



PRODUCTION OF DESALINATED WATER & ELECTRICITY USING ALGAE PONDS

A Thesis

Submitted to the Faculty of Engineering
Ain Shams University for the Fulfillment
of the Requirement of PhD. Degree
in Civil Engineering

by

Eng. ELBARAA LOUYE ELSAYED
MOHAMED ELGHAZY

B.Sc. in Civil Engineering, 2010, Faculty of Engineering, AASTMT

M.Sc. in Civil Engineering, 2015, Faculty of Engineering, AASTMT

Supervisors

Prof. Dr. MOHAMED EL HOSSIENY EL NADI.

Professor of Sanitary & Environmental Engineering
Faculty of Engineering, Ain Shams University, Cairo, EGYPT

Dr. NANY ALY HASSAN NASR

Associate Professor of Sanitary & Environmental Engineering
Faculty of Engineering, Ain Shams University, Cairo, EGYPT

Dr. OLA DEYAA SALAH EL DIN EL
MONAYERY

Associate Professor of Sanitary & Environmental Engineering
Faculty of Engineering, AASTMT, Cairo, EGYPT

2020



PRODUCTION OF DESALINATED WATER & ELECTRICITY USING ALGAE PONDS

A Thesis

Submitted to the Faculty of Engineering
Ain Shams University for the Fulfillment
of the Requirement of PhD. Degree
in Civil Engineering

by

Eng. ELBARAA LOUYE ELSAYED
MOHAMED ELGHAZY

B.Sc. in Civil Engineering, 2010, Faculty of Engineering, AASTMT

M.Sc. in Civil Engineering, 2015, Faculty of Engineering, AASTMT

THESIS APPROVAL

EXAMINERS COMMITTEE

SIGNATURE

Prof. Dr. Mohamed Fathy Hamoda

Professor of Environmental Engineering

Faculty of Engineering, El Kuwait University, Kuwait

Prof. Dr. Tarek Ismail Mahmoud Sabri

Prof. of Sanitary & Environmental Engineering

Ain Shams University, Cairo, Egypt.

Prof. Dr. Mohamed El Hossieny El Nadi

Prof. of Sanitary & Environmental Engineering

Ain Shams University, Cairo, Egypt.

Date:- ---/--/2020

DEDICATION

This work took a period from my life. I wish to dedicate it to whom suffered to educate, prepare, build capacity and help myself to be as I am,

TO MY Grand FATHER Soul

My first mentor

TO MY Parents

For the suffering for my sake

TO MY siblings

For bearing with me

TO MY Wife

For her support

TO My Main supervisor

For introducing me to new possibilities

STATEMENT

This dissertation is submitted to Ain Shams University, Faculty of Engineering for the degree of PhD. in Civil Engineering.

The work included in this thesis was carried out by the author in the department of Public Works, Faculty of Engineering, Ain Shams University, from January 2017 to November 2019.

No part of the thesis has been submitted for a degree or a qualification at any other University or Institution.

Date:- ---/--/2020

Signature:- -----

Name:- *ELBARAA LOUYE ELSAYED MOHAMED ELGHAZY*

ACKNOWLEDGMENT

*The author wishes to express his deep gratitude to **Dr. Mohamed El Hossieny Abdel Rahman El Nadi**, Professor of Sanitary & Environmental Engineering, Faculty of Engineering, Ain Shams University, for his patient guidance, helpful suggestions, great support, cooperation and help in thesis and laboratory work.*

*Also, great thanks to **Dr. Nany Aly Hassan Nasr**, Associate Professor of Sanitary Engineering, Faculty of Engineering, Ain Shams University, for her help, encouragement and cooperation during the preparation of this study.*

*Also, great thanks to **Dr. Ola Deyaa Salah El Din El Monayery**, Associate Professor of Sanitary Engineering, Faculty of Engineering, AASTMT, for her support and big efforts during the preparation and writing of this thesis.*

Also, sincere thanks to the staff and personnel of Sanitary Engineering Section, Faculty of Engineering, Ain Shams University, for facilities, encouragement and cooperation during the course of this study.

ABSTRACT

Name :- EL Baraa Louye Elsayed Mohamed Elghazy

Title :- “Production of Desalinated Water & Electricity Using Algae Ponds”

Faculty : Faculty of Engineering, Ain Shams University

Specialty : Civil Eng., Public works Department

Summary:

Water and energy are two of the most essential resources for human life on earth. With the growing world population, water shortage and fossil fuel depletion have become tangible threats. Seawater desalination and renewable energy sources represent an effective and long-term solution for the ongoing exhaustion of fresh water and energy sources. Most methods of desalination and energy production have technical, economic, and environmental drawbacks. This study presents a new environment-friendly approach for electricity generation and desalination using microalgae.

Electricity production and desalination using the freshwater algae *Chlorella vulgaris* were first investigated on a lab-scale and then tested again on a larger scale. Lab-scale electricity experiments involved constructing a bio-photovoltaic cell that uses an algal biofilm as an anode. The cell was investigated under conditions of varying salinity, cell height and anode to cathode distance. Desalination by *C. vulgaris* was examined by adding algae to water samples with different salinities and measuring the salinity level hourly for 12 hours. To test for practicality, a larger-scale pilot experiment was done examining the potential of *C. vulgaris* to simultaneously cause desalination and energy production and to determine the design equation for such system in algae ponds.

Regarding energy production, the proposed algal bio-photovoltaic cell produced a maximum of 0.12 W/m². The best output was at an anode-cathode spacing, height and salinity of 2 cm, 15 cm and 20000 TDS respectively. In addition, salt removal from all samples was achieved at varying levels and times depending on the starting salinity. According to the results, *C. vulgaris* requires only 50-60 hours for desalination through a multi-step process. The pilot scale experiment succeeded in achieving the lab results. Furthermore, a model was

designed based on the experimental results and produced two equations. The first yields the removal efficiency according to inlet TDS, retention time, and number of basins in the series. The second provides the amount of produced electricity according to inlet TDS

In conclusion, the proposed system provides a , rapid, and clean method of desalination and electricity generation using the green algae *Chlorella vulgaris*.

SUPERVISORS: Prof. Dr. Mohamed El Hossieny El Nadi,
Dr. Nany Ayi Hassan Nasr
Dr. Ola Deyaa Salah Eldin El Monayery

KEYWORDS: *Algae ponds, Desalination, Electricity production,*

TABLE OF CONTENTS

INTRODUCTION.....	1
1.1 Introduction	1
1.2 Study Objectives.....	2
1.3 Scope of Work	2
1.3.1 THEORETICALWORK	2
1.3.2 PRACTICAL APPLICATION.....	3
1.4 Thesis Organization.....	3
1.4.1 CHAPTER I: INTRODUCTION	4
1.4.2 CHAPTER II: LITERATURE REVIEW	4
1.4.3 CHAPTER III: MATERIAL AND METHODS	4
1.4.4 CHAPTER IV: RESULTS OF EXPERIMENTAL WORK	4
1.4.5 CHAPTER V: MODELING OF ALGAE PONDS	4
1.4.6 CHAPTER VI: DISCUSSION	5
1.4.7 CHAPTER VII: CONCLUSION	5
LITERATURE REVIEW.....	6
2.1 INTRODUCTION	6
2.2 DESALINATION Methods & technique	6
2.2.1 Mechanical Methods:	7
2.2.2 Solar methods	11
2.2.3 Drawbacks of conventional Desalination	12
2.2.4 Biological desalination	13
2.2.5 Desalination using Algae ponds	14
2.3 Production of electricity USING ALGAe	16
2.3.1 Microbial fuel cells.....	16
2.3.2 Types of microbial fuel cells (MFCs)	17
2.3.3 Difficulties facing bio-photovoltaics	19

METHODOLOGY	21
3.1 Introduction	21
3.2 LABSCALE	21
3.2.1 Algae Culture.....	21
3.2.2 Power output investigation	24
3.2.3 Desalination investigation	30
3.3 Pilot scale.....	32
3.3.1 Large scale culture.....	32
3.3.2 Biofilm formation	33
3.3.3 Simultaneous Desalination and electricity generation experiment	33
3.4 Measurements	36
3.4.1 TDS.....	36
3.4.2 Hemocytometer	38
3.4.3 Other measuring devices	38
RESULTS	45
4.1 OVERVIEW	45
4.2 EXPERIMENTAL RESULTS	45
4.2.1 Laboratory scale results	45
4.2.2 Pilot results	59
MODEL	61
5.1 INTRODUCTION	61
5.2 MODEL DESIGN	64
5.3 MODEL DETERMINATION	64
5.4 DESALINATION EQUATION GENERATION	66
5.4.1 Input Scripts.....	66
5.5 ELECTRICTY PRODUCTION EQUATION	69
DISCUSSION	72

6.1	Introduction	72
6.2	EXPERIMENTAL RESULTS	72
6.2.1	Lab scale results discussion.....	72
6.3	PILOT RESULTS	82
6.4	MODEL ANALYSIS	84
6.4.1	Model verification	84
	CONCLUSION	88
7.1	Introduction	88
7.2	Recommendation	90
7.3	Further and future work.....	90
	REFERENCE	91

LIST OF TABLES

Chapter 3 Methodology

Table (3/1) Chemical constituents of used media types.....	22
Table (3/2) different scenarios performed to test the production of electricity.....	29
Table (3/3) Initial salinities of the ten different specimens.....	30

Chapter 4 Results

Table (4/1) Comparison between results of UST and BG11 after 7 days	46
Table (4/2) Growth of <i>Chlorella vulgaris</i> algae in large scale unit for 8 days.....	48
Table (4/3) Hourly TDS measurements for the ten specimens	50
Table (4/4) Produced current from the three cells.....	60

Chapter 5 Model

Table (5/1) Data used for analysis.....	65
Table (5/2) Constants used for equation corresponding to each zone.....	69
Table (5/3) Data used for analysis.....	69

Chapter 6 Discussion

Table (6/1) Calculations of the removal efficiency.....	76
Table (6/2) Calculations of the retention time	77
Table (6/3) Desalination Execution calculation	79
Table (6/4) The additional experimental work for Verification.....	85
Table (6/5) Results of model verification	86
Table (6/6) Electricity data and verification	87

LIST OF FIGURES

Figure (2/1) Multi stage flash design	7
Figure (2/2) Multi Effect Desalination [4]	8
Figure (2/3) Vapor compression [5].....	9
Figure (2/4) Indirect freezing process [8]	10
Figure (2/5) Solar Gradient ponds.....	11
Figure (2/6) General MFC configuration	17
Figure (2/7) Double chamber MFC [30]	17
Figure (2/8) A single-chamber microbial fuel cell without an air cathode [34]	18
Figure (2/9) Power output of different anode materials	20
Figure (3/1) <i>Chlorella vulgaris</i> bottle culture specimen.....	23
Figure (3/2) Biofilm generation stages.....	25
Figure (3/3) Biofilm second trial.....	26
Figure (3/4) Brachionus calyciflorus in algal biofilm sample under light microscope	26
Figure (3/5) Biofilms third trial.....	27
Figure (3/6) Bio-photovoltaic structure design side view	28
Figure (3/7) Bio-photovoltaic actual cell	28
Figure (3/8) Filter used for algae separation	31
Figure (3/9) Algae culture unit.....	32
Figure (3/10) large biofilms during the settling process	33
Figure (3/11) Components of the large scale bio-photovoltaic.....	34
Figure (3/12) A complete assembly of the large scale bio-photovoltaic..	35
Figure (3/13) A bio-photovoltaic cell in operation	36
Figure (3/14) EC TDS meter.....	37
Figure (3/15) TDS refractometer.....	37
Figure (3/16) Micropipette	39
Figure (3/17) Hemocytometer.....	40
Figure (3/18) Light Microscope	41
Figure (3/19) Light intensity	42
Figure (3/20) Sensitive balance.....	43
Figure (3/21) Sensitive MultiMeter.....	44
Figure (4/1) Algae culture unit.....	47
Figure (4/2) Number of cells for every single day	48
Figure (4/3) Growth rate curve for cell culture	49

Figure (4/4) Number of folds curve for cell culture.....	49
Figure (4/5) Different images for hemocytometer under microscope showing different cell counts.	49
Figure (4/6) Specimen with initial TDS 38 salt removal results after filtration every hour on a 12 hour period	51
Figure (4/7) Specimen with initial TDS 35 salt removal results after filtration every hour on a 12 hour period	51
Figure (4/8) Specimen with initial TDS 32 salt removal results after filtration every hour on a 12 hour period	52
Figure (4/9) Specimen with initial TDS 29 salt removal results after filtration every hour on a 12 hour period	52
Figure (4/10) Specimen with initial TDS 26 salt removal results after filtration every hour on a 12 hour period	53
Figure (4/11) Specimen with initial TDS 21 salt removal results after filtration every hour on a 12 hour period	53
Figure (4/12) Specimen with initial TDS 17 salt removal results after filtration every hour on a 12 hour period	54
Figure (4/13) Specimen with initial TDS 13 salt removal results after filtration every hour on a 12 hour period	54
Figure (4/14) Specimen with initial TDS 10 salt removal results after filtration every hour on a 12 hour period	55
Figure (4/15) Specimen with initial TDS 5 salt removal results after filtration every hour on a 12 hour period	55
Figure (4/16) All specimens salt removal results after filtration every hour on a 12 hour period.....	56
Figure (4/17) Electrical output for different cathode anode spacing over one hour duration	57
Figure (4/18) Electrical output for different heights over one hour duration.....	58
Figure (4/19) Electrical output for different salt concentrations over one hour duration	59
Figure (5/1) MatLab Input Script	66
Figure (5/2-c) MatLab output for zone 3	68
Figure (5/3) Relation between inlet TDS and electricity production	70
Figure (6/1) Calculated salinity removal level from the lab scale results	74
Figure (6/2) Calculated retention time from the lab scale results	75
Figure (6/3) Water flow TDS vs time	80

Figure (6/4) Relation between TDS & Produced Electricity Current	83
Figure (6/5) TDS & Electricity Current versus Time	83

CHAPTER I

INTRODUCTION

1.1 INTRODUCTION

For the time being, the availability of water appears sufficient for current demands. However, it is anticipated that water scarcity will occur in the near future. Water is the most important element for all living organisms, in addition to its political value. Seawater is the most available water resource, and desalination has become the key to overcome the water scarcity. Several methods have been applied for water desalination but all the available procedures have technical, economic and environmental problems. This has encouraged researchers to consider biological desalination using the natural activity of photosynthetic microorganisms such as algae.

This was previously applied with the fresh water algae *Scenedesmus obliquus* that consumes salts from saline water to create a suitable environment for its survival. Concurrently, some researches succeeded to produce electricity from algae in stabilization ponds applied to treat wastewater. This has opened the field to the use of desalination algae ponds to produce electricity, which may then cover its own energy needs.

Since there are various efforts and research projects towards producing clean energy and implementing a wide capacity of desalination approaches at feasible construction and operating cost, therefore the biological desalination by algae ponds seems to be a promising solution that needs more research effort to investigate and determine all its governing parameters.

This study is dedicated to investigating the possibility of such system, however, more work will be required for the enhancement of the electric output. The value of this study is very significant, as it introduces a new way of supplying enough resources to the future generation either water or power.