

Contents

CERTIFICATE	iii
DECLARATION BY THE CANDIDATE	v
COPYRIGHT TRANSFER CERTIFICATE	vii
ACKNOWLEDGMENT	ix
ABSTRACT	xxviii
Chapter-1 Introduction and Background	(1-25)
1.1. Introduction.....	1
1.2. Biodiesel.....	4
1.3. Source of biodiesel.....	4
1.3.1 <i>Edible plant oils</i>	4
1.3.2 <i>Non-edible plant oils</i>	5
1.3.3 <i>Waste oils and animal fats</i>	6
1.4 Processes/methods to produce the biodiesel.....	6
1.4.1 <i>Blending/Dilution</i>	7
1.4.2 <i>Micro-emulsification</i>	7
1.4.3 <i>Pyrolysis/Thermal cracking</i>	8
1.4.4 <i>Trans-esterification (Alcoholysis)</i>	8
1.5 Homogeneous catalysis for trans-esterification process.....	10
1.5.1 <i>Homogeneous base-catalyzed trans-esterification reaction</i>	10
1.5.2 <i>Homogeneous acid-catalyzed trans-esterification reaction</i>	11
1.5.3 <i>Homogeneous acid and base catalysts for the two-steps trans-esterification reaction</i>	11
1.6 Heterogeneous catalysts for trans-esterification process.....	12

1.6.1 <i>Heterogeneous base-catalyzed trans-esterification reaction</i>	12
1.6.2 <i>Heterogeneous acid-catalyzed trans-esterification reaction</i>	13
1.6.3 <i>Heterogeneous bi-functional catalysts or two-steps trans-esterification process</i>	13
1.7 Biocatalysts for trans-esterification reaction.....	14
1.8 Supercritical method.....	14
1.9 Availability of biodiesel feedstock.....	17
1.10 Biodiesel used in CI engine.....	20
1.11 Mathematical and computational modelling.....	22
1.12 Life cycle assessment of biodiesel.....	24

Chapter-2 Literature review..... (26-54)

2.1 Introduction.....	26
2.2 Biodiesel as a fuel.....	26
2.3 Engine performance and emission with application of biodiesel.....	27
2.3.1 <i>Performance</i>	28
2.3.2 <i>Emissions</i>	33
2.4 Numerical modelling of CI engine with used of biodiesel.....	36
2.5 Life cycle assessment of vegetable oil plants in biodiesel production.....	45
2.5.1 <i>Energy and Economic consideration</i>	45
2.5.2 <i>Global warming potential</i>	49
2.6 Findings.....	52
2.7 Research Gap.....	53
2.8 Objective.....	53

Chapter-3 Experimentation..... (55-92)

3.1 Introduction.....	55
3.2 Oil extraction.....	55
3.2.1 <i>Decorticator</i>	57
3.2.2 <i>Expeller</i>	57
3.2.3 <i>Filter</i>	58
3.3 Biodiesel Production.....	60
3.3.1 <i>Acid-Esterification</i>	60
3.3.2 <i>Alkaline Trans-esterification</i>	61
3.3.3 <i>Description of transesterification unit</i>	62
(a) <i>Caustic mixing tank</i>	62
(b) <i>Reactor</i>	62
(c) <i>Condenser</i>	62
(d) <i>Receiver</i>	63
(e) <i>Washing tank</i>	63
3.4 Testing of biodiesel on VCR engine.....	69
3.4.1 <i>Experimental set-up</i>	69
3.4.2 <i>ICEngineSoft</i>	76
(a) <i>Combustion analysis</i>	77
(b) <i>Performance against load/speed for constant/variable speed engines</i>	77
3.4.3 <i>Experimental methodology</i>	78
3.5 Emission analysis.....	82
3.6 Instrumentation.....	83
3.6.1 <i>Measurement of calorific value</i>	83
3.6.2 <i>Measurement of density</i>	84

3.6.3	<i>Measurement of viscosity</i>	86
3.6.4	<i>Measurement of flash point and fire point</i>	87
3.6.5	<i>Acid value and iodine value</i>	89
3.7	Experimental Uncertainty.....	90
Chapter-4 Mathematical Model of CI Engine..... (93-120)		
4.1	Introduction.....	93
4.2	Power cycle.....	95
4.2.1	<i>Compression</i>	95
4.2.2	<i>Combustion</i>	97
(a)	<i>Development of an empirical correlation for burning duration</i> ...	98
(b)	<i>Initial combustion temperature</i>	102
(c)	<i>Initiation of the two-zone calculation</i>	102
4.2.3	<i>Expansion (two-zone expansion)</i>	106
(a)	<i>Unburned mixture temperature</i>	109
(b)	<i>Product (burned) temperature</i>	109
(c)	<i>Cylinder pressure</i>	110
4.3	Species formation.....	112
4.3.1	<i>Rate Kinetics of NO formation</i>	115
4.3.2	<i>CO formation</i>	117
4.4	Validation of mathematical modelling.....	117
4.5	Main programme.....	120
Chapter-5 Energy and Economic Analysis..... (121-165)		
5.1	Introduction.....	121

5.2 Methodology.....	121
5.3 Data Collection.....	123
5.3.1 <i>Cultivation data collection</i>	124
5.3.2 <i>Oil extraction data collection</i>	125
5.3.3 <i>Biodiesel conversion data collection</i>	126
5.4 Requirement of men and materials.....	128
5.4.1 <i>Jatropha</i>	128
(a) <i>Cultivation</i>	128
(b) <i>Oil extraction</i>	129
(c) <i>Biodiesel production</i>	130
5.4.2 <i>Mahua</i>	130
(a) <i>Cultivation</i>	130
(b) <i>Oil extraction</i>	131
(c) <i>Biodiesel production</i>	132
5.4.3 <i>Neem</i>	132
(a) <i>Cultivation</i>	132
(b) <i>Oil extraction</i>	133
(c) <i>Biodiesel production</i>	133
5.4.4 <i>Palm</i>	134
(a) <i>Cultivation</i>	134
(b) <i>Oil extraction</i>	135
(c) <i>Biodiesel production</i>	135
5.4.5 <i>Coconut</i>	135
(a) <i>Cultivation</i>	135
(b) <i>Oil extraction</i>	136

<i>(c) Biodiesel production.....</i>	136
5.4.6 Karanja.....	137
<i>(a) Cultivation.....</i>	137
<i>(b) Oil extraction.....</i>	138
<i>(c) Biodiesel production.....</i>	139
5.4.7 Jojoba.....	139
<i>(a) Cultivation.....</i>	139
<i>(b) Oil extraction.....</i>	140
<i>(c) Biodiesel production.....</i>	141
5.4.8 Tung.....	141
<i>(a) Cultivation.....</i>	141
<i>(b) Oil extraction.....</i>	142
<i>(c) Biodiesel production.....</i>	142
5.5 Energy analysis.....	143
5.5.1 Calculation of energy input and output.....	143
<i>(a) Cultivation.....</i>	144
<i>(b) Oil extraction.....</i>	144
<i>(c) Biodiesel production.....</i>	145
5.5.2 Energy input and output analysis.....	146
5.5.3 Energy input/output after maturity of plants.....	147
5.5.4 Energy input analysis with methanol recovery.....	148
5.5.5 Energy analysis of input-output energy used in the biodiesel production.....	151
5.5.6 Energy indicators.....	156
5.6 Economic analysis.....	157

<i>5.6.1</i>	<i>Cultivation cost.....</i>	158
<i>5.6.2</i>	<i>Oil extraction cost.....</i>	159
<i>5.6.3</i>	<i>Biodiesel production cost.....</i>	159
<i>5.6.4</i>	<i>Economic analysis of biodiesel production.....</i>	161
<i>5.6.5</i>	<i>Economic indicators.....</i>	165
Chapter-6 Results and Discussion..... (166-199)		
<i>6.1</i>	<i>Experimental analysis of biodiesel.....</i>	166
<i>6.1.1</i>	<i>Engine Performance.....</i>	166
<i>(a)</i>	<i>Brake power (BP).....</i>	166
<i>(b)</i>	<i>Brake specific fuel consumption (BSFC).....</i>	168
<i>6.1.2</i>	<i>Exhaust Emissions.....</i>	169
<i>(a)</i>	<i>Carbon monoxide (CO).....</i>	170
<i>(b)</i>	<i>Oxides of nitrogen (NO_x)</i>	172
<i>6.2</i>	<i>Computational Analysis.....</i>	174
<i>6.2.1</i>	<i>Effect of biodiesel blends.....</i>	175
<i>(a)</i>	<i>Peak cylinder pressure (Pmax).....</i>	175
<i>(b)</i>	<i>BMEP and IMEP.....</i>	176
<i>(c)</i>	<i>Brake power and indicated power.....</i>	177
<i>(d)</i>	<i>BSFC and ISFC.....</i>	178
<i>(e)</i>	<i>NO formation.....</i>	179
<i>6.2.2</i>	<i>Effect of injection timing.....</i>	180
<i>(a)</i>	<i>Peak cylinder pressure (Pmax).....</i>	180
<i>(b)</i>	<i>BMEP and IMEP.....</i>	181
<i>(c)</i>	<i>Brake power and indicated power.....</i>	182

(d) BSFC and ISFC.....	183
(e) NO formation.....	184
6.2.3 Effect of stroke/bore ratio for B20 of Neem biodiesel.....	185
(a) With varying speed with fixed CR.....	186
i. Peak cylinder pressure (P_{max}).....	186
ii. BMEP and IMEP.....	186
iii. Brake power and indicated power.....	188
iv. BSFC and ISFC.....	188
v. NO formation.....	190
(b) With varying compression ratio at fixed rpm.....	191
i. Peak cylinder pressure (P_{max}).....	191
ii. BMEP and IMEP.....	191
iii. Brake power and indicated power.....	192
iv. BSFC and ISFC.....	193
v. NO formation.....	194
6.3 Energy and Economic analysis of biodiesel plants.....	195
6.3.1 Energy analysis.....	195
6.3.2 Economic analysis.....	196
Chapter-7 Conclusions and Scope for Future Work..... (200-206)	
7.1 Conclusions.....	200
7.1.1 Experimental.....	200
7.1.2 Computational.....	201
(a) Biodiesel blends.....	202
(b) Injection timing.....	202

(c) <i>Stroke/Bore ratios</i>	203
i. <i>At different engine speed</i>	203
ii. <i>At different compression ratio</i>	204
7.1.3 <i>Energy and Economic</i>	204
7.2 Scope for Future Work.....	206
References.....	207
Publications.....	242
Appendices.....	244