

Contents

1	Introduction	1
1.1	Potential Contribution of Energy Crops as Biofuels for Heat Generation	1
1.2	Development Needs for Heating Systems Based on Energy Crops. The Spanish Case	3
1.3	Overall Aims and Specific Objectives of This Research	5
1.4	Research Context and Scope	5
1.5	Structure of This Work	8
1.6	Relation to Spanish Research Projects and European Institutions	10
	References	11
2	Biofuel Characteristics and Grate Conversion	15
2.1	Characteristics of Biomass and Fuel Quality Upgrading	15
2.1.1	Main Components in Biomass	15
2.1.2	Association Forms of Inorganic Matter	16
2.1.3	Upgrading Biofuels as Pellets	17
2.1.4	Control Quality of Pellets and Combustion Performance	18
2.2	Biofuel Conversion in Grate-Fired Systems	20
2.2.1	General Characteristics of Grate Technologies	20
2.2.2	Combustion Process on the Grate	22
2.2.3	Air Requirements and Distribution During Grate Combustion	24
2.3	Ash-Related Aspects in Grate-Fired Systems	25
2.3.1	Occurrence of Ash Phenomena and Practical Effects	25
2.3.2	Behavior of Inorganic Elements During Biofuel Combustion	28
	References	37

3	Research Methodology	43
3.1	Fuels	43
3.1.1	Energy Crop Pellets	46
3.1.2	Stemwood Pellets	49
3.1.3	Cassava Pellets	50
3.2	Conversion Systems	51
3.2.1	Medium-Scale Combustion Unit, 250 kW _{th}	51
3.2.2	Residential-Scale Combustion Unit, 25 kW _{th}	59
3.2.3	Laboratory-Scale Reactor	65
3.3	Ash Characterization Methods	72
3.3.1	Chemical Characterization Techniques	72
3.3.2	Other Characterization Methods	76
3.4	Standards for Thermal Efficiency and Emissions	82
	References	82
4	Combustion Performance in a Medium Scale Grate-Fired Unit	85
4.1	Experimental Results	85
4.1.1	Operating Conditions and Temperature Profile	85
4.1.2	Total Energy Distribution	90
4.1.3	Thermal Efficiency	91
4.1.4	CO Emissions	92
4.1.5	NO _x Emissions	93
4.1.6	Characteristics of Solid Residues Collected After Combustion	93
4.2	Discussions of the Energy Crop Combustion Behavior	97
4.2.1	Unburnt Matter and Thermal Efficiency	97
4.2.2	NO _x Emissions	100
4.3	Final Remarks	103
	References	104
5	Ash Fractionation Behavior During Fixed-Bed Combustion	107
5.1	Experimental Results	107
5.1.1	Fuel Categorization	107
5.1.2	Operating Conditions and Temperature Profile	109
5.1.3	Ash Fractionation Behavior	111
5.2	Discussions of Ash Transformation and Fractionation	117
5.2.1	Poplar	117
5.2.2	Brassica	118
5.2.3	Cassava	121
5.3	Final Remarks	122
	References	123

6	Transformation Routes of K, Cl, S and P	125
6.1	Experimental Results	125
6.1.1	Relative Release for K, Cl, S and P Versus Temperature	125
6.1.2	Macroscopic Observations of the Residual Ash	128
6.1.3	Chemical Characterization of the Residual Ash by SEM-EDS and P-XRD	128
6.2	Discussions of K, Cl, S and P Transformations	132
6.2.1	K-Release	132
6.2.2	Cl-Release	133
6.2.3	S-Release	134
6.2.4	P-Release	135
6.2.5	Comparison with Release Data for Other Biofuel Types	136
6.3	Final Remarks	142
	References	143
7	Overall Assessment	145
7.1	Grate Combustion Operability	145
7.1.1	Influencing Factors on Grate Operability	145
7.1.2	Measures for Overcoming Ash Effects on Grate Operability	150
7.2	Particulate Matter Emissions	152
7.2.1	Influencing Factors on Particle Formation Routes	152
7.2.2	Measures for Reduction of Particulate Matter Emissions	153
7.3	NO _x Emissions	154
7.3.1	Influencing Factors on NO _x Formation	154
7.3.2	Measures for Overcoming Effects Related to NO _x Emissions	155
	References	157
8	Conclusions, Research Contributions and Prospects for Future Work	161
8.1	Conclusions	161
8.2	Research Contributions	164
8.2.1	Chapter 3: Research Methodology	164
8.2.2	Chapter 4: Combustion Performance in a Medium-Scale Grate-Fired Unit	164
8.2.3	Chapter 5: Ash Fractionation Behavior During Fixed-Bed Combustion	165
8.2.4	Chapter 6: Transformation Routes of K, Cl, S and P	166
8.2.5	Chapter 7: Overall Assessment	167

8.3 Prospects for Future Work	168
References	169
Appendix A: Publications	171
Appendix B: Additional Experimental Data	177

Grate-Fired Energy Crop Conversion

Experiences with *Brassica Carinata* and *Populus* sp.

Díaz-Ramírez, M.C.

2015, XX, 194 p. 47 illus., 10 illus. in color., Hardcover

ISBN: 978-3-319-20758-2