



Culturing and Harvesting Marine Microalgae for the Large-scale Production of Biodiesel

This thesis is presented for the degree of Masters of Engineering Science
in the school of Chemical Engineering

Submitted by:

Suraj Sathe

(1167160)

Supervisors:

Dr. David Lewis

Dr. Peter Ashman

Microalgal Engineering Research Group (MERG)

Declaration

This work contains no material that has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis when deposited in the University Library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968.

Signed:.....

Suraj Shivajirao Sathe

Date:...../...../.....

Acknowledgement

First of all I am thankful to my supervisors Dr David Lewis, senior lecturer and postgraduate co-ordinator, and Dr Peter Ashman, acting head of school, for their cheerful guidance, patience and encouragement throughout the project.

I would like to express my gratitude especially towards Professor Michael Borowitzka and his team from Murdoch University, Western Australia for their technical assistance with culturing microalgae in laboratory and outdoor raceway ponds and for supplying the starter culture of MUR230 and MUR232.

I am most indebted to Mr Stephen Pahl for his genuine help in managing the outdoor raceway ponds, and important guidelines in writing my thesis. I would like to acknowledge Mr Andrew Lee and Mr Steven Amos for their initial assistance with counting the cells and culturing the algae.

I'd like to extend my heartiest thanks to Mr Jason Peak and Mr Jeffrey Hiorns from the Chemical Engineering Workshop for their advices and the construction of the experimental apparatus.

This project had partial financial support from the Asia-Pacific Partnership on Clean Development and Climate in relation to the project "A fully integrated process for biodiesel production from microalgae in saline water." The Research Abroad Scholarship from Adelaide University is also gratefully acknowledged.

The encouragement from everyone at the Department of Chemical Engineering during the degree was also most appreciated. I would especially like to thank all the postgraduate students and my friends outside the university, for their friendships, encouraging words and valuable discussion.

I would like to ameliorate my acknowledgement by extending my thanks to my mother, father, Richa and all my family members for their love, support and encouragement.

Abstract

In the commercial production of biodiesel from marine microalgae, the cost and efficiency of harvesting technique affects the overall cost and production of biodiesel. The commercial harvesting techniques being used for harvesting microalgae include centrifugation and filtration preceded by flocculation. Centrifugation and filtration are very high cost processes and different flocculation techniques like chemical flocculation, auto-flocculation and bio-flocculation (microbial flocculation) are being developed to achieve more efficiency in flocculation of algal biomass at lower costs. In this project, 'Electroflocculation'- a common process for flocculating contaminants, organic matter and metal ions from waste water was applied to flocculate marine microalgae.

The studies presented in the thesis aim to

1. determine the effect of electroflocculation on the flocculation of marine microalgae at lab scale
2. investigate the factors affecting electroflocculation i.e. current density, time, material of electrodes, distance between electrodes, salinity of the cultures and pH
3. scale-up the lab scale electroflocculation process to pilot-scale and investigate the cost effectiveness of pilot-scale electroflocculation process
4. theoretically optimize, design and analyse the costs for electroflocculation process, based on experiments performed and data available in literature
5. culture marine microalgae species starting from lab-scale to outdoor raceway ponds and study the reliability and stability of the cultures over a long period

The lab-scale experiments on electroflocculation of marine microalgae showed that this technique successfully flocculated the microalgae from the culture solution and the flocs floated to the surface that can be easily scrapped off and used for further dewatering or extraction purposes. Investigation of factors affecting electroflocculation indicated that factors like current density, time, distance between electrodes and electrode material should be optimized for lowering the costs. The higher salinity of cultures and pH around 7 are favourable factors for harvesting marine microalgae using electroflocculation.

Following the success of lab-scale experiments a 100L pilot-scale setup was built to analyse the cost effectiveness of electroflocculation at this scale. Results showed that minimum power requirement of 0.168kWh/m^3 was noted with more than 95% removal efficiency and concentration factor of 25 times was achieved.

The study also introduced a several key factors in understanding the optimization, design, and cost analysis of the process and to overcome the process drawbacks of electroflocculation.

The results enhance the current understanding of the electroflocculation process and further studies required to apply electroflocculation as a harvesting technique at large scale in the process of production of biodiesel from microalgae in saline water.

Prior to harvesting the marine microalgae species were cultured in laboratory upto 20L and outdoor raceway ponds upto 400L. The growth rate and productivities of the microalgae cultures in outdoor raceway ponds were investigated regularly over a period of 9 months and productivities of $1\text{-}5\text{gm}^{-2}\text{day}^{-1}$ were reported. The study of effect of changing environmental factors on the growth rate and productivities showed that the marine microalgae species are reliable and stable and suitable for large scale culturing in the production of biodiesel.

Table of Contents

Declaration	i
Acknowledgement	ii
Abstract	iii
Table of Contents	v
List of Figures	viii
List of Tables	ix
Chapter 1. Introduction	1
1.1 Background	1
1.2 Thesis Organisation	4
Chapter 2. Literature Review	5
2.1 Culturing Microalgae	5
2.1.1 Microalgae Culturing Systems.....	5
2.1.2 Factors Influencing the Growth of Microalgae.....	6
2.1.3 Summary	9
2.2 Harvesting Microalgae	10
2.2.1 Centrifugation	10
2.2.2 Filtration.....	12
2.2.3 Sedimentation	13
2.2.4 Flotation	14
2.2.5 Flocculation.....	15
2.2.6 Electroflocculation	17
2.2.7 Summary	22
2.3 Objectives of the Research.....	23
Chapter 3. Culturing marine microalgae species MUR230 and MUR232	24
3.1 Introduction.....	24

3.2 Materials and Methods.....	24
3.2.1 Procedure for Culturing MUR230 & MUR232 upto 1L	24
3.2.2 Procedure and Setup for Culturing MUR230 and MUR232 in 15L Carboys	25
3.2.3 Culturing MUR230 and MUR232 in Outdoor Raceway Ponds	27
3.2.4 Procedure for Calculating the Harvest Volume	30
3.2.5 Preparation of Media.....	31
3.2.6 Counting Cells Using a Hemacytometer under Light Microscope.....	33
3.2.7 Determination of Ash Free Dry Weight (AFDW)	34
3.3 Results.....	34
3.3.1 Culturing MUR230 and MUR232 in Outdoor Raceway Ponds	34
3.3.2 Ash Free Dry Weight (AFDW).....	39
3.4 Conclusion	40
Chapter 4. Electroflocculation- A Potential Method of Harvesting Marine Microalgae	42
4.1 Introduction.....	42
4.1.1 Factors Affecting Electroflocculation.....	42
4.2 Materials and methods	44
4.2.1 Laboratory Study of Factors Affecting Electroflocculation	44
4.2.2 Pilot-scale Study of Electroflocculation	46
4.2.3 Recovery Efficiency and Concentration Factor	48
4.3 Results and discussion	49
4.3.1 Laboratory Study of Factors Affecting Electroflocculation	49
4.3.2 Pilot-scale Study of Electroflocculation	56
4.3.3 Recovery Efficiency and Concentration Factor	57
4.4 Conclusions.....	58
4.4.1 Laboratory Study of Factors Affecting Electroflocculation	58
4.4.2 Pilot-scale Study of Electroflocculation	59

4.4.3 Recovery Efficiency and Concentration Factor	60
4.4.4 Summary	60
Chapter 5. Electroflocculation – Optimization, Design, Cost Analysis and Process Drawbacks	61
5.1 Introduction.....	61
5.2 Optimization of Electroflocculation Process	61
5.2.1 Optimization of Current Density	61
5.2.2 Optimization of Time.....	62
5.2.3 Optimization of Distance between Electrodes	63
5.2.4 Electrode Material.....	63
5.2.5 Salinity and pH	64
5.3 Design of Electroflocculation Unit	65
5.3.1 Design Factors	65
5.4 Cost Analysis	69
5.4.1 Power Costs	69
5.4.2 Cost of Electrode Replacement.....	69
5.4.3 Additional Costs.....	70
5.5 Process Drawbacks	71
5.5.1 Periodic Replacement of Anodes.....	71
5.5.2 Fouling of Electrodes	71
5.5.3 Instability of the Floccs.....	72
5.5.4 Corrosion in Marine Environment	73
Chapter 6. Conclusions.....	74
6.1 Electroflocculation.....	74
6.2 Culturing Marine Microalgae Species MUR230 and MUR232	75
Nomenclatures.....	76
References.....	77

List of Figures

Figure 1.1 Steps involved in the process of production of biodiesel	2
Figure 3.1 Cultures of MUR230 and MUR232 inoculated in the laboratory from 1ml to 1L	25
Figure 3.2 15L Cultures of MUR230 and MUR232 cultured from 1L flasks	27
Figure 3.3 Outdoor raceway ponds located on the roof, at University of Adelaide	28
Figure 3.4 Cultures of MUR230 and MUR232 inoculated in the outdoor raceway ponds upto 400L from 15L inoculum	30
Figure 3.5 Neubauer ruling (Andersen, 2005)	33
Figure 3.6 Pond data for MUR230	37
Figure 3.7 Pond data for MUR232	38
Figure 4.1 a. Lab-scale 1L electroflocculation setup b. Circuit diagram for the setup	44
Figure 4.2 Equipment for the study of distance between electrodes	46
Figure 4.3 Electroflocculation setup at University of Adelaide with six lead cathodes and three aluminium anode tubes	47
Figure 4.4 Effect of current on time and voltage required for complete flocculation of 1L culture of MUR230; Electrode material: Aluminium; Electrode surface area 93.75cm^2 ; Distance between electrodes:7cm; DC power supply 50A/150V.....	51
Figure 4.5 Power required for electroflocculation of MUR230 for increasing current density (calculation based on data from a 1L culture); Electrode material: Aluminium; Electrode surface area: 93.75cm^2 ; Distance between electrodes:7cm; DC power supply 50A/150V	51
Figure 4.6 Electroflocculation with SS-304 electrodes	53
Figure 4.7 Electroflocculation with SS-316 electrodes	53
Figure 4.8 Electroflocculation with Mild Steel electrodes	53
Figure 4.9 Electroflocculation with Aluminium electrodes.....	54
Figure 4.10 Electroflocculation with Galvanized steel electrodes.....	54
Figure 4.11 Electroflocculation with Copper electrodes	54
Figure 4.12 Electroflocculation with Bronze electrodes.....	55
Figure 4.13 Effect of change in distance between electrodes on current and voltage .	56

Figure 5.1 Graph representing the standard curve for estimating the optimal current density value at maximum removal efficiency and minimum power requirement for harvesting microalgae using electroflocculation; time required will be the time for complete flocculation of microalgae cultures at each value of current density	62
Figure 5.2 Figure representing optimal time range and threshold time at constant current density for microalgal biomass removal using electroflocculation	63
Figure 5.3 Design factors for electroflocculation unit	65
Figure 5.4 Electroflocculation cell with two monopolar electrodes	67
Figure 5.5 Electroflocculation cell with monopolar electrodes in series connection ..	67
Figure 5.6 Electroflocculation cell with monopolar electrodes in parallel connection	68
Figure 5.7 Electroflocculation cell with bipolar electrodes	68
Figure 5.8 Left-floated floccs after electroflocculation, Right-settled floccs after few minutes.....	72

List of Tables

Table 2.1 Commercial microalgae culture systems currently in use different locations with approximate volume and the algal species cultured (Borowitzka, 1999)	6
Table 2.2 Energy requirements for different centrifugation equipments.....	11
Table 2.3 Energy requirements for different filtration equipments	13
Table 3.1 Recipe for f/2-medium.....	32
Table 3.2 Recipe for Trace metal solution.....	33
Table 3.3 AFDW results for MUR230	39
Table 3.4 AFDW results for MUR232	40
Table 4.1 Characteristics of different electroflocculation experiments	48
Table 4.2 Electroflocculation experiments performed with different electrode materials.....	52
Table 4.3 Effect of surface area of electrodes on the power requirement	55
Table 4.4 Effect of salinity on the power requirement for electroflocculation.....	56
Table 4.5 Results for pilot-scale electroflocculation experiments.....	57
Table 4.6 Results for recovery efficiency and concentration factor	57

Table 5.1 Results for electroflocculation experiments with Al and combination of Al-SS-316 electrodes; Electrode surface area: 93.75cm^2 ; Distance between electrodes: 7cm.....64