Cairo University

OPTIMIZATION OF PHOTOBIOREACTOR DESIGN FOR MICROALGAE TO PRODUCE BIODIESEL

By

Samar Abdullah Gouda El-Mekkawi

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
in
Chemical Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2016

OPTIMIZATION OF PHOTOBIOREACTOR DESIGN FOR MICROALGAE TO PRODUCE BIODIESEL

By
Samar Abdullah Gouda El-Mekkawi

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
in
Chemical Engineering

Under the Supervision of

Prof. Dr. Nabil M. Abdelmonem
Professor of Chemical and Environmental Engineering
Faculty of Engineering, Cairo University

Dr. Ahmed H. Elahwany
Associate Professor of Chemical Engineering and Biotechnology
Faculty of Engineering, Cairo University

Prof. Dr. Nagwa N. El-Ibiari
Professor of Chemical Engineering
Chemical Engineering Department
National Research Centre, Egypt

Dr. Ola A. El-Ardy
Associate Professor of Chemical Engineering
Chemical Engineering Department
National Research Centre, Egypt

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2016

OPTIMIZATION OF PHOTOBIOREACTOR DESIGN FOR MICROALGAE TO PRODUCE BIODIESEL

By

Samar Abdullah Gouda El-Mekkawi

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
in
Chemical Engineering

Approved by the
Examining Committee

____
Prof. Dr. Nabil M. Abdelmonem, Thesis Main Advisor

____
Dr. Ahmed H. Elahwany, Member

____
Prof. Dr. Magdi F. Abadir, Internal Examiner

____
Prof. Dr. Gamila H. Ali, External Examiner
National Research Centre, Egypt

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2016

Acknowledgments

I wish to express my sincere gratitude to Prof. Dr. Nabil Mahmoud Abdelmonem the main supervisor and Dr. Ahmed Hussein Elahwany, Cairo University for their support and valuable comments. Many thanks are due to Prof. Dr. Ibrahim Ismail and Prof. Dr. Tarek Mostafa, Cairo University for sharing information.

I am indebted to Prof. Dr. Nagwa Naga El-Ibiari and Dr. Ola Ahmed El-Ardy, the supervisors from National Research Centre for their support and timely advice. Many thanks are due to Prof. Dr. Guzine El-Diwani and Prof. Dr. Sanaa Abo El-Enin for their sincere interest and their continuous encouragement.

I wish to express my sincere gratitude to the staff of the Water Pollution Department, National Research Centre, for their unlimited aid in accomplishment of this task, their assistance and their friendly welcome.

Finally, I am deeply thankful to my family for their sincere support and encouragement. I am indebted to my colleagues for their guidance and technical support.

Dedication

To my father
To the memory of my mother

Table of Contents

List of Tables

List of Figures

List of Abbreviation

A	Irradiance as coded variable
AAD	Absolute Average Deviation
Adj. R^2	Adjusted residual squared – Statistics
ANOVA	Analysis of variance – Statistics
B	Initial inoculum concentration as coded variable
BG11	Blue-Green Algae medium
c	Speed of light
C	Initial inoculum concentration as actual variable
CI	Confidence interval – Statistics
C.V.	Coefficient of variation – Statistics
dCO_2	Dissolved carbon dioxide
df	degrees of freedom - statistics
DNA	Deoxyribonucleic acid, the primary carrier of genetic information found in the chromosomes of almost all organisms.
DO	Dissolved Oxygen
E	Irradiance
E_p	Energy of photon
EPA	Environmental Production Agency
FFD	Flux Flow Density
f	Frequency
GC	Gas chromatography analysis
GHG	Greenhouse Gas
h	Blank's constant
I	Irradiance as actual variable
K_I	Monod constant
LCA	Life cycle assessment
LED	Light emitting diode
lm	luminous
N_A	Avogadro's Number
NO_x	Nitrogen oxides
N_p	Number of photon
OD	Optical density
OPEC	Organization of the Petroleum Exporting Countries
P	growth rate
PAH	Polycyclic aromatic hydrocarbon
PAR	Photosynthetic Active Radiation
PBR	Photobioreactor
PFD	Photon Flux Density
PI	Prediction interval – Statistics

P-I curve	Photosynthetic light response curve
PPD	Photosynthetic photon density
Pred. R^2	Predicted residual squared – Statistics
PRESS	Predicted residual error sum of squares – Statistics
PUFA	Poly unsaturated fatty acids
PVC	Poly vinyl chloride
R^2	Residual squared – Statistics
RSM	Response surface methodology
ROI	Return on investment
S/V	illuminated surface to volume ratio
SFA	Saturated fatty acids
TAG	Triacylglyceride
vvm	volume of air per volume of liquid per minute (unit of air flow rate)
μ	Specific growth rate
α	Hyperbolic tangent model's constant
σ	Standard deviation – Statistics
λ	Light wave length
η_{photon}	Photon efficiency