

**OPTIMIZATION OF ANAEROBIC CODIGESTION  
PROCESSES OF LIGNOCELLULOSIC MATERIALS  
OF DIFFICULT DEGRADATION WITH RESIDUES  
FROM ANDEAN LIVESTOCK**

**INDEX OF CONTENTS**

## TABLE OF CONTENTS

<b>ACKNOWLEDGEMENTS</b> .....	<b>v</b>
<b>ABSTRACT</b> .....	<b>vii</b>
<b>RESUMEN</b> .....	<b>ix</b>
<b>RESUM.</b> .....	<b>xi</b>
<b>DISSERTATION OUTLINE</b> .....	<b>xvi</b>
<b>DISSEMINATION OF RESULTS</b> .....	<b>xviii</b>
<b>I. INTRODUCTION</b> .....	<b>6</b>
1. Pre-treatment of Animal Manure Biomass to Improve Biogas Production: A Review .....	9
1.1 Hydrolysis in Anaerobic Digestion of Animal Waste .....	10
1.2 Pre-treatments and Techniques to Improve the Digestion of Animal Manure	12
1.2.1 Physical Pre-treatments .....	12
1.2.2 Physicochemical Pre-treatments .....	13
1.2.3 Chemical Pre-treatments .....	14
1.2.4 Biological Thermal Pre-treatments .....	15
1.3 Application of Pre-treatments to Livestock Waste .....	17
1.3.1 Pre-treatments Applied to Cow Manure.....	17
1.3.2 Pre-treatments Applied to Pig Manure.....	20
1.3.3 Pre-treatments Applied to Poultry Manure .....	23
1.4 Summary of the Effects of Pre-treatment on Animal Manure.....	25
1.4.1 Comparison of the Main Pre-treatments .....	25
1.4.2 Effect of Pre-treatments on Cow, Pig and Poultry Manure.....	26
1.5 Perspectives and Challenges of Animal Manure Pre-treatments.....	27
Conclusions.....	28
Author Contributions .....	28
Funding .....	29
Acknowledgments .....	29
Conflicts of Interest .....	29
References.....	29
2. Review of mathematical models for the anaerobic digestion process.....	39
2.1 Exponential model .....	41

2.1.1 Model of Gomperzt .....	44
2.2 Kinetic models .....	49
2.2.1 Model based on the transfer function.....	52
2.2.2 Cone model .....	52
2.2.3 Comparison of models .....	53
Conclusion .....	54
References .....	54
<b>II. OBJECTIVES.....</b>	<b>60</b>
1. General objective.....	62
2. Specific objectives.....	62
<b>II. CHAPTERS.....</b>	<b>63</b>
<b>CHAPTER I. Biochemical potential of methane (BMP) of camelid waste and the Andean region agricultural crops.....</b>	<b>65</b>
ABSTRACT .....	67
1. Introduction .....	68
2. Materials and methods .....	69
2.1 Origin of substrates and inoculum .....	69
2.2 Characterization of raw materials and biogas .....	69
2.3 Experimental methodology .....	70
2.4 Kinetic modelling .....	71
2.5 Calculation of theoretical performance and biodegradability.....	72
3. Results and discussion .....	72
3.1 Characterization of substrates and inoculums .....	72
3.2 Cumulative production of biogas and methane from agricultural and livestock waste .....	73
3.3 Kinetic model analysis.....	75
3.4 Evaluation of the different kinetic models.....	76
3.5 Biodegradability and theoretical yield .....	79
Conclusions .....	81
Acknowledgments .....	81
References .....	81
<b>CHAPTER II. Effect of the co-digestion of agricultural lignocellulosic residues with manure from South American camelids.....</b>	<b>89</b>

ABSTRACT .....	91
1. Introduction .....	92
2. Materials and methods .....	93
2.1 Substrates, co-substrates and inoculum used .....	93
2.2 Experimental methodology .....	94
2.3 Theoretical methane potential .....	96
2.4 Biodegradability and synergistic and antagonistic effects of substrates.....	96
2.5 Kinetic fit models.....	97
3. Results .....	98
3.1 Characterization of the raw material.....	98
3.1.1 Main substrates used. ....	98
3.1.2 Co-substrates used.....	99
3.2 Generation and methane potential from camelid manure .....	99
3.2.1 Comparison of SIR from BMP tests .....	99
3.2.2 Influence of co-substrates on the co-digestion of BMP assays.....	102
3.2.3 Biodegradability and synergistic effects .....	103
3.3 Kinetics .....	104
3.3.1 Effects on latency ( $t_{lag}$ ).....	104
3.3.2 Effects on hydrolysis and on the maximum rate of methane production ( $v_{max}$ )	104
3.3.3 Effects on maximum methane yield ( $M_e$ ) .....	105
3.3.4 Evaluation of the different kinetic models of co-digestion.....	106
4. Discussion .....	109
Conclusions .....	110
References .....	110

**CHAPTER III. Anaerobic co-digestion of slaughter residues with agricultural waste of amaranth quinoa and wheat..... 122**

ABSTRACT .....	124
1. Introduction .....	125
2. Materials and methods.....	126
2.1 Substrates, co-substrates and inoculum used .....	126
2.2 Theoretical methane production .....	126
2.3 Biodegradability of anaerobic co-digestion .....	127
2.4 Experimental setup and procedure.....	128

2.5 Experimental modelling of the data to estimate the BMP.....	129
3. Results.....	130
3.1 Characteristics of the raw material.....	130
3.2 Potential methane production.....	131
3.3 Kinetic study of the anaerobic digestion of slaughterhouse waste.....	135
4. Discussion.....	138
Conclusions.....	140
References.....	141

**CHAPTER IV. Evaluation of methane production from the anaerobic co-digestion of manure of guinea pig with lignocellulosic Andean’s residues.....150**

ABSTRACT.....	152
1. Introduction.....	153
2. Materials and methods.....	154
2.1 Substrates and inoculum.....	154
2.2 Experimental setup and procedure.....	154
2.3 Biogas measurements and estimation of its composition.....	154
2.4 Characterization of the substrate and inoculum.....	155
2.5 Theoretical BMP.....	156
2.6 Biodegradability and synergy.....	157
2.7 Kinetic Models to Predict BMP.....	157
2.8 Statistical analysis.....	158
3. Results.....	159
3.1 Characterization of the physicochemical properties of the raw material.....	159
3.2 Effects of inoculum on biogas production.....	160
3.3 Effect of lignocellulosic residues on co-digestion.....	161
3.4 Biogas composition of CY waste.....	162
3.5 Kinetic study.....	164
4. Discussion.....	168
4.1 Effect of ISR on biomethane potential and biodigester stability.....	168
4.2 Effect of co-digestion on biomethane potential and process stability.....	168
Conclusions.....	170
References.....	170
<b>IV. GENERAL DISCUSSION.....</b>	<b>183</b>

1.1 Physicochemical characterization of raw materials and theoretical methane production .....	183
1.2 Effect of inoculum on AD in animal manure materials with lignocellulosic .....	186
1.3 Effect of co-digestion of lignocellulosic materials in animal manure: synergy and antagonism .....	188
1.4 Kinetic study of anaerobic digestion .....	190
References .....	191
<b>V. CONCLUSIONS.....</b>	<b>200</b>