*, 11(8): 1135-1138.
- Yoo, J.J., Choi, S.P., Kim, J.Y., Chang, W.S. and Sim, S.J. (2013). Development of thin-film photo-bioreactor and its application to outdoor culture of microalgae. *Bioprocess and Biosystems Engineering*, 36(6): 729-736.
- Yoon, J.H., Shin, J.H. and Park, T.H. (2008). Characterization of factors influencing the growth of *Anabaena variabilis* in bubbles column reactor. *Bioresource Technology*, 99: 1204-1210.
- Zarrouk, C. (1966). Contribution à l'étude d'une cyanophyce'e. Influence de divers facteurs physiques et chimiques sur la croissance et la photosynthèse de *Spirulina maxima* Geilster. PhD Thesis, Université de Paris, Paris, France.
- Zeng, M.T. and Vonshak, A. (1998). Adaptation of *Spirulina platensis* to salinity-stress. *Comparative Biochemical and Physiology, Part: A*, 120: 113–118.
- Zhang, K., Kurano, N. and Miyachi, S. (1999). Outdoor culture of a cyanobacterium with a vertical flat-plate photobioreactor: effects on productivity of the reactor orientation, distance setting between the plates, and culture temperature. *Applied Microbiology and Biotechnology*, 52: 781-786.
- Zhang K., Kurano N. and Miyachi S. (2002). Optimized aeration by carbon dioxide gas for microalgal production and mass transfer characterization in a vertical flat-plate photobioreactor. *Bioprocess and Biosystem Engineering*, 25: 97-101.
- Zittelli, G.C., Biondi, N., Rodolfi, L. and Tredici, M.R. (2013). Photobioreactors for mass production of microalgae. In: A. Richmond, & Q. Hu (Ed.), *Handbook of Microalgal Culture: Applied Phycology and Biotechnology* (pp. 225-266). Oxford: Blackwell Publishing.