

Table of Content

Table of Content

Abstract	I-III
Declaration by the candidate	IV
Certificate of supervisor	V
Acknowledgement	VI-VII
Table of Content	VIII-XII
List of Figures	XIII-XIX
List of Tables	XX
List of Schemes	XXI
List of Abbreviations	XXII-XXIII
Chapter 1	1-40
1. Introduction	2-8
1.1. Alternative renewable options	8-11
1.2. Biofuels	12
1.2.1. Bioethanol	12-13
1.2.2. Biodiesel	13
1.2.3. Bio-Jet (SAF)	14
1.2.4. Biochar	14-15
1.2.5. Biogas	15
1.3 Biofuel characterization based on feedstock	16-17
1.4 Microalgae	17-20
1.5 Microalgae biofuel	20-22
1.6 Microalgae cultivation systems	22
1.6.1 Raceway Pond system	22-23
1.6.2 Stirred circular pond system	23-24
1.6.3 Tubular photobioreactor	24-25
1.6.4 Flat Plate photobioreactor	25
1.6.5 Airlift photobioreactor	26
1.6.6 Plastic bag photobioreactor	27-28
1.6.7 Descending film	28-29
1.6.8 Internally illuminated photobioreactor	29-30

Table of Content

1.7	Problem statement and objectives of the study	30-31
Chapter 2		42-65
2.	Literature review	43
2.1	Commercial microalgae culture systems	43-45
2.2	Microalgae culture system design parameters	45
2.2.1	Light	45
2.2.1.1	Light Intensity	46
2.2.1.2	Light wavelength	46
2.2.1.3	Light duration	46-47
2.2.1.4	Light distribution	47
2.2.2	Mixing and hydrodynamics	47-48
2.2.3	Gas exchange	48
2.2.4	Temperature control	49
2.2.5	Material selection	49-50
2.2.6	Nutrients supply	50
2.2.7	Efficient control of the culture parameters	51
2.3	Optimization techniques	51
2.3.1	Response Surface Methodology	51-52
2.3.2	Taguchi Method	52-53
2.3.3	Gaussian Process Regression (GPR)	53-55
Chapter 3		66-122
Chapter 3A		69-97
3A.	To design and develop a photobioreactor (PBR) for mass-scale microalgae cultivation.	70
3A.1	Design and development of Internally Illuminated Stirred Light Column Photobioreactor (IISLCP)	70-74
3A.2.1	Design and development of Internally Illuminated Airlift Photobioreactor (IIAP)	74-77
3A.2.2	Electronic control system to control the IIAP	77-80
3A.3.1	Design and development of Stacked Tray Automated Modular Photobioreactor (STAMP)	81-84
3A.3.2	Electronic control system to control the STAMP	85-87
3A.3.3	Assessment of biofouling in the STAMP system	88
3A.4	Microalgae strain and culture conditions	88-90

Table of Content

3A.5	Chemicals used for the study	90-91
3A.6	Microalgae growth monitoring	91
3A.6.1	Microalgae cell count based growth estimation	91-92
3A.6.2	Microalgae growth estimation by gravimetric analysis	92-93
3A.6.3	Microalgae growth estimation by optical density	94
3A.7	Microalgae lipid extraction and quantification	94
Chapter 3B		98-111
3B.	To optimize the culture conditions and improve the biomass and lipid productivity.	99
3B.1	Response Surface Methodology (RSM) based optimization of microalgae culture parameters.	99-101
3B.1.1	Biomass productivity	101-102
3B.1.2	Lipid productivity	102
3B.1.3	Statistical analysis	102
3B.2.	Development of experimental setup for RSM-based microalgae culture experiments.	103
3B.2.1	Design and development of the microalgae culture chamber (MCC)	103-104
3B.2.2	Design and development of the electronic control system	104-107
3B.2.3	Selection of LEDs for optimization	107
3B.3	Experimentation methodology of the RSM-based experiments	107-109
Chapter 3C		112-122
3C.	To analyze the algal biomass and biofuel properties produced from the microalgae cultured in the developed PBR.	113
3C.1	Harvesting microalgae biomass	113
3C.1.1	Microalgae harvesting using centrifugation	113-114
3C.1.2	Microalgae harvesting using chemical flocculation	114-115
3C.2	Drying harvested microalgae biomass	115
3C.3	Calorific value of microalgae biomass	115-116
3C.4	Ash content of microalgae biomass	116
3C.5	Lipid Extraction	116-117
3C.6	Acid value and free fatty acid of microalgae lipid	117
3C.7	GC-MS analysis of microalgae lipid	118
3C.8	Transesterification for biodiesel production	118
3C.9	¹ H-NMR analysis of microalgae lipid and microalgae biodiesel	118-119

Table of Content

3C.10	Acid value of microalgae biodiesel	119
3C.11	Density of the microalgae biodiesel	119
3C.12	Calorific value (CV) of the microalgae biodiesel	120
3C.13	Carbon residue of the microalgae biodiesel	120
3C.14	Statistical Analysis	120
Chapter 4		123-176
Chapter 4A		125-141
4A.	To design and develop a photobioreactor (PBR) for mass-scale microalgae cultivation.	126
4A.1	Design philosophy of the Internally Illuminated Stirred Light Column Photobioreactor (IISLCP)	126-127
4A.1.1	Microalgae culture analysis in the IISCLP system	128-129
4A.2	Design philosophy of the Internally Illuminated Airlift Photobioreactor (IIAP)	129-131
4A.2.1	Temperature control of the IIAP system	131-132
4A.3	The issue with biofouling in a photobioreactor	132-134
4A.4	Design philosophy of the Stacked Tray Automated Modular Photobioreactor (STAMP)	134-136
4A.4.1	Growth analysis of <i>Chlorella homosphaera</i> microalgae species in the developed STAMP system.	136-137
4A.4.2	Evaluation of biofouling in the STAMP system	138
4A.4.3	Temperature control in the developed STAMP system	139
4A.5	Summary	139
Chapter 4B		142-165
4B.	To optimize the culture conditions and improve the biomass and lipid productivity	143
4B.1.	Choosing LEDs for optimization of microalgae growth	143-144
4B.2.	Response surface methodology (RSM) based optimization of operational parameters for optimum biomass and lipid productivity.	144-145
4B.2.1	Investigating the effect of input parameters on biomass productivity of <i>C homosphaera</i> .	146-151
4B.2.2	Investigating the effect of input parameters on lipid productivity of <i>C homosphaera</i> .	151-156
4B.2.3	Modelling and validation	156-157
4B.2.4	Optimization of the input parameters	157-160
4B.3	Implementing the optimized values in the STAMP system	160-161
4B.4.	Summary	162

Table of Content

Chapter 4C	166-176
4C To analyze the algal biomass and biofuel properties produced from the microalgae cultured in the developed PBR.	167
4C.1 Calorific value of Chlorella homosphaera biomass	167-168
4C.2 Ash content of Chlorella homosphaera biomass	168-169
4C.3 Lipid content of Chlorella homosphaera biomass	170
4C.4 Lipid characterization of Chlorella homosphaera microalgae using GCMS	170-171
4C.5 ¹ H NMR analysis of C homosphaera lipid and biodiesel	171-173
4C.6 Characterization of fuel properties of the derived biodiesel	173-174
4C.7 Summary	174
Chapter 5	177-179
5 Conclusion and future scope	178
5.1 Conclusion	178-179
5.2 Future scope	179
Annexure I	i-viii
Annexure II	ix-xiii
Annexure III	xiv-xxv
Annexure IV	xxvi-xxxiv
List of Publications	xxxv