OPTIMIZATION OF WOODY BIOMASS TORREFACTION IN INERT AND OXIDATIVE ATMOSPHERES USING COMBINED EXPERIMENTAL AND MODELLING APPROACH

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Declaration

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other University or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

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ABSTRACT

Torrefaction is a thermochemical pretreatment method to increase the energy density of biomass. The process is carried out at 200-300 ^{0}C in an inert atmosphere. However, large-scale use of inert gas is neither realistic nor economical. More than 50% of industrial flue gas in Sri Lanka is greater than 200 ^{o}C and has less than 10% oxygen content which is suitable as a torrefaction medium. Lab-scale torrefaction experiments were conducted for Gliricidia and Rubberwood, at 250-300 ^{o}C temperature range and 30–60 minutes in nitrogen and 3%, 6%, 9% oxygen environments to understand the torrefaction behaviour. TGA and FTIR were used to characterize raw and torrefied biomass. In the lab-scale experiments in inert torrefaction, Gliricidia and Rubberwood showed more than 30% mass loss under the most severe conditions, resulting in a 22.8% and 11.6% volatile drop, respectively. The higher heating value of the torrefied product increased from 18.9 MJ/kg to 30.15 MJ/kg for Rubberwood and from 19.46 MJ/kg to 28.2 MJ/kg for Gliricidia under the most severe conditions. The severity factor was modified by finding the optimum fitted parameter ω, establishing a feedstock-specific relationship between torrefaction severity and operating conditions. The normalized severity factor shows a linear correlation with the properties of torrefied biomass, which could facilitate torrefaction modelling. Rubberwood shows its optimum oxidative torrefaction properties at 300 ^{o}C temperature and 31-min residence time and 9% oxygen, whereas Giricidia shows it at 286 ^{o}C temperature at a 60-min residence time and 9% of oxygen. A process model was developed for oxidative torrefaction, and results show that CO_2 has the highest volume fraction, followed by CO and CH_4 in the non-condensable product and water has the highest fraction in the condensable product. Acetic acid, formic acid, phenols and furfurals were other dominant components.

Keywords: Gliricidia, Rubberwood, Torrefaction, Oxidative torrefaction, Process simulation, Aspen Plus

TABLE OF CONTENTS

1. Introduction 1

2. Literature ReviewLiterature Review 3

2.1 Biomass 3

2.1.1 Composition of Biomass 3

2.1.2 Fuelwood 3

2.1.3 Pretreatment 5

2.2 Torrefaction 6

2.2.1 Introduction of Torrefaction 6

2.2.2 Properties of Torrefied products 8

2.2.3 Parameters that influence the torrefaction process. 11

2.2.4 Oxidative Torrefaction 13

2.2.5 Torrefaction in the Flue Gas Atmosphere 14

2.2.6 Torrefaction Technology 15

2.2.7 Torrefaction modelling 19

2.2.8 Performance Evaluation Indices of Torrefaction 20

2.2.9 Optimization of torrefaction parameters 22

2.2.10 Applications of torrefied product 24

2.3 Waste Heat Availability in Sri Lanka 25

2.4 Gliricidia and Rubberwood 26

3. Research Methodology Research Methodology 28

3.1 Analysis of the torrefaction behaviour of Gliricidia and Rubberwood in inert and oxidative atmospheres 28

3.1.1 Identifying practical ranges of flue gas temperatures and oxygen levels as well as the utilization potentials available in the Sri Lankan industries 28

3.1.2 Evaluating the torrefaction behaviour of Gliricidia and Rubberwood at different temperatures and oxygen levels. 29

3.2 Optimization of the Oxidative Torrefaction Process Parameters of Gliricidia and Rubberwood 33

3.3 Model development to simulate industrial integrated flue gas driven biomass torrefaction process 33

3.3.1 Moisture Removal 34
3.3.2 Conversion of Dry Biomass 35
3.3.3 Final Product Output 35
3.3.4 Modifying the NSF integrated with Oxygen Concertation 36
4. Results and Discussions 38
4.1. Summary of Flue gas Survey 38
4.2. Thermal behaviour 40
4.3. Functional groups 42
4.4. Torrefaction Performance 44
4.4.1 Solid yield 44
4.4.2 Composition of the torrefied product 47
4.4.3 Energy content 55
4.4.4 Energy yield 57
4.4.5 Energy-mass co-benefit index (EMCI) 58
4.5. Relationship between torrefaction severity and properties of torrefied biomass 59
4.6. Oxidative Torrefaction 63
4.6.1 Box–Behnken design and analysis 63
4.6.2 Solid yield with process conditions 64
4.6.3 Enhancement of C with process conditions 68
4.6.4 Enhancement of HHV with process conditions 73
4.6.5 Energy yield with process conditions 77
4.6.6 The ratio of VM with process conditions 81
4.6.7 The ratio of FC with process conditions 85
4.6.8 Factorial analysis 89
4.6.9 Response Optimisation 91
4.7. Process model for oxidative torrefaction 93
4.7.1 Model validation 93
4.7.2 Process simulations results 95
5. CONCLUSIONS 103
References 106

LIST OF FIGURES

Figure 1 : Schematic description of the different torrefaction stages [22]..... 6

Figure 2: TGA and DTG curves of cedarwood [23]..... 7

Figure 3 : Torrefied biomass at van krevelen diagram [11].....10

Figure 4 : DSC curve of lignocellulose components [79].....18

Figure 5 : Lab-scale Torrefaction Reactor 29

Figure 6 : Schematic view of the experimental apparatus 30

Figure 7 : Aspen Plus model for torrefaction process 34

Figure 8 : Reported % No. of companies with different flue gas temperature ranges39

Figure 9 : Reported % No. of companies with different oxygen concentration ranges in flue gas 39

Figure 10 : TGA curves of two fuels before and after torrefaction 40

Figure 11 : DTG curves of two fuels before and after torrefaction 41

Figure 12 : FTIR spectra of raw and torrefied Gliricidia 43

Figure 13 : FTIR spectra of raw and torrefied Rubberwood.....43

Figure 14 : Solid yield of two fuels at different torrefaction conditions 45

Figure 15 : Proximate analysis of Rubberwood 47

Figure 16 : Proximate analysis of Gliricidia 48

Figure 17 : Volatile matter removal of two fuels at different torrefaction conditions48

Figure 18 : Fixed carbon enhancement of two fuels at different torrefaction conditions 49

Figure 19 : Ultimate analysis of Rubberwood.....50

Figure 20 : Ultimate analysis of Gliricidia.....50

Figure 21 : Carbon enhancement of two fuels at different torrefaction conditions....51

Figure 22 : Oxygen removal of two fuels at different torrefaction conditions.....52

Figure 23 : Nitrogen removal of two fuels at different torrefaction conditions 53

Figure 24 : Van-Krevelen diagram of raw biomass, torrefied biomass, and coal 54

Figure 25 : HHV of two fuels at different torrefaction conditions 55

Figure 26 : HHV enhancement of two fuels at different torrefaction conditions.....56

Figure 27 : Energy yield of two fuels at different torrefaction conditions 57

Figure 28 : Energy-mass co-benefit index of two fuels at different torrefaction conditions 58

Figure 29 : SF profile of Gliricidia 60

Figure 30 : SF profile of Rubberwood 61

Figure 31 : Variation of oxygen removal with NSF 62

Figure 32 : Variation of HHV enhancement with NSF 62

Figure 33 : Solid yield of Rubberwood at different severities (a) inert (b) 3% Oxygen (c) 6% Oxygen (d) 9% Oxygen 66

Figure 34 : Solid yield of Gliricidia at different severities (a) inert (b) 3% Oxygen (c) 6% Oxygen (d) 9% Oxygen 67

Figure 35 : C enhancement of Rubberwood at different severities (a)inert (b) 3% Oxygen (c) 6% Oxygen (d) 9% Oxygen 71

Figure 36 : C enhancement of Gliricidia at different severities (a) inert (b) 3% Oxygen (c) 6% Oxygen (d) 9% Oxygen 72

Figure 37 : HHV enhancement of Rubber at different severities (a)inert (b)3% Oxygen (c) 6% Oxygen (d) 9% Oxygen 75

Figure 38 : HHV enhancement of Gliricidia at different severities (a) inert (b) 3% Oxygen (c) 6% Oxygen (d) 9% Oxygen 76

Figure 39 : Energy yield of Rubberwood at different severities (a)inert (b)3% Oxygen (c) 6% Oxygen (d) 9% Oxygen 79

Figure 40 : Energy yield of Gliricidia at different severities (a)inert (b)3% Oxygen (c) 6% Oxygen (d) 9% Oxygen 80

Figure 41 : VM ratio of Rubber at different severities (a) inert (b) 3% Oxygen (c) 6% Oxygen (d) 9% Oxygen 83

Figure 42 : VM ratio of Gliricidia at different severities (a)inert (b)3% Oxygen (c) 6% Oxygen (d) 9% Oxygen 84

Figure 43 : FC ratio of Rubber at different severities (a)inert (b)3% Oxygen (c) 6% Oxygen (d) 9% Oxygen 87

Figure 44 : FC ratio of Gliricidia at different severities (a)inert (b)3% Oxygen (c) 6% Oxygen (d) 9% Oxygen 88

Figure 45 : Factorial analysis of a. Mass yield, b. Energy yield, c. C enhancement ..89

Figure 46 : Factorial analysis of a. HHV enhancement, b. FC ratio, c. VM ratio 90

Figure 47 : Simulated results with experimental results of Solid yield 94

Figure 48 : Simulated results with experimental results % of Carbon 95

Figure 49 : Liquid, Solid, gases products out of torrefaction of Rubberwood 96

Figure 50 : Liquid, Solid, gases products out of torrefaction of Gliricidia 96

Figure 51 : Fraction of CO_2 during torrefaction of Rubberwood 97

Figure 52 : Fraction of CO_2 during torrefaction of Gliricidiawood.....97

Figure 53 : Fraction of CO during torrefaction of a) Rubberwood b) Gliricidia 98

Figure 54 : Fraction of CH_4 during torrefaction of a) Rubberwood b) Gliricidia 98

Figure 55 : Fraction of water during torrefaction of a) Rubberwood b) Gliricidia .99

Figure 56 : Fraction of Formic acid from total acid during torrefaction of a) Rubber b) Gliricidia 100

Figure 57 : Fraction of Acetic acid from total acid during torrefaction of a) Rubber b) Gliricidia 101

Figure 58 : % of phenol /Non Acid during torrefaction of a) Rubber b) Gliricidia 102

Figure 59 : % of Furfural / Non Acid during torrefaction of a) Rubber b) Gliricidia 102

LIST OF TABLES

Table 2.1 : Cell constituent of hardwood and softwood 4
Table 2.3 : Survey results on Stationary Combustion Systems in Sri Lanka.....26
Table 3.1 : Tested conditions (Temperature and Residence time) 30
Table 3.2 : Experimental Conditions 32
Table 4.1 **:** Sector-wise categorization of responded companies 38
Table 4.2 **:** P-values of non-reduced model 63
Table 4.3 : Coded Coefficients Rubberwood (Final reduced model).....64
Table 4.4 : Coded Coefficients Gliricidia (Final reduced model) 65
Table 4.5 **:** Coded Coefficients Rubberwood (Final reduced model).....68
Table 4.6 **:** Coded Coefficients Gliricidia (Final reduced model).....69
Table 4.7 **:** Coded Coefficients Rubberwood (Final reduced model).....74
Table 4.8 : Coded Coefficients Gliricidia (Final reduced model) 74
Table 4.9 : Coded Coefficients (Final reduced model) Rubberwood 77
Table 4.10 **:** Coded Coefficients (Final reduced model) Gliricidia.....78
Table 4.11 : Coded Coefficients (Final reduced model) Rubber.....81
Table 4.12 : Coded Coefficients (Final reduced model) Gliricidia 82
Table 4.13 Coded Coefficients (Final reduced model) Rubberwood 86
Table 4.14 : Coded Coefficients (Final reduced model) Gliricidia 86
Table 4.15 : Response Optimisation of Rubberwood 91
Table 4.16 Response optimization of Gliricidia.....92
Table 4.17 : Optimum parameter of Rubberwood and Gliricidia.....92
Table 4.18 : Values at optimum conditions of Rubberwood and Gliricidia 92
Table 4.19 : Input data for model 93
Table 4.20 : Simulated cases 94
Table 4.21 Input parameters.....95

LIST OF ABBREVIATIONS

Abbreviation	Description
AWL	- Anhydrous Weight Loss
BBD	- Box-Behnken Design
BOI	- Board Of Investment
CCD	- Central Composite Design
CEA	- Central Environmental Authority
DC	- Decarbonization
DH	- Dehydrogenation
DO	- Deoxygenation
DSC	- Differential Scanning Calorimetry
DTG	- Derivative Thermogravimetry
EFB	- Empty Fruit Bunches
EMCI	- Energy-Mass Co-benefit Index
FC	- Fixed Carbon
FTIR	- Fourier-Transform Infrared Spectroscopy
HGI	- Hardgrove Grindability Index
HHV	- Higher Heating Value
NSF	- Normalized Severity Factor
RKS	- Redlich-Kwong-Soave
SEM	- Scanning Electron Microscopic
SF	- Severity Factor
TGA	- Thermo Gravimetric Analysis
TSF	- Torrefaction Severity Factor
TSI	- Torrefaction Severity Index
VM	- Volatile Matter

LIST OF APPENDICES

Appendix	Description	Page
Appendix A	Survey on stationary combustion systems in Sri Lanka	122