

**STUDIES ON CHARACTERISATION OF
BIOMASS FOR GASIFICATION**

by

Mrs. ANURADHA GANESH

(Nee: N. ANURADHA)

Chemical Engineering Department

Submitted

**in fulfilment of the requirements
of the Degree of
Doctor of Philosophy**

to the

Indian Institute of Technology, Delhi

New Delhi - 110 016

INDIA

April, 1990

C E R T I F I C A T E

This is to certify that the thesis entitled 'Studies on Characterisation of Biomass for Gasification' being submitted by Mrs. ANURADHA GANESH (Nee: N. Anuradha) to the Indian Institute of Technology, Delhi, for the award of the degree of 'Doctor of Philosophy' is a record of bonafide research work carried out under our guidance and supervision and has fulfilled the requirements for the submission, which, to our knowledge, has reached the requisite standard.

The results obtained in this thesis have not been submitted in part or in full to any other University or Institute for the award of any degree.



Prof. P.D. Grover

(Supervisor)

April, 1990



Dr. P.V.R. Iyer

(Supervisor)

Dedicated
to my dear parents

ACKNOWLEDGEMENTS

The Biomass Conversion Laboratory at the Chemical Engineering Department, Indian Institute of Technology, Delhi, was being established by the time that I had been completing Bachelor of Engineering (Chemical Engineering) at the Panjab University, Chandigarh. Given the scenario towards the closing years of the 80s and the decade of the 90s, 'wealth from waste' had become the inevitable slogan. But mere status of a slogan would have left it perhaps only meaningless; and the said Laboratory has been one among the few to give substance to that slogan in India.

Picking up from the abiding benevolence of Mr. M.S. Vishwanathan, the most elderly member in the Department, Prof. P.D. Grover, the architect and the spirit of the above Laboratory, inducted me into the details of the studies forming the text of this dissertation with great potential for multi-directional follow up in eventual sets of studies in consonance with the above slogan. The indefatigable enthusiasm with which Prof. Grover sustained the efforts, big and small, throughout the studies and even thereafter has been the running thread throughout the fabric of this work.

Much is owed to the co-guide, Dr. P.V.R. Iyer, Assistant Professor in the same Department, as well as to other faculty seniors - Dr. T.R. Rao and Dr. B.P. Mani, Assistant Professors - who all never flinched in steadying up the tempo of the work.

Colleagues, professional and otherwise, the recollection of whom would be a pleasant privilege to acknowledge in the context, include several - Shri Siddhartha Gaur, Miss Vibha Bansal, Shri Sanjay Khattar, Dr. S.S. Sambi and Mrs. Vinita Kumari. In particular, Shri Siddhartha Gaur outshines in his ever ready constructive interlocutions and timely help of every description - much by his second nature.

Progress of work for the several experiments has had memorable inputs from Dilbagh Singh, Nayak and Ramdev at the Laboratory.

Curricular as well as extra-curricular consultations with Dr. K.K. Singh of the Department of Non-Conventional Energy Sources (DNES), Government of India, and Shri Shirish Gedam and Dr. (Mrs.) Karuna Jain of the Indian Institute of Technology, Bombay, have been a source of clarity, inspiration and support.

People at home have ensured that there shall be no moments of despondency; and simple words of thanks will not be adequate for Sam, my brother, Mummy, Daddy and Ganesh, my husband. On the same category, I prefer to put the name of Mrs. V. Menon at the Department of Civil Engineering, Indian Institute of Technology, Delhi.

I am unable to help the situation that the acknowledgements herein might be incommensurate in the case of at least a few individuals - Prof. P.D.Grover and Shri Siddhartha Gaur, in particular.

Anuradha Ganesh
Anuradha Ganesh
(Nee) N. Anuradha

ABSTRACT

Decisions on use of biomass for gasifiers need a study of their thermochemical properties and ash content and its deformation and fusion temperatures. The variability of devolatilisation rates with increasing temperatures holds the clue for several decisions. The maximum rates of devolatilisation (except for Bamboo dust) of most biomass occur in the temperature range of 320°C to 500°C. Lignin is the main component in the biomass decomposing in this temperature range and hence these vapours can be called Potential Tar Forming Volatiles (PTFV). Ash content, ash fusion temperatures, peak devolatilisation rates and the PTFV fractions, within them, provide a comprehensive categorisation of biomass. Such categorisation would help in assessing any biomass as gasifier feed. Partial pyrolysis to reduce the PTFV, consistent with retaining a good portion of the raw biomass and with restricting the ash percentage in the char, is highly worthwhile before biomass char is used in any gasifier. The influence on pyrolysis characteristics of different atmospheres (carbondioxide, steam and nitrogen) is explainable.

Unsuitability of Rice husk for a gasifier arises because of its high silica content, which, in its crystalline form at higher temperatures, embeds the carbon and prevents carbon reactions. Reduction under steam would, however, aid the carbon conversions along with yielding valuable amorphous silica.

Rice straw is infested with problems not only due to silica but also high potash contents leading to early ash fusion, rendering it unsuitable for gasification except if suitably impregnated.

Two empirical correlations have been developed which could jointly predict the Ultimate analysis from Proximate analysis.

CONTENTS

CHAPTER	TITLE	PAGE NO.
Chapter - 1	Introduction and Scope of Study	1
1.1	Biomass: Incidence and Utility	1
1.2	Gasification as a Preferred Route	2
1.3	Scope of Characterisation Studies	2
1.4	Detailed Objectives of the Studies	3
1.5	Biomass Studied	4
1.5.1	General Groups	4
1.5.2	Paddy-Derivatives	4
1.6	Correlation between Proximate and Ultimate Analyses	4
1.7	Format of the Thesis	5
Chapter - 2	Biomass - A Future Renewable Source of Energy and Feedstock	8
2.1	Introduction - Need for Certain Studies	8
2.2	Biomass - A Renewable Source of Energy	8
2.2.1	Forest Wood	12
2.2.2	Crop Residues	13
2.2.3	Food Processing Residues	14
2.3	Chemicals from Biomass	16
2.4	Integrated Management of Agro-Residues	17
2.5	The 5F's and Planning Scenarios	22
2.6	Routes of Biomass Utilisation for Energy	22
2.6.1	Gasification - Advantages and Disadvantages	24

Chapter - 3	Gasification - Chemistry and State-of-the-Art	28
3.1	Introduction - Gasification (Process and Technology)	28
3.2	Reactions in a Gasifier; Zoning	28
3.3	Reactors	31
3.4	The Incidence of Gasification Technology	34
3.5	Fuel Characteristics and Relevance to Gasification	39
Chapter - 4	Thermochemical Characteristics in Gasifier System Design	42
4.1	Introduction	42
4.2	Relevance of Fuel Properties to Gasification	43
4.3	Rate of Devolatilisation in Combustion and Gasification	46
4.4	Effect of Process Variables on Pyrolysis	47
4.5	Scope for Investigations	51
Chapter - 5	Literature Review	53
5.1	Introduction: Properties of Biomass as a Basis for Classification	53
5.2	Classification based on Fuel Properties	53
5.3	Broad Comparison of Coal versus Biomass Characterisation	55
5.3.1	Ultimate Analysis	55
5.3.2	Ash Content	59
5.3.3	Moisture Content	59
5.3.4	Volatile Content	59
5.4	Role of Volatile Matter in Gasification	61
5.5	Kinetics of Pyrolysis of Wood and Cellulose	63
5.6	Scope for Further Studies	70

Chapter - 6	Biomass Characterisation	71
6.1	Introduction	71
6.2	Biomass Materials Studied	72
6.3	Experimental Procedures	73
6.3.1	Proximate Analysis: Procedure	73
6.3.2	Ultimate Analysis	75
6.3.3	Heating Value	75
6.3.4	Ash Deformation and Fusion Temperature	76
6.3.5	Thermogravimetric (TG) Studies	78
6.4	Results and Discussions	79
6.4.1	A Resume	79
6.4.2	Conventional Analysis as a Basis for Classification	80
6.4.2.1	Proportions of F.C., V.M. and Ash	80
6.4.2.2	Biomass distinguished from Wood	82
6.4.2.3	The Preponderant Role of Ash in Biomass Characterisation	82
6.4.3	Analysis of TG Studies on Pyrolysis	86
6.4.3.1	Problem Identification	86
6.4.3.2	Data Plots	86
6.4.3.3	Handling Data Deficiency	102
6.4.3.4	Thermal Decomposition of Biomass Constituents (A Resume)	102
6.4.3.5	Decomposition Products of Wood Pyrolysis: An Overview	104
6.4.4	Drying cum Pyrolysis Characteristics	106
6.4.4.1	Substitutable Feeds to a Gasifier: A Possibility	107
6.4.4.2	Release of Tar as Part of Overall Devolatilisation	109

6.4.4.3	PTFV - A Concept Proposed	110
6.4.4.4	The Final Phase of Devolatilisation	111
6.4.5	Critique on Adaptation as Design Factors: (Volatiles and Ash)	112
6.4.5.1	Arhar stalks	112
6.4.5.2	An Overview of the Characterisation of the Biomass Studied	113
6.4.5.3	A Typical Format of Comparisons	115
6.4.5.4	On Characterisation of Other Biomass	116
6.4.5.4.A	Forestalling Tar Formation	118
6.4.5.5	Pictorial Representation of the Characterisation	118
6.5	Calculation of A.E. of the Pyrolysis Reaction	122
6.6	Partial Pyrolysis	127
6.6.1	Briquetting	128
6.6.2	Advantages of Partially Pyrolysed Biomass (Briquetted or otherwise)	128
6.6.3	Disadvantages	129
6.6.4	Choosing between Partial Pyrolysis and Tar Clean-up System	130
6.6.5	Pyrolysers	130
6.6.5.1	Batch Pyrolyser	131
6.6.5.2	Mechanised Pyrolyser	132
6.6.6	Assessment of the Efficacy of Partial Pyrolysis	132
6.6.7	Results of Gasification of Charred Biomass	135
6.6.7.1	Discussion of the Results	137
6.7	Choice of Charring Temperatures	138
6.7.1	On the Problem	138
6.7.2	Preparation of Char	139

6.7.3	Scenario of Constraints in the Choice of Charring Temperature	139
6.7.4	Chars of Groundnut shells	141
6.7.5	Chars of Pine needles	142
6.7.6	Chars of Corn cobs	142
6.7.7	Chars of Cotton stalks	143
6.7.8	A Postscript to Choice of Charring Temperature	143
6.8	Effect of Atmospheres on Pyrolysis of Raw Biomass	143
6.8.1	Scope of Study	143
6.8.2	Procedure and Results	144
6.8.2.1	The Profile of the Plots, Discussions	149
6.8.3	The Pyrolysis in an Updraft Gasifier	152
6.9	Effect of Char-forming Temperatures on Subsequent Pyrolysis of the Char	153
6.9.1	Scope of Study	153
6.9.2	Results and Discussions	154
Appendix	Design of a Gasifier (for Charred Biomass)	160
6A.1	Basic Specifications	160
6A.2	Design Calculations for the Gasifier (G-45)	160
6A.3	Fabrication Provisions	163
6A.4	Other Appurtenances of the Gasifier System	166
6A.4.1	Wetted Wall Cyclone (Thermo-Separator)	167
6A.4.2	Drum Filter cum Surge Tank	167
6A.4.5	The Total System	169

Chapter - 7	Combustion and Gasification Characteristics of Rice Husk	171
7.1	Introduction	171
7.1.1	Availability of Rice Husk	171
7.1.2	Classical use of Rice Husk in Gasifiers	171
7.1.3	Use of Rice Husk in Boilers	173
7.2	Towards Better Combustion of Rice Husk	173
7.3	Rice Husk Composition	174
7.4	Experimental Procedure	175
7.4.1	Scope	175
7.4.2	Experimental Process	175
7.5	Observations	180
7.6.1	Discussions of Results from SEM	180
7.6.2	Discussions of Results from TGA	181
7.7	Field Studies	192
7.8	Conclusions	192
Chapter - 8	Rice Straw and Its Thermochemical Characteristics	194
8.1	Availability of Rice Straw	194
8.2	Conventional Uses of Rice Straw	194
8.3	Physical Structure of Rice Straw and Its Bearing on the Study of its Thermochemical Properties	196
8.4	Rice Straw as a Fuel - A Recollection	200
8.5	A Pathfinder for the Study	201
8.6	Composition of Rice Straw	201
8.7	The Experiments - Procedure and Results	203
8.8	Discussion of the Results including the Figures	212
8.8.1	On SEM Results	212

8.8.2	On Presentation of Data	213
8.8.3	Discussions on Data Presented	213
8.8.3.A	Pyrolysis Rates for Knots, Stems and Whole Straw	213
8.8.3.B	A Word on the 'Comments' in the Tables	214
8.8.3.C	Ash: Contents and Fusion Temperatures	214
8.8.3D	Relative Extent of Reaction under CO ₂ and Steam Atmospheres and Role of Potash	216
8.9	Recommendations for Extensions of the Study	216
Chapter - 9	Prediction of Ultimate Analysis from Proximate Analysis	219
9.1	Factors affecting Proximate Analysis	219
9.2	Procedures of Proximate Analysis for Coal Not Good Enough for Biomass	219
9.3	The Role of H/C Ratio	220
9.4	Correlation Expressions	221
9.5	Applicability of the Correlations	224
Chapter - 10	Conclusions	225
	References	230
	Bio-data	242