INTEGRATED SYSTEM FOR OPTIMIZED ALGAL PRODUCTION IN OPEN PONDS

By

Tarek Farouk Aly Fayed

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR Of PHILOSOHY
In
Chemical Engineering

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Title of Thesis:

INTEGRATED SYSTEM FOR OPTIMIZED ALGAL PRODUCTION IN OPEN PONDS

Key Words:

Algae; open pond; Fluidized Bed Combustion; Biomass Residues ;Wastewater

Summary:

The present work aims to setup an integrated system which can optimize the microalgae productivity in open ponds along with reducing the capital and operating costs needed to be commercially viable, through: enhancing the method of mixing suspended algae to increase the pond depth without any increase in the power consumption. Additionally, using captured CO_2 released from incineration of agriculture residues in fluidized bed combustion, as a source of CO_2 and using municipal wastewater ingredients as a source of cheap macro nutrients.

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Table of Contents

ACKNOWLEDGMENTS ……. I
TABLE OF CONTENTS …… II
LIST OF TABLES ……. VI
LIST OF FIGURES…… VII
LIST OF ABBREV1ATIONS …….. IX
NOMENCLATURE……... X
ABSTRACT ……... XI
CHAPTER 1:INTRODUCTION
1.1 Introduction ……... **1**
1. 2 Capital and Running Cost for Some Factors Affecting Algal Open Pond Systems…….. 1
1. 2. 1 Power Needed for Paddlewheels……. 2
1. 2. 2 Pond Liners …….. 3
1. 2. 2.1 Fiberglass properties as coating pond liners……. 3
1. 2. 3 Nutrient Consumption…….. 3
1. 2. 4 Covered vs Uncovered Raceway Pond…… 4
1.3 The innovated algal System …….. 4
1. 4 Characteristics of Wastewater in Egypt and Role of Algae in Bioremediation……. 5
1. 5 Amount and Characteristics of Burning Rice Straw and Corn Stalk in Egypt..... . . **6**
1. 5.1 Types of Emissions from Biomass Combustion **……** 8
1.6 Methodology of the Present Work ……... 11
CHATER 2: LITERATURE REVIEW
2.1 Introduction ……. 13
2.2 Major Groups of Algae ……... 14
2.2.1 Macro-algae…… 14
2.2.2 Cyanobacteria …… 14
2.2.3 Microalgae…….. 14
2.3 Why Microalgae……... 15
2.3.1 Masters of Photosynthesis ……. 15
2.3.2 No Occupation of Arable Land…….. 15
2.3.3 Onsite Solution……... 15
2.3.4 High Oil Productivity…… 15
2.3.5 Algae Cultivation does not Need Herbicides or Pesticides…… 16
2.3.6 Diverse Uses of Algal Yield……... 16
2.3.7 Easy Carbon Dioxide Injection to Cultivation Medium……. 16
2.3.8 Algal-Feedstock Based on Non-Food Resource…… 16
2.3.9 Eutrophication ……... 16
2.4 Major Chemical Composition of Microalgae Biomass …… 16
2.4.1 Proteins……... 17
2.4.2 Carbohydrates……. 17
2.4.3 Nutraceutical…….. 18
2.5 Factors Affecting Algal Growth Rate …… 19

2.5.1	Light ……..	19
2.5.2	Temperature ……..	20
2.5.3	Mixing ……...	20
2.5.4	Nutrients ……	20
2.5.4.1	Macronutrients ……..	20
2.5.4.2	Micronutrients……	22
2.5.5	Gas exchange……..	23
2.5.6	Hydraulic retention time…….	23
2.5.7	pH ……..	24
2.5.8	Oxygen Inhibition of Production……	24
2.5.9	Culture Contamination……...	25
2.5.10	Dependence of Photosynthesis on Culture Depth ……	25
2.6	**Cultivation Techniques……....**	**26**
2.6.1	Open Pond Culture Systems …….	26
2.6.1.1	Raceway pond and its operation……	30
2.6.2	Closed Photobioreactors ……	33
2.6.2.1	Tubular PBR……...	34
2.6.2.2	Helical PBR……	35
2.6.2.3	Airlift PBR ……...	35
2.6.2.4	Heterotrophic culture systems……	35
2.6.2.5	Flat panel (Flat Plate) PBR…….	36
2.6.3	Immobilized Cultures…….	37
2.6.3.1	Matrix-immobilized microalgae…….	38
2.6.3.2	Algal biofilms…….	38
2.7	**Harvesting and Dewatering Systems…….**	**40**
2.7.1	Flocculation……	40
2.7.2	Dissolved Air Flotation DAF ……	42
2.7.3	Filtration…….	42
2.7.4	Centrifugation…….	42
2.8	**Biofuels From Microalgae……...**	**42**
2.8.1	Biodiesel…….	42
2.8.2	Ethanol ……	43
2.8.3	Biogas ……...	43
2.8.4	Bio-oil and syngas …….	43
2.8.5	Non-Fuel Products From Microalgae…….	44
2.8.5.1	Animal feed ……...	44
2.8.5.2	Human consumption……..	44
2.8.5.3	Fertilizer ……	44
2.9	**Roles of Microalgae in Pollution Mitigation …….**	**45**
2.9.1	Water pollution mitigation ……	45
2.9.2	Air Pollution Mitigation ……	45
2.10	**Challenges Confronted Algal Production……..**	**46**
2.10.1	Nutrient Supply and Recycling…….	46
2.10.2	Gas Transfer and Exchange……	47
2.10.3	PAR Delivery…….	48
2.10.4	Culture Integrity ……	48
2.10.5	Environment Control…….	48
2.10.6	Land and Water Availability …….	48

2.10.7	Harvesting ……	49
2.11	**The Multi-impeller as a New Technique for Algal Mixing ..**	**49**
2.11.1	Multiple-impeller Design Variation ……..	50
2.11.2	Power Number……	51
2.12	**Principle of Combustion** ……	**51**
2.12.1	Stoichiometric and Excess-air Combustion……...	52
2.12.2	Determination of the Excess Air Value…….	54
2.12.3	Effect of Humidity in Combustion Process……	55
2.13	**Fluidized-bed Combustion…….**	**55**
2.13.1	Advantages of Fluidized Bed Reactors**……..**	57
2.13.2	The Principle of Fluidization…….	57
2.13.2.1	Vertical type FBC ……...	59
2.13.2.2	Horizontal type FBC …….	59
2.13.3	Pollution Abatement……..	60
2.14	**Evaporation from Water Surfaces …….**	**60**
2.15	**Baffling …….**	**61**
CHAPTER 3:	**REDUCING ALGAL PRODUCTION COST USING MOBILE MIXER AND WASTEWATER INGREDIENTS**	
3.1	**Introduction ……...**	**62**
3.2	**Assumptions ……...**	**62**
3.3	**Materials and Methods……..**	**62**
3.3.1	Algal Strain……	**62**
3.3.2	Wastewater……	63
3.3.3	Analytical Methods……...	64
3.4	**Experimental Methods……**	66
3.3.1	The Paddlewheel Raceway Pond …….	67
3.4.2	The Straight Pond with Mobile Mixer …….	69
3.5	**Results and Discussion……**	**73**
3.5.1	Growth Rate …….	73
3.5.2	Ammonium Removal……	74
3.5.3	Nitrate Removal ……...	75
3.5.4	Dissolved Phosphate Removal …….	76
3.5.5	Comparisons between Economics of Raceway Pond and Innovated Pond	77
CHAPTER 4:	**MICROALGAL BIOREMEDATION OF WASTEWATER AND CO_2 EMISSIONS FROM BURNING OF AGRICULTURE RESIDUES**	
4.1	**Introduction …….**	**79**
4.2	**Materials……...**	**79**
4.2.1.	Algal Strain……	79
4.2.2.	Analytical Method…….	80
4.2.3	Wastewater Source…….	82
4.2.4	CO_2 Source……	82
4.3	**Methods……**	**83**
4.3.1	Fluidized Bed Combustor…….	84
4.3.2	CO_2 Addition……..	89
4.3.2	Pond with Mobile Mixer……	92
4.4	**RESULTS AND DISCUSSION……...**	**95**
4.4.1	Growth Rate ……..	95

4.4.2 Total Nitrogen Removal……. 96
4.4.3 Ammonium Removal ……. 96
4.4.4 Nitrate Removal……. 97
4.4.5 Dissolved Phosphate Removal …….. 98
CHATER 5: CONCLUSION
5.1 Introduction ……. 99
5.1 Conclusion……. 99
References …… 100

List of Tables

Table 1.1	Amount of agriculture residues in Egypt ……...	7
Table 1.2	Compostion of corn stalk and rice straw ……	8
Table 1.3	Major forms of Nitrogen Oxides (NOx)……..	9
Table 2.1	Comparison of oil productivity for algae and other corps…….	15
Table 2.2	Ratios of the main components for some types of algae……	18
Table 2.3	Excess air value of specific combustion processes…….	53
Table 2.4	CO_2 max for specific fuels……..	55
Table 2.5	Gas composition combustion at different gas conditions and Excess air **(**EA) ……..	55
Table 3.1	Typical Composition of wastewater ……..	63
Table 3.2	Percentage of suspended algae with time……...	72
Table 4.1	Typical composition of wastewater ……...	82
Table 4.2	Concentrations of gases released from burning of agriculture residues in mg/m^3 (ppm) ……	83

List of Figures

Fig.1.1	Baseline capital cost results for a single raceway pond ……..	1
Fig.1.2	Baseline of operating cost results for a single raceway pond …….	2
Fig 1.3	The open burning of rice husk causes severe air pollution……..	7
Fig 2.1	Wide spectrum of products from microalgae ……..	13
Fig.2.2	Effect of light intensity on the growth of microalgae …….	19
Fig.2.3	Variation of irradiance with raceway pond depth at various concentrations of algal biomass in the culture ……	26
Fig.2.4	Baffles for smoothening the turnaround of the fluid at the semicircular ends of a raceway pond ……..	28
Fig.2.5	Dead zones in a raceway in the absence of the flow deflector baffles ……..	29
Fig.2.6	Modified configuration of the raceway dividing wall to eliminate the dead zones near its ends……	29
Fig.2.7	Typical view of raceway pond ……	30
Fig.2.8	Typical view of airlift-based mixing systems …….	31
Fig.2.9	The irradiance-depth profile at 30 cm and dry biomass 0.5g L^{-1}….	32
Fig.2.10	A view of one types of photobioreactor …….	33
Fig.2.11	A tubular photobioreactor with parallel run horizontal tubes ……	34
Fig.2.12	Schematic Representation of Helical PBRs ……	35
Fig.2.13	Schematic Representation of PBR ……..	36
Fig 2.14	A view of pumping gases in PBR ……...	37
Fig.2.15	Immobilized for algal culturing ……..	37
Fig.2.16a	The biofilm photobioreactor for algal culturing …….	38
Fig.2.16b	The biofilm photobioreactor for algal culturing …….	39
Fig.2.17	Chemical flocculation of algal harvesting……	41
Fig.2.18	Bioflocculation of algal harvesting……..	41
Fig.2.19	Mitigation of CO_2 fixation and wastewater using microalgae ……	45
Fig.2.20	Schematic View of Stirred tanks using multiple impellers……..	49
Fig.2.21	Hydrofoil impeller and pitched cylindrical three-blade turbine…...	51
Fig.2.22	Stoichiometric combustion …….	52
Fig.2.23	Excess air combustion……..	53
Fig.2.24	Combustion profile……...	54
Fig.2.25	Schematic view of fluidized bed combustion ……	56
Fig.2.26	Ideal Fluidization Curve ……..	58
Fig.2.27	Pressure Drop as a Function of Gas Velocity……..	59
Fig. 3.1	Micratinnium Pusillum Species as Appearing Under a Light Microscope ……..	63
Fig. 3.2	Collection point of wastewater sample……	64
Fig.3.3	Automatic micro Kjeldall Vapodest used for the determination of NH_4^- , $N-NO_3^-$ and total nitrogen …….	64
Fig 3.4	Inductively coupled plasma spectrometry used for the determination of soluble phosphorus and total phosphorus ……...	65
Fig. 3.5	Portable pH meter ……...	65
Fig. 3.6	Hemocytometer to count the number of cells ……	66
Fig. 3.7	Figure 3.6 A Schematic view of Hemocytometer ……..	66
Fig. 3.8	A top view of a raceway pond …….	68

Fig. 3.9	A front view of a raceway pond ……..	68
Fig. 3.10	Schematic top view of a pond with mobile electromechanical mixer…….	69
Fig. 3.11	Front view of pilot straight pond with mobile mixer …….	70
Fig. 3.12	The top view of pilot pond with impellers……...	70
Fig. 3.13	Schematic side view of a pond with mobile electromechanical mixer ……	71
Fig. 3.14	Fronts and side view for mixing shaft with 3 impellers …….	72
Fig 3.15	Top and side view for motor carrier and gearbox……	73
Fig. 3.16	Rate of changing cell density at 30 cm and 100 cm pond depth ….	73
Fig. 3.17	Algal dry-weight at 30 cm and 100 cm pond depth ……	74
Fig. 3.18	Rate of ammonium removal with time…….	75
Fig. 3.19	Rate of nitrate removal with time…….	76
Fig. 3.20	Rate of dissolved Phosphate removal with time……..	76
Fig 3.21	Comparison the capital cost parameters for the two ponds…….	77
Fig.3.22	Comparison the operating cost parameters for the two ponds……	78
Fig 4.1	Micratinnium Pusillum Species as Appearing Under a Light Microscope……	79
Fig 4.2	Digital anemometer……..	81
Fig 4.2	Digital anemometer……...	81
Fig 4.3	Portable gas analyzer ……...	81
Fig 4.4	Al Qalyoubia drain……	82
Fig. 4.5	Chopped of dried corn stalk and rice husk……...	83
Fig. 4.6	A schematic diagram of the conical FBC…….	85
Fig. 4.7	A view of the conical FBC……...	86
Fig. 4.8	A schematic diagram of the screw biomass feeder …….	87
Fig. 4.9	A schematic diagram of water filter…….	87
Fig. 4.10	A view of Water filter connections……..	88
Fig. 4.11	Carbon dioxide solubility in water at (100Kpa)……...	89
Fig. 4.12	A schematic diagram of the CO_2 gases tank and its connections….	90
Fig. 4.13	Complete carbon dioxide supply system …….	90
Fig. 4.14	Pond carbon dioxide diffusers …….	91
Fig. 4.15	Schematic view of CO_2 gas diffuser ……...	92
Fig. 4.16	A view of the completed integrated system for algal open pond …	93
Fig. 4.17	A schematic diagram of the completed integrated system for algal open pond …….	94
Fig. 4.18	Algae cell density over cultivation days ……..	95
Fig. 4.19	Algae dry weight over cultivation days ……...	95
Fig. 4.20	Rate of total nitrogen removal with time……..	96
Fig. 4.21	Rate of ammonium removal with time ……	97
Fig. 4.22	Rate of nitrate removal with time ……	97
Fig. 4.23	Rate of dissolved phosphate removal with time …….	98

List of Abbreviations

ASU	Air Separation Unit
BOD	Biochemical oxygen demand
BFC	Fluidized-bed Combustion
CCS	Carbon Capture and Storage
CFB	Circulating fluidized bed
COD	Chemical oxygen demand
COP	Cost of production
DAF	Dissolved Air Flotation
DIC	Dissolved inorganic carbon
DO	Dissolved oxygen
DW	Dry weight
FBC	Fluidized-bed combustion
HRAP	High rate algae pond
HRT	Hydraulic retention time
ISAC	Integrated system for algae cultivation
LF	Liquid Filter
NOx	Oxides of Nitrogen (NOx) are emissions which may include Nitric Oxide (NO),Nitrogen Dioxide (NO2) and Nitrous Oxide (N2O).
PAR	Photosynthetically active radiation
PBR	Photobioreactors
PFD	Photon-flux density
PFBC	Pressurized Fluidized-bed Combustion
pH	Potential of hydrogen
ppm	Parts per million
RBCs	Rotating biological contactors
rpm	Revolution per minute or rotation per minute
SPM	Solid particle material

NOMENCLATURE

A	Surface area of raceway	m^2
d_h	Hydraulic diameter of flow channel	m
D_i	Impellers diameter	m
e	Efficiency of the motor, drive, and the paddlewheel	-
f_M	Manning channel roughness factor	$s\ m^{-1/3}$
g	Gravitational acceleration	m
h	Culture depth in pond	m
P	Power requirement for paddlewheel	$m^2\ kg\ s^3$
Re	Reynolds Number	-
u	Flow velocity in channel	$m\ s^{-1}$
w	Channel width	m
ρ	Density of algal broth	$kg\ m^{-3}$
I_o	Io Incident irradiance on the surface of the pond	$\mu E\ m^{-2}\ s^{-1}$
I_L	Local irradiance at depth L	$\mu E\ m^{-2}\ s^{-1}$
Dp	Pond Depth	m
lc	Depth at which the local irradiance level is at the light compensation point	m
Cx	Biomass concentration	$kg\ m^{-3}$
Ka	Light absorption coefficient of the biomass	$\mu E\ m^{-2}\ s^{-1}$

ABSTRACT

Microalgae can metabolize various waste streams and convert the wastes into carbohydrates, lipids and proteins, which can be used to produce a wide variety of products. Lipids can be processed into biodiesel; carbohydrates into bioethanol and biomethanol; and proteins can be used as food supplement for humans and animal feedstock. Thus, microalgal cultivation can contribute to CO_2 mitigation and nutrients recovery from wastewater and thus could be considered of high economic value. The present work aims to setup an integrated system which can optimize the microalgae productivity in open ponds along with reducing the capital cost needed to be commercially viable, through:

1-Enhancing the method of mixing of suspended algae to keep the algae cells always suspended next to the surface of the culture allowing the ability of increasing the depth of the algae pond without any increase in the power consumption, as well as the use of the economic paddlewheel method for mixing algal broth. Moreover increasing the depth of the algae pond leads to a decrease in the needed land area infrastructure.

2- Using captured CO_2 released from incineration of agriculture residues (rice husk and corn stalk) in fluidized bed combustion, as a source of cheap carbon dioxide.

3- Using municipal wastewater ingredients (e.g., nitrogen and phosphorus) as a source of cheap macro nutrients.

Results proved that microalgae cultivated in a 90 cm deep straight pond equipped with mobile electro-mechanical mixer, achieved the same growth rate, with lower power consumption than that cultivated in a traditional 30 cm deep raceway pond. Moreover, reductions in ammonia and dissolved phosphate concentrations in wastewater in a straight pond are approximately equal to that in a traditional raceway pond.

Microalgae cultivated in a pond pumped with CO_2 gas resulting from the incineration of agriculture residues (rice husk and corn stalk), achieved higher growth rate with lower hydraulic retention time than that cultivated without feeding carbon dioxide.

The final result showed that the capital cost of algal production was reduced by about 30% as a result of reducing cost of mixing by about 25 % which represents over 10% from the total cost.