TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>CHAPTER NO.</th>
<th>TITLE</th>
<th>PAGE NO.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td></td>
<td>iii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td></td>
<td>xvii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td></td>
<td>xix</td>
</tr>
<tr>
<td>LIST OF SYMBOLS AND ABBREVIATIONS</td>
<td></td>
<td>xxiii</td>
</tr>
<tr>
<td>1</td>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>1.1</td>
<td>ENERGY SOURCES</td>
<td>1</td>
</tr>
<tr>
<td>1.1.1</td>
<td>Non-Renewable Energy Sources</td>
<td>1</td>
</tr>
<tr>
<td>1.1.2</td>
<td>Renewable Energy Sources</td>
<td>2</td>
</tr>
<tr>
<td>1.2</td>
<td>PROSPECTS OF RENEWABLE ENERGY SOURCES</td>
<td>2</td>
</tr>
<tr>
<td>1.3</td>
<td>CONCEPTS OF BIOMASS AND ITS DEVELOPMENT</td>
<td>3</td>
</tr>
<tr>
<td>1.3.1</td>
<td>Global Scenario</td>
<td>5</td>
</tr>
<tr>
<td>1.3.2</td>
<td>Indian Scenario</td>
<td>5</td>
</tr>
<tr>
<td>1.4</td>
<td>THE ENVIRONMENTAL IMPACTS OF BIOENERGY</td>
<td>6</td>
</tr>
<tr>
<td>1.5</td>
<td>IMPORTANCE OF BIOMASS</td>
<td>8</td>
</tr>
<tr>
<td>1.6</td>
<td>BIOENERGY TECHNOLOGY AND TRENDS</td>
<td>10</td>
</tr>
<tr>
<td>1.7</td>
<td>SUSTAINABLE CRITERIA</td>
<td>11</td>
</tr>
<tr>
<td>1.8</td>
<td>ADVANTAGES AND APPLICATIONS OF BIO ENERGY</td>
<td>13</td>
</tr>
<tr>
<td>CHAPTER NO.</td>
<td>TITLE</td>
<td>PAGE NO.</td>
</tr>
<tr>
<td>------------</td>
<td>--------------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>1.9</td>
<td>BARRIERS IN THE IMPLEMENTATION OF BIOENERGY</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>1.9.1 Economic Barriers</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>1.9.2 Technical Barriers</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>1.9.3 Logistical Barriers</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>1.9.4 International Trade Barriers</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>1.9.5 Ecological Barrier</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>1.9.6 Methodological Barriers</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>1.9.7 Legal (National) Barriers</td>
<td>22</td>
</tr>
<tr>
<td>1.10</td>
<td>BASIC CONCEPT OF THE WORK</td>
<td>22</td>
</tr>
<tr>
<td>1.11</td>
<td>OBJECTIVES</td>
<td>26</td>
</tr>
<tr>
<td>1.12</td>
<td>MOTIVATION</td>
<td>27</td>
</tr>
<tr>
<td>2</td>
<td>LITERATURE SURVEY</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>METHODOLOGY</td>
<td>59</td>
</tr>
<tr>
<td>3.1</td>
<td>INTRODUCTION</td>
<td>59</td>
</tr>
<tr>
<td>3.2</td>
<td>THEORY OF GASIFICATION</td>
<td>62</td>
</tr>
<tr>
<td>3.3</td>
<td>TYPES OF GASIFIER</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>3.3.1 Downdraft Gasifier</td>
<td>64</td>
</tr>
<tr>
<td>3.4</td>
<td>GASIFICATION TECHNOLOGY</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>3.4.1 The Gasification Process</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>3.4.1.1 Air gasification</td>
<td>68</td>
</tr>
<tr>
<td></td>
<td>3.4.1.2 Steam gasification</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>3.4.1.3 Oxygen gasification</td>
<td>70</td>
</tr>
<tr>
<td>3.5</td>
<td>CHARCOAL MANAGEMENT</td>
<td>70</td>
</tr>
<tr>
<td>3.6</td>
<td>ASH HANDLING</td>
<td>71</td>
</tr>
<tr>
<td>3.7</td>
<td>COMPARISON OF GASIFIERS</td>
<td>71</td>
</tr>
<tr>
<td>CHAPTER NO.</td>
<td>TITLE</td>
<td>PAGE NO.</td>
</tr>
<tr>
<td>-------------</td>
<td>--------------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>3.8</td>
<td>TEMPERATURE OF THE SYNGAS</td>
<td>73</td>
</tr>
<tr>
<td>3.9</td>
<td>CLEANING METHODOLOGY</td>
<td>73</td>
</tr>
<tr>
<td>3.10</td>
<td>COMPOSITION OF THE YIELD</td>
<td>75</td>
</tr>
<tr>
<td>3.11</td>
<td>GAS FLOW MEASUREMENT</td>
<td>77</td>
</tr>
<tr>
<td>4</td>
<td>EXPERIMENTAL SET-UP AND PROCEDURE</td>
<td>80</td>
</tr>
<tr>
<td>4.1</td>
<td>INTRODUCTION</td>
<td>80</td>
</tr>
<tr>
<td>4.2</td>
<td>SYSTEM DESCRIPTION AND WORKING</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(135Kg/hr)</td>
<td></td>
</tr>
<tr>
<td>4.2.1</td>
<td>Reactor</td>
<td>81</td>
</tr>
<tr>
<td>4.2.2</td>
<td>Cooling and Cleaning System</td>
<td>83</td>
</tr>
<tr>
<td>4.2.2.1</td>
<td>Cyclone</td>
<td>83</td>
</tr>
<tr>
<td>4.2.2.2</td>
<td>Cooler and scrubber</td>
<td>84</td>
</tr>
<tr>
<td>4.2.2.3</td>
<td>Moisture trap</td>
<td>86</td>
</tr>
<tr>
<td>4.2.3</td>
<td>Chilled Cooler</td>
<td>87</td>
</tr>
<tr>
<td>4.2.4</td>
<td>Fabric Filter</td>
<td>88</td>
</tr>
<tr>
<td>4.2.5</td>
<td>Gas Piping and Venturi</td>
<td>89</td>
</tr>
<tr>
<td>4.2.6</td>
<td>Water Bubbler</td>
<td>89</td>
</tr>
<tr>
<td>4.2.7</td>
<td>Flare Device</td>
<td>90</td>
</tr>
<tr>
<td>4.2.8</td>
<td>Blower</td>
<td>91</td>
</tr>
<tr>
<td>4.2.9</td>
<td>Water Cooling and Treating System</td>
<td>91</td>
</tr>
<tr>
<td>4.2.10</td>
<td>Safety Features of the System</td>
<td>93</td>
</tr>
<tr>
<td>4.2.11</td>
<td>Instrumentation</td>
<td>94</td>
</tr>
<tr>
<td>4.3</td>
<td>EXPERIMENTAL PROCEDURE FOR GASIFIER OPERATION</td>
<td>94</td>
</tr>
<tr>
<td>4.4</td>
<td>TROUBLE SHOOTING FOR GASIFIER</td>
<td>96</td>
</tr>
<tr>
<td>4.5</td>
<td>ENGINE START UP</td>
<td>98</td>
</tr>
<tr>
<td>4.6</td>
<td>MONITORING THE SYSTEM</td>
<td>98</td>
</tr>
<tr>
<td>CHAPTER NO.</td>
<td>TITLE</td>
<td>PAGE NO.</td>
</tr>
<tr>
<td>------------</td>
<td>------------------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>4.7</td>
<td>SYSTEM DESCRIPTION AND WORKING</td>
<td>101</td>
</tr>
<tr>
<td></td>
<td>(6kg/hr)</td>
<td>101</td>
</tr>
<tr>
<td>4.7.1</td>
<td>Temperature Measurement</td>
<td>101</td>
</tr>
<tr>
<td>4.7.2</td>
<td>Smoke Measurement</td>
<td>102</td>
</tr>
<tr>
<td>4.7.3</td>
<td>Gas Chromatography</td>
<td>103</td>
</tr>
<tr>
<td>4.7.4</td>
<td>Methods/Instruments</td>
<td>103</td>
</tr>
<tr>
<td>5</td>
<td>OVERVIEW OF FUZZY LOGIC AND MICROCONTROLLER</td>
<td>105</td>
</tr>
<tr>
<td>5.1</td>
<td>INTRODUCTION</td>
<td>105</td>
</tr>
<tr>
<td>5.1.1</td>
<td>Need for Fuzzy Controller</td>
<td>106</td>
</tr>
<tr>
<td>5.2</td>
<td>BLOCK DIAGRAM</td>
<td>107</td>
</tr>
<tr>
<td>5.2.1</td>
<td>Rule Base</td>
<td>107</td>
</tr>
<tr>
<td>5.2.2</td>
<td>Inference Mechanism</td>
<td>107</td>
</tr>
<tr>
<td>5.2.3</td>
<td>Fuzzification</td>
<td>108</td>
</tr>
<tr>
<td>5.2.4</td>
<td>Defuzzification</td>
<td>108</td>
</tr>
<tr>
<td>5.3</td>
<td>FUZZY SYSTEM DESIGN</td>
<td>108</td>
</tr>
<tr>
<td>5.3.1</td>
<td>Choosing Inputs &amp; Outputs</td>
<td>108</td>
</tr>
<tr>
<td>5.3.2</td>
<td>Putting Control Knowledge into Rule Base</td>
<td>109</td>
</tr>
<tr>
<td></td>
<td>5.3.2.1 Linguistic descriptions</td>
<td>109</td>
</tr>
<tr>
<td></td>
<td>5.3.2.2 Rules</td>
<td>109</td>
</tr>
<tr>
<td></td>
<td>5.3.2.3 Rule base</td>
<td>110</td>
</tr>
<tr>
<td>5.3.3</td>
<td>Fuzzy Quantification of Knowledge</td>
<td>110</td>
</tr>
<tr>
<td>5.3.4</td>
<td>Inference Process</td>
<td>111</td>
</tr>
<tr>
<td>5.3.5</td>
<td>Defuzzification</td>
<td>112</td>
</tr>
<tr>
<td></td>
<td>5.3.5.1 Center of gravity (COG) method</td>
<td>112</td>
</tr>
<tr>
<td></td>
<td>5.3.5.2 Center - average method</td>
<td>113</td>
</tr>
<tr>
<td>CHAPTER NO.</td>
<td>TITLE</td>
<td>PAGE NO.</td>
</tr>
<tr>
<td>------------</td>
<td>----------------------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>5.4</td>
<td>GRAPHICAL DEPICTION OF FUZZY DECISION MAKING</td>
<td>113</td>
</tr>
<tr>
<td>5.5</td>
<td>MAMDANI METHOD</td>
<td>114</td>
</tr>
<tr>
<td>5.6</td>
<td>SUGENO METHOD</td>
<td>115</td>
</tr>
<tr>
<td>5.7</td>
<td>MERITS OF FUZZY LOGIC</td>
<td>116</td>
</tr>
<tr>
<td>5.8</td>
<td>DEMERITS OF FUZZY LOGIC</td>
<td>116</td>
</tr>
<tr>
<td>5.9</td>
<td>INTRODUCTION OF AT89C51 MICROCONTROLLER</td>
<td>117</td>
</tr>
<tr>
<td></td>
<td>5.9.1 Features</td>
<td>118</td>
</tr>
<tr>
<td>5.10</td>
<td>BLOCK DESCRIPTION</td>
<td>118</td>
</tr>
<tr>
<td>5.11</td>
<td>MODES OF OPERATION</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td>5.11.1 Idle Mode</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td>5.11.2 Power-down Mode</td>
<td>123</td>
</tr>
<tr>
<td>5.12</td>
<td>PROGRAMMING THE FLASH</td>
<td>123</td>
</tr>
<tr>
<td></td>
<td>5.12.1 Algorithm</td>
<td>124</td>
</tr>
<tr>
<td>5.13</td>
<td>PARALLEL PORT INTERFACING</td>
<td>124</td>
</tr>
<tr>
<td>5.14</td>
<td>HARDWARE PROPERTIES</td>
<td>125</td>
</tr>
<tr>
<td>5.15</td>
<td>PORT ADDRESSES</td>
<td>126</td>
</tr>
<tr>
<td>5.16</td>
<td>STANDARD PARALLEL PORT (SPP)</td>
<td>127</td>
</tr>
<tr>
<td></td>
<td>5.16.1 Data Port</td>
<td>127</td>
</tr>
<tr>
<td></td>
<td>5.16.2 Status Port</td>
<td>128</td>
</tr>
<tr>
<td></td>
<td>5.16.3 Control Port</td>
<td>128</td>
</tr>
<tr>
<td>5.17</td>
<td>MODES OF OPERATION</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>5.17.1 Centronics Mode</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>5.17.2 Nibble Mode</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>5.17.3 Byte Mode</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>5.17.4 EPP Mode</td>
<td>130</td>
</tr>
</tbody>
</table>
CHAPTER NO. | TITLE | PAGE NO.
--- | --- | ---
5.17.5 | ECP Mode | 130
5.18 | MONITORING IN LabVIEW | 130
5.18.1 | Front Panel of VI | 130
5.18.2 | Block Diagram of VI | 131
5.18.3 | Advantages | 131

6 | SYSTEM IDENTIFICATION AND CONTROLLER IMPLEMENTATION | 133
6.1 | INTRODUCTION | 133
6.1.1 | Empirical Models Development | 133
6.1.2 | Mechanistic Models Development | 134
6.1.3 | Comparison of Empirical and Mechanistic Models | 134
6.2 | EXPERIMENTAL STUDY ON BIOMASS GASIFIER SYSTEM (135Kg/hr) | 135
6.2.1 | Definition of Gas Yield | 136
6.2.2 | Effect of Moisture on the Gas Yield | 136
6.2.3 | Effect of Size of the Wood on Gasification | 139
6.2.4 | Effect of Various Feed Materials on the Yield | 141
6.2.5 | Effect of Tar on the Yield | 142
6.2.6 | Effect of Temperature on the Yield | 144
6.2.7 | Rate of Flow of Gas | 144
6.3 | DEVELOPMENT OF STATIC MODEL FOR BIOMASS GASIFIER SYSTEM (135Kg/hr) | 146
6.3.1 | Biomass Consumption ($F_{hb}$) | 147
6.3.2 | Equivalence Ratio (ER) | 148
<table>
<thead>
<tr>
<th>CHAPTER NO.</th>
<th>TITLE</th>
<th>PAGE NO.</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3.3</td>
<td>CO/CO\textsubscript{2} ratio</td>
<td>148</td>
</tr>
<tr>
<td>6.3.4</td>
<td>Temperature (T)</td>
<td>149</td>
</tr>
<tr>
<td>6.4</td>
<td>FUZZY MODELLING</td>
<td>150</td>
</tr>
<tr>
<td>6.5</td>
<td>DESIGN OF FLC FOR BIOMASS GASIFIER SYSTEM (135Kg/hr)</td>
<td>156</td>
</tr>
<tr>
<td>6.5.1</td>
<td>Prototype Design of FLC</td>
<td>163</td>
</tr>
<tr>
<td>6.6</td>
<td>EXPERIMENTAL STUDY ON BIOMASS GASIFIER SYSTEM (6Kg/hr)</td>
<td>166</td>
</tr>
<tr>
<td>6.6.1</td>
<td>Development of Dynamic Model of Biomass Gasifier System (6Kg/hr)</td>
<td>166</td>
</tr>
<tr>
<td>6.7</td>
<td>CONVENTIONAL CONTROLLER DESIGN</td>
<td>169</td>
</tr>
<tr>
<td>6.8</td>
<td>DESIGN OF FLC FOR DOWNDRAFT BIOMASS GASIFIER</td>
<td>170</td>
</tr>
<tr>
<td>6.9</td>
<td>DESIGN OF SELF TUNING FLC FOR BIOMASS GASIFIER SYSTEM</td>
<td>173</td>
</tr>
<tr>
<td>6.10</td>
<td>DEVELOPMENT OF AUTOMATIC ASH HANDLING SYSTEM</td>
<td>175</td>
</tr>
<tr>
<td>6.10.1</td>
<td>Design of FLC for Ash handling System</td>
<td>176</td>
</tr>
</tbody>
</table>

7 RESULTS AND DISCUSSION 181

7.1 RESULTS AND DISCUSSION OF BIOMASS GASIFIER SYSTEM (135Kg/hr) 181

7.1.1 Lower Heating Value Analysis 181

7.1.2 Static Model Analysis 182

7.1.3 Fuzzy Model Analysis 185

7.1.4 Fuzzy Implementation Analysis (135kg/hr) 186

7.2 RESULTS AND DISCUSSION OF BIOMASS GASIFIER SYSTEM (6Kg/hr) 188
<table>
<thead>
<tr>
<th>CHAPTER NO.</th>
<th>TITLE</th>
<th>PAGE NO.</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.2.1</td>
<td>Conventional Controller Implementation Analysis</td>
<td>188</td>
</tr>
<tr>
<td>7.2.2</td>
<td>Fuzzy Controller Implementation Analysis</td>
<td>189</td>
</tr>
<tr>
<td>7.2.3</td>
<td>Self Tuning Fuzzy Controller Implementation Analysis</td>
<td>191</td>
</tr>
<tr>
<td>7.3</td>
<td>COMPARISON OF CONTROLLERS</td>
<td>194</td>
</tr>
<tr>
<td>7.4</td>
<td>ASH HANDLING SYSTEM WITH FLC</td>
<td>194</td>
</tr>
<tr>
<td>8</td>
<td>CONCLUSION AND FUTURE WORK</td>
<td>196</td>
</tr>
<tr>
<td>8.1</td>
<td>GENERAL</td>
<td>196</td>
</tr>
<tr>
<td>8.2</td>
<td>FUTURE WORK</td>
<td>199</td>
</tr>
<tr>
<td>APPENDIX 1:</td>
<td>EMISSION CHARACTERISTICS</td>
<td>201</td>
</tr>
<tr>
<td>APPENDIX 2:</td>
<td>PRESSURE AT VARIOUS SECTIONS OF THE SYSTEM</td>
<td>203</td>
</tr>
<tr>
<td>APPENDIX 3:</td>
<td>UNLOADING THE REACTOR FOR REPAIR – PROCEDURE</td>
<td>205</td>
</tr>
<tr>
<td>APPENDIX 4:</td>
<td>MOISTURE CONTENT IN WOOD</td>
<td>207</td>
</tr>
<tr>
<td>APPENDIX 5:</td>
<td>GASIFIER SPECIFICATIONS</td>
<td>209</td>
</tr>
<tr>
<td>APPENDIX 6:</td>
<td>RECOMMENDED BIOMASS</td>
<td>211</td>
</tr>
<tr>
<td>APPENDIX 7:</td>
<td>GASIFIER EFFLUENT</td>
<td>212</td>
</tr>
<tr>
<td>APPENDIX 8:</td>
<td>CALORIFIC VALUE IN THE GASIFICATION</td>
<td>214</td>
</tr>
<tr>
<td>CHAPTER NO.</td>
<td>TITLE</td>
<td>PAGE NO.</td>
</tr>
<tr>
<td>------------------------------</td>
<td>--------------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>APPENDIX 9:</td>
<td>RECOMMENDED SPARES</td>
<td>216</td>
</tr>
<tr>
<td>APPENDIX 10:</td>
<td>WASTE MANAGEMENT</td>
<td>217</td>
</tr>
<tr>
<td>APPENDIX 11: TECHNO ECONOMICS</td>
<td>DETAILS</td>
<td>220</td>
</tr>
<tr>
<td>APPENDIX 12: EXPERIMENTAL SETUP</td>
<td>PHOTOS</td>
<td>221</td>
</tr>
<tr>
<td></td>
<td>REFERENCES</td>
<td>226</td>
</tr>
<tr>
<td></td>
<td>LIST OF PUBLICATIONS</td>
<td>237</td>
</tr>
<tr>
<td></td>
<td>CURRICULUM VITAE</td>
<td>238</td>
</tr>
</tbody>
</table>
### LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE NO.</th>
<th>TITLE</th>
<th>PAGE NO.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Carbon content of various fuel types (Tibbs 1993)</td>
<td>6</td>
</tr>
<tr>
<td>1.2</td>
<td>The concentration of gasses in the atmosphere in 1750 and 2004</td>
<td>7</td>
</tr>
<tr>
<td>3.1</td>
<td>Advantages and disadvantages of various gasifiers</td>
<td>72</td>
</tr>
<tr>
<td>3.2</td>
<td>Composition of producer gas from various feed stocks</td>
<td>72</td>
</tr>
<tr>
<td>4.1</td>
<td>Materials and methods used for the present investigation</td>
<td>104</td>
</tr>
<tr>
<td>5.1</td>
<td>Port 3 – pin functions</td>
<td>121</td>
</tr>
<tr>
<td>5.2</td>
<td>Pin assignments of the D-type 25 pin parallel port connector</td>
<td>126</td>
</tr>
<tr>
<td>5.3</td>
<td>Parallel port addresses</td>
<td>127</td>
</tr>
<tr>
<td>5.4</td>
<td>Data port</td>
<td>127</td>
</tr>
<tr>
<td>5.5</td>
<td>Status port</td>
<td>128</td>
</tr>
<tr>
<td>5.6</td>
<td>Control port</td>
<td>129</td>
</tr>
<tr>
<td>6.1</td>
<td>Yield relation with moisture</td>
<td>138</td>
</tr>
<tr>
<td>6.2</td>
<td>Yield characteristics with size</td>
<td>140</td>
</tr>
<tr>
<td>6.3</td>
<td>Yield and calorific value relation with different feed materials</td>
<td>141</td>
</tr>
<tr>
<td>6.4</td>
<td>Yield relation with different feed materials</td>
<td>142</td>
</tr>
<tr>
<td>6.5</td>
<td>Recorded biomass gasifier plant data</td>
<td>146</td>
</tr>
<tr>
<td>6.6</td>
<td>Rules for plant modeling</td>
<td>154</td>
</tr>
<tr>
<td>6.7</td>
<td>Rules for adjusting frequency of grate</td>
<td>161</td>
</tr>
<tr>
<td>6.8</td>
<td>Rules for adjusting air flow rate</td>
<td>161</td>
</tr>
<tr>
<td>6.9</td>
<td>Rules for fuzzy logic controller</td>
<td>172</td>
</tr>
<tr>
<td>TABLE NO.</td>
<td>TITLE</td>
<td>PAGE NO.</td>
</tr>
<tr>
<td>-----------</td>
<td>------------------------------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>6.10</td>
<td>Rule base for $G_e$</td>
<td>174</td>
</tr>
<tr>
<td>6.11</td>
<td>Rule base for $G_{ec}$</td>
<td>175</td>
</tr>
<tr>
<td>6.12</td>
<td>Rules for fuzzy logic controller</td>
<td>178</td>
</tr>
<tr>
<td>7.1</td>
<td>Comparison of various controllers in temperature process</td>
<td>194</td>
</tr>
<tr>
<td>A 1.1</td>
<td>Exhaust gas characteristics</td>
<td>202</td>
</tr>
<tr>
<td>A 2.1</td>
<td>Typical pressure at various sections of the system</td>
<td>203</td>
</tr>
<tr>
<td>A 4.1</td>
<td>Effect of moisture in gasification system</td>
<td>208</td>
</tr>
<tr>
<td>A 5.1</td>
<td>Gasifier specifications</td>
<td>209</td>
</tr>
<tr>
<td>A 5.2</td>
<td>System elements</td>
<td>210</td>
</tr>
<tr>
<td>A 6.1</td>
<td>Recommended biomass</td>
<td>211</td>
</tr>
<tr>
<td>A 7.1</td>
<td>The composition of the effluent</td>
<td>212</td>
</tr>
<tr>
<td>A 7.2</td>
<td>Characteristics of gasification effluent</td>
<td>212</td>
</tr>
<tr>
<td>A 9.1</td>
<td>Recommended spares</td>
<td>216</td>
</tr>
<tr>
<td>A 11.1</td>
<td>Unit generation cost</td>
<td>220</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE NO.</th>
<th>TITLE</th>
<th>PAGE NO.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Up-draft gasifier</td>
<td>23</td>
</tr>
<tr>
<td>1.2</td>
<td>Downdraft gasifier</td>
<td>23</td>
</tr>
<tr>
<td>1.3</td>
<td>Cross draft gasifier</td>
<td>24</td>
</tr>
<tr>
<td>3.1</td>
<td>Feeds used for the gasification</td>
<td>60</td>
</tr>
<tr>
<td>3.2</td>
<td>Biomass feed used in the work</td>
<td>60</td>
</tr>
<tr>
<td>3.3</td>
<td>Product of gasification</td>
<td>62</td>
</tr>
<tr>
<td>3.4</td>
<td>Types of gasifiers</td>
<td>63</td>
</tr>
<tr>
<td>3.5</td>
<td>Downdraft gasifier</td>
<td>64</td>
</tr>
<tr>
<td>3.6</td>
<td>Representing the stages of gasification</td>
<td>66</td>
</tr>
<tr>
<td>3.7</td>
<td>Venturimeter</td>
<td>77</td>
</tr>
<tr>
<td>4.1</td>
<td>Sectional view of reactor</td>
<td>82</td>
</tr>
<tr>
<td>4.2</td>
<td>Cyclone and ashbin</td>
<td>84</td>
</tr>
<tr>
<td>4.3</td>
<td>Cooler and scrubber</td>
<td>85</td>
</tr>
<tr>
<td>4.4</td>
<td>Moisture trap</td>
<td>86</td>
</tr>
<tr>
<td>4.5</td>
<td>Chilled cooler</td>
<td>87</td>
</tr>
<tr>
<td>4.6</td>
<td>Fabric filter</td>
<td>88</td>
</tr>
<tr>
<td>4.7</td>
<td>Venturimeter setup</td>
<td>89</td>
</tr>
<tr>
<td>4.8</td>
<td>Water Bubbler</td>
<td>90</td>
</tr>
<tr>
<td>4.9</td>
<td>Flare device</td>
<td>90</td>
</tr>
<tr>
<td>4.10</td>
<td>Blower</td>
<td>91</td>
</tr>
<tr>
<td>4.11</td>
<td>Water flow scheme</td>
<td>92</td>
</tr>
<tr>
<td>4.12</td>
<td>Schematic diagram of the biomass plant</td>
<td>99</td>
</tr>
<tr>
<td>5.1</td>
<td>Response of fuzzy and PID controller</td>
<td>106</td>
</tr>
<tr>
<td>FIGURE NO.</td>
<td>TITLE</td>
<td>PAGE NO.</td>
</tr>
<tr>
<td>------------</td>
<td>------------------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>5.2</td>
<td>Fuzzy system</td>
<td>107</td>
</tr>
<tr>
<td>5.3</td>
<td>Types of membership functions</td>
<td>111</td>
</tr>
<tr>
<td>5.4</td>
<td>Graphical depiction of fuzzy decision making</td>
<td>113</td>
</tr>
<tr>
<td>5.5</td>
<td>Recommendation #1 of fuzzy decision making</td>
<td>114</td>
</tr>
<tr>
<td>5.6</td>
<td>Recommendation #2 of fuzzy decision making</td>
<td>114</td>
</tr>
<tr>
<td>5.7</td>
<td>AT89C51RC block diagram</td>
<td>119</td>
</tr>
<tr>
<td>6.1</td>
<td>% Yield versus %moisture</td>
<td>139</td>
</tr>
<tr>
<td>6.2</td>
<td>%Yield and size of the wood on different trials</td>
<td>140</td>
</tr>
<tr>
<td>6.3</td>
<td>%Yield and different feed materials</td>
<td>142</td>
</tr>
<tr>
<td>6.4</td>
<td>Subsystem for biomass consumption</td>
<td>147</td>
</tr>
<tr>
<td>6.5</td>
<td>Subsystem for equivalence ratio</td>
<td>148</td>
</tr>
<tr>
<td>6.6</td>
<td>Subsystem for CO/CO2 ratio</td>
<td>149</td>
</tr>
<tr>
<td>6.7</td>
<td>Subsystem for temperature</td>
<td>149</td>
</tr>
<tr>
<td>6.8</td>
<td>MATLAB simulink model of the gasifier</td>
<td>150</td>
</tr>
<tr>
<td>6.9</td>
<td>Membership function for $H_p$</td>
<td>152</td>
</tr>
<tr>
<td>6.10</td>
<td>Membership function for $f_g$</td>
<td>152</td>
</tr>
<tr>
<td>6.11</td>
<td>Membership function for flow</td>
<td>152</td>
</tr>
<tr>
<td>6.12</td>
<td>Membership function for temperature</td>
<td>153</td>
</tr>
<tr>
<td>6.13</td>
<td>Membership function for CO/CO$_2$</td>
<td>153</td>
</tr>
<tr>
<td>6.14</td>
<td>Block diagram of the gasifier control system</td>
<td>157</td>
</tr>
<tr>
<td>6.15</td>
<td>Simulation of control system</td>
<td>158</td>
</tr>
<tr>
<td>6.16</td>
<td>Membership function for $H_p$ (moisture content)</td>
<td>159</td>
</tr>
<tr>
<td>6.17</td>
<td>Membership function for error $T$</td>
<td>159</td>
</tr>
<tr>
<td>6.18</td>
<td>Membership function for error CO/CO$_2$</td>
<td>159</td>
</tr>
<tr>
<td>6.19</td>
<td>Membership function for air flow rate</td>
<td>160</td>
</tr>
<tr>
<td>6.20</td>
<td>Membership function for grate frequency of rotation</td>
<td>160</td>
</tr>
<tr>
<td>6.21</td>
<td>Circuit diagram of the FLC</td>
<td>165</td>
</tr>
<tr>
<td>6.22</td>
<td>Flow chart of the FLC</td>
<td>165</td>
</tr>
<tr>
<td>FIGURE NO.</td>
<td>TITLE</td>
<td>PAGE NO.</td>
</tr>
<tr>
<td>-----------</td>
<td>----------------------------------------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>6.23</td>
<td>Response of temperature versus time</td>
<td>168</td>
</tr>
<tr>
<td>6.24</td>
<td>PID controller for downdraft gasifier</td>
<td>170</td>
</tr>
<tr>
<td>6.25</td>
<td>Membership function of error T</td>
<td>171</td>
</tr>
<tr>
<td>6.26</td>
<td>Membership function of change in error T</td>
<td>171</td>
</tr>
<tr>
<td>6.27</td>
<td>Membership function of air flow rate</td>
<td>172</td>
</tr>
<tr>
<td>6.28</td>
<td>Simulation of fuzzy logic controller</td>
<td>172</td>
</tr>
<tr>
<td>6.29</td>
<td>Block diagram of self tuning fuzzy control</td>
<td>174</td>
</tr>
<tr>
<td>6.30</td>
<td>Block diagram of self tuning controller in LabVIEW</td>
<td>175</td>
</tr>
<tr>
<td>6.31</td>
<td>Membership function of inputs</td>
<td>177</td>
</tr>
<tr>
<td></td>
<td>(a) Error of pressure (b) Rate of change of error</td>
<td></td>
</tr>
<tr>
<td>6.32</td>
<td>Membership function of output</td>
<td>177</td>
</tr>
<tr>
<td>6.33</td>
<td>Current to voltage converter</td>
<td>180</td>
</tr>
<tr>
<td>6.34</td>
<td>Voltage to current converter</td>
<td>180</td>
</tr>
<tr>
<td>7.1</td>
<td>Relationship between the lower heating value and CO/CO₂ ratio</td>
<td>182</td>
</tr>
<tr>
<td>7.2</td>
<td>Relationship between the lower heating value and temperature</td>
<td>182</td>
</tr>
<tr>
<td>7.3</td>
<td>CO/CO₂ ratio versus airflow rate</td>
<td>183</td>
</tr>
<tr>
<td>7.4</td>
<td>Temperature versus airflow rate</td>
<td>183</td>
</tr>
<tr>
<td>7.5</td>
<td>Biomass consumption versus air flow rate</td>
<td>184</td>
</tr>
<tr>
<td>7.6</td>
<td>Equivalence ratio versus air flow rate</td>
<td>185</td>
</tr>
<tr>
<td>7.7</td>
<td>Temperature versus airflow rate</td>
<td>186</td>
</tr>
<tr>
<td>7.8</td>
<td>CO/CO₂ ratio versus airflow rate</td>
<td>186</td>
</tr>
<tr>
<td>7.9</td>
<td>Response of temperature with fuzzy controller</td>
<td>187</td>
</tr>
<tr>
<td>7.10</td>
<td>Response of CO/CO₂ ratio with fuzzy controller</td>
<td>187</td>
</tr>
<tr>
<td>7.11</td>
<td>Response of process to PID controller</td>
<td>189</td>
</tr>
<tr>
<td>7.12</td>
<td>Response of process to PI controller</td>
<td>189</td>
</tr>
<tr>
<td>7.13</td>
<td>Response of process to fuzzy controller (set point = 400)</td>
<td>190</td>
</tr>
</tbody>
</table>
FIGURE NO. | TITLE | PAGE NO.
--- | --- | ---
7.14 | Response of process to fuzzy controller (set point = 600) | 190
7.15 | Response of process to fuzzy controller (set point = 500) | 191
7.16 | Response of process to fuzzy controller (set point = 750) | 191
7.17 | Response to self tuning fuzzy controller (set point = 400) | 192
7.18 | Response to self tuning fuzzy controller (set point = 750) | 192
7.19 | Response to self tuning fuzzy controller (set point = 500) | 193
7.20 | Response to self tuning fuzzy controller (set point = 600) | 193
7.21 | Response of pressure control loop with set point 1 Kg/Cm² | 195
7.22 | Response of pressure control loop with set point 1.5 Kg/Cm² | 195
7.23 | Response of pressure control loop with set point 2 Kg/Cm² | 195
A 12.1 | Bio materials (Eucalyptus) waste wood | 221
A 12.2 | Blower | 221
A 12.3 | Screw conveyer motor setup | 222
A 12.4 | Downdraft biomass gasifier setup | 222
A 12.5 | Thermocouple inside the reactor | 223
A 12.6 | Gas chromatography | 223
A 12.7 | Standard calibration gas mixture containing CO₂ | 224
A 12.8 | O₂, N₂, CH₄, CO peaks in wood sample | 224
A 12.9 | Interfacing circuits | 225
A 12.10 | 100 kW Cummins gas engine | 225
LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOLS

\( \Delta p_1 \) - Inference in the Gas Pressure at the Venturiometer Opening
\( F_a \) - Air Flow Rate
\( \text{CO} \) - Carbon Monoxide
\( \Delta T \) - Change in temperature
\( T_d \) - Derivative Time Constant
\( \$ \) - Dollar
\( e(t) \) - Error
\( \text{€} \) - Euro
\( F_g \) - Frequency of Rotation of the Grate
\( H_2 \) - Hydrogen
\( u(t) \) - Input
\( T_i \) - Integral Time Constant
\( M_b \) - Material Factor
\( H_p \) - Moisture
\( K_p \) - Proportional Gain
\( \Delta e(t) \) - Rate of Change of Error
\( T \) - Temperature
\( \text{CH}_4 \) - Traces of Methane

GREEK LETTERS

\( ^0\text{C} \) - Degree centigrade
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALE</td>
<td>Address Latch Enable</td>
</tr>
<tr>
<td>ASCII</td>
<td>American Standard Code for Information Interchange</td>
</tr>
<tr>
<td>ADC</td>
<td>Analog to Digital Convertor</td>
</tr>
<tr>
<td>ADG</td>
<td>Atmospheric Downdraft Gasifiers</td>
</tr>
<tr>
<td>AUG</td>
<td>Atmospheric Updraft Gasifiers</td>
</tr>
<tr>
<td>ACW</td>
<td>Auto-Chro Win</td>
</tr>
<tr>
<td>BCL</td>
<td>Battelle Columbus Laboratory</td>
</tr>
<tr>
<td>BTU</td>
<td>British Thermal Unit</td>
</tr>
<tr>
<td>BFB</td>
<td>Bubble Fluidized Bed</td>
</tr>
<tr>
<td>CRC</td>
<td>Char Reduction Reactor</td>
</tr>
<tr>
<td>CFCS</td>
<td>Chloro Fluoride Carbons</td>
</tr>
<tr>
<td>CFB</td>
<td>Circulating Fluidized Bed</td>
</tr>
<tr>
<td>CDM</td>
<td>Clean Development Mechanisms</td>
</tr>
<tr>
<td>CRE</td>
<td>Coal Research Establishment</td>
</tr>
<tr>
<td>CHP</td>
<td>Combined Heat and Power</td>
</tr>
<tr>
<td>CGPL</td>
<td>Combustion, Gasification &amp; Propulsion Laboratory</td>
</tr>
<tr>
<td>DAQ</td>
<td>Data Acquisition</td>
</tr>
<tr>
<td>DMT</td>
<td>Deutsche Montan Technologic</td>
</tr>
<tr>
<td>DAC</td>
<td>Digital to Analog Convertor</td>
</tr>
<tr>
<td>DIR</td>
<td>Directory</td>
</tr>
<tr>
<td>DDGS</td>
<td>Distillers Dried Grains with Soluble</td>
</tr>
<tr>
<td>ESD</td>
<td>Ecologically Sustainable Development</td>
</tr>
<tr>
<td>EUF</td>
<td>Energy Utilization Factor</td>
</tr>
<tr>
<td>EU</td>
<td>Engine Unit</td>
</tr>
<tr>
<td>EQB</td>
<td>Environmental Quality Board</td>
</tr>
<tr>
<td>ER</td>
<td>Equivalence Ratio</td>
</tr>
<tr>
<td>FLC</td>
<td>Fuzzy Logic Controller</td>
</tr>
<tr>
<td>GC</td>
<td>Gas Chromatograph</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>GLC</td>
<td>Gas Liquid Chromatography</td>
</tr>
<tr>
<td>GSC</td>
<td>Gas Solid Chromatography</td>
</tr>
<tr>
<td>GHG</td>
<td>Green House Gas</td>
</tr>
<tr>
<td>HHV</td>
<td>High Heating Value</td>
</tr>
<tr>
<td>IBTS</td>
<td>Improved Biomass Technologies</td>
</tr>
<tr>
<td>IR</td>
<td>Infra Red</td>
</tr>
<tr>
<td>IGCC</td>
<td>Integrated Gasification Combined Cycle</td>
</tr>
<tr>
<td>IEC</td>
<td>International Electrotechnical Commission</td>
</tr>
<tr>
<td>IEA</td>
<td>International Energy Agency</td>
</tr>
<tr>
<td>LPG</td>
<td>Liquefied Petroleum Gas</td>
</tr>
<tr>
<td>LC</td>
<td>Liquid Chromatography</td>
</tr>
<tr>
<td>LLC</td>
<td>Liquid Liquid Chromatography</td>
</tr>
<tr>
<td>LSC</td>
<td>Liquid Solid Chromatography</td>
</tr>
<tr>
<td>LHV</td>
<td>Low Heating Value</td>
</tr>
<tr>
<td>MMW</td>
<td>Making of Modern World</td>
</tr>
<tr>
<td>MCV</td>
<td>Medium Calorific Value</td>
</tr>
<tr>
<td>MPC</td>
<td>Model Predictive Control</td>
</tr>
<tr>
<td>MIMO</td>
<td>Multi Input Multi Output</td>
</tr>
<tr>
<td>MSW</td>
<td>Municipal Solid Waste</td>
</tr>
<tr>
<td>NSES</td>
<td>National Strategy on Ecologically Sustainable Development</td>
</tr>
<tr>
<td>NCS</td>
<td>Non-Conventional Energy Sources</td>
</tr>
<tr>
<td>PC</td>
<td>Personal Computer</td>
</tr>
<tr>
<td>PVC</td>
<td>Polyvinyl Chloride</td>
</tr>
<tr>
<td>PRDS</td>
<td>Pressure Reducing and Desuperheating Station</td>
</tr>
<tr>
<td>PCFBG</td>
<td>Pressurized Fluidized Bed Systems Either Circulating</td>
</tr>
<tr>
<td>PROINFA</td>
<td>Programme of Incentives for Alternative Electricity Sources</td>
</tr>
<tr>
<td>PI</td>
<td>Proportional- Integral</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>PID</td>
<td>Proportional-Integral-Derivative</td>
</tr>
<tr>
<td>PYR</td>
<td>Pyrolysis</td>
</tr>
<tr>
<td>SISO</td>
<td>Single-Input-Single-Output</td>
</tr>
<tr>
<td>S.T.P</td>
<td>Standard Temperature Pressure</td>
</tr>
<tr>
<td>SOC</td>
<td>System on a Chip</td>
</tr>
<tr>
<td>TCC</td>
<td>Tar Cracking Chamber</td>
</tr>
<tr>
<td>T</td>
<td>Temperature</td>
</tr>
<tr>
<td>TCD</td>
<td>Thermal Conductivity Detector</td>
</tr>
<tr>
<td>WEC</td>
<td>World Energy Council</td>
</tr>
<tr>
<td>FIGURE NO.</td>
<td>TITLE</td>
</tr>
<tr>
<td>-----------</td>
<td>--------------------------------------------------------------</td>
</tr>
<tr>
<td>6.23</td>
<td>Response of temperature versus time</td>
</tr>
<tr>
<td>6.24</td>
<td>PID controller for downdraft gasifier</td>
</tr>
<tr>
<td>6.25</td>
<td>Membership function of error T</td>
</tr>
<tr>
<td>6.26</td>
<td>Membership function of change in error T</td>
</tr>
<tr>
<td>6.27</td>
<td>Membership function of air flow rate</td>
</tr>
<tr>
<td>6.28</td>
<td>Simulation of fuzzy logic controller</td>
</tr>
<tr>
<td>6.29</td>
<td>Block diagram of self tuning fuzzy control</td>
</tr>
<tr>
<td>6.30</td>
<td>Block diagram of self tuning controller in LabVIEW</td>
</tr>
<tr>
<td>6.31</td>
<td>Membership function of inputs</td>
</tr>
<tr>
<td></td>
<td>(a) Error of pressure (b) Rate of change of error</td>
</tr>
<tr>
<td>6.32</td>
<td>Membership function of output</td>
</tr>
<tr>
<td>6.33</td>
<td>Current to voltage converter</td>
</tr>
<tr>
<td>6.34</td>
<td>Voltage to current converter</td>
</tr>
<tr>
<td>7.1</td>
<td>Relationship between the lower heating value and</td>
</tr>
<tr>
<td></td>
<td>CO/CO₂ ratio</td>
</tr>
<tr>
<td>7.2</td>
<td>Relationship between the lower heating value and temperature</td>
</tr>
<tr>
<td>7.3</td>
<td>CO/CO₂ ratio versus airflow rate</td>
</tr>
<tr>
<td>7.4</td>
<td>Temperature versus airflow rate</td>
</tr>
<tr>
<td>7.5</td>
<td>Biomass consumption versus air flow rate</td>
</tr>
<tr>
<td>7.6</td>
<td>Equivalence ratio versus air flow rate</td>
</tr>
<tr>
<td>7.7</td>
<td>Temperature versus airflow rate</td>
</tr>
<tr>
<td>7.8</td>
<td>CO/CO₂ ratio versus airflow rate</td>
</tr>
<tr>
<td>7.9</td>
<td>Response of temperature with fuzzy controller</td>
</tr>
<tr>
<td>7.10</td>
<td>Response of CO/CO₂ ratio with fuzzy controller</td>
</tr>
<tr>
<td>7.11</td>
<td>Response of process to PID controller</td>
</tr>
<tr>
<td>7.12</td>
<td>Response of process to PI controller</td>
</tr>
<tr>
<td>7.13</td>
<td>Response of process to fuzzy controller (set point = 400)</td>
</tr>
<tr>
<td>FIGURE NO.</td>
<td>TITLE</td>
</tr>
<tr>
<td>-----------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>7.14</td>
<td>Response of process to fuzzy controller (set point = 600)</td>
</tr>
<tr>
<td>7.15</td>
<td>Response of process to fuzzy controller (set point = 500)</td>
</tr>
<tr>
<td>7.16</td>
<td>Response of process to fuzzy controller (set point = 750)</td>
</tr>
<tr>
<td>7.17</td>
<td>Response to self tuning fuzzy controller (set point = 400)</td>
</tr>
<tr>
<td>7.18</td>
<td>Response to self tuning fuzzy controller (set point = 750)</td>
</tr>
<tr>
<td>7.19</td>
<td>Response to self tuning fuzzy controller (set point = 500)</td>
</tr>
<tr>
<td>7.20</td>
<td>Response to self tuning fuzzy controller (set point = 600)</td>
</tr>
<tr>
<td>7.21</td>
<td>Response of pressure control loop with set point</td>
</tr>
<tr>
<td></td>
<td>1 Kg/Cm$^2$</td>
</tr>
<tr>
<td>7.22</td>
<td>Response of pressure control loop with set point</td>
</tr>
<tr>
<td></td>
<td>1.5 Kg/Cm$^2$</td>
</tr>
<tr>
<td>7.23</td>
<td>Response of pressure control loop with set point</td>
</tr>
<tr>
<td></td>
<td>2 Kg/Cm$^2$</td>
</tr>
<tr>
<td>A 12.1</td>
<td>Bio materials (Eucalyptus) waste wood</td>
</tr>
<tr>
<td>A 12.2</td>
<td>Blower</td>
</tr>
<tr>
<td>A 12.3</td>
<td>Screw conveyer motor setup</td>
</tr>
<tr>
<td>A 12.4</td>
<td>Downdraft biomass gasifier setup</td>
</tr>
<tr>
<td>A 12.5</td>
<td>Thermocouple inside the reactor</td>
</tr>
<tr>
<td>A 12.6</td>
<td>Gas chromatography</td>
</tr>
<tr>
<td>A 12.7</td>
<td>Standard calibration gas mixture containing CO$_2$</td>
</tr>
<tr>
<td>A 12.8</td>
<td>O$_2$, N$_2$, CH$_4$, CO peaks in wood sample</td>
</tr>
<tr>
<td>A 12.9</td>
<td>Interfacing circuits</td>
</tr>
<tr>
<td>A 12.10</td>
<td>100 kW Cummins gas engine</td>
</tr>
</tbody>
</table>
LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOLS

\( \Delta p_1 \) - Inference in the Gas Pressure at the Venturimeter Opening

\( F_a \) - Air Flow Rate

\( \text{CO} \) - Carbon Monoxide

\( \Delta T \) - Change in temperature

\( T_d \) - Derivative Time Constant

\$ - Dollar

e(t) - Error

\( \varepsilon \) - Euro

\( F_g \) - Frequency of Rotation of the Grate

\( H_2 \) - Hydrogen

u(t) - Input

\( T_i \) - Integral Time Constant

\( M_b \) - Material Factor

\( H_p \) - Moisture

\( K_p \) - Proportional Gain

\( \Delta e(t) \) - Rate of Change of Error

\( T \) - Temperature

\( \text{CH}_4 \) - Traces of Methane

GREEK LETTERS

\( ^0\text{C} \) - Degree centigrade
<table>
<thead>
<tr>
<th>ABBREVIATION</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALE</td>
<td>Address Latch Enable</td>
</tr>
<tr>
<td>ASCII</td>
<td>American Standard Code for Information Interchange</td>
</tr>
<tr>
<td>ADC</td>
<td>Analog to Digital Convertor</td>
</tr>
<tr>
<td>ADG</td>
<td>Atmospheric Downdraft Gasifiers</td>
</tr>
<tr>
<td>AUG</td>
<td>Atmospheric Updraft Gasifiers</td>
</tr>
<tr>
<td>ACW</td>
<td>Auto-Chro Win</td>
</tr>
<tr>
<td>BCL</td>
<td>Battelle Columbus Laboratory</td>
</tr>
<tr>
<td>BTU</td>
<td>British Thermal Unit</td>
</tr>
<tr>
<td>BFB</td>
<td>Bubble Fluidized Bed</td>
</tr>
<tr>
<td>CRC</td>
<td>Char Reduction Reactor</td>
</tr>
<tr>
<td>CFCS</td>
<td>Chloro Fluoride Carbons</td>
</tr>
<tr>
<td>CFB</td>
<td>Circulating Fluidized Bed</td>
</tr>
<tr>
<td>CDM</td>
<td>Clean Development Mechanisms</td>
</tr>
<tr>
<td>CRE</td>
<td>Coal Research Establishment</td>
</tr>
<tr>
<td>CHP</td>
<td>Combined Heat and Power</td>
</tr>
<tr>
<td>CGPL</td>
<td>Combustion, Gasification &amp; Propulsion Laboratory</td>
</tr>
<tr>
<td>DAQ</td>
<td>Data Acquisition</td>
</tr>
<tr>
<td>DMT</td>
<td>Deutsche Montan Technologic</td>
</tr>
<tr>
<td>DAC</td>
<td>Digital to Analog Convertor</td>
</tr>
<tr>
<td>DIR</td>
<td>Directory</td>
</tr>
<tr>
<td>DDGS</td>
<td>Distillers Dried Grains with Soluble</td>
</tr>
<tr>
<td>ESD</td>
<td>Ecologically Sustainable Development</td>
</tr>
<tr>
<td>EUF</td>
<td>Energy Utilization Factor</td>
</tr>
<tr>
<td>EU</td>
<td>Engine Unit</td>
</tr>
<tr>
<td>EQB</td>
<td>Environmental Quality Board</td>
</tr>
<tr>
<td>ER</td>
<td>Equivalence Ratio</td>
</tr>
<tr>
<td>FLC</td>
<td>Fuzzy Logic Controller</td>
</tr>
<tr>
<td>GC</td>
<td>Gas Chromatograph</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Definition</td>
</tr>
<tr>
<td>--------------</td>
<td>------------</td>
</tr>
<tr>
<td>GLC</td>
<td>Gas Liquid Chromatography</td>
</tr>
<tr>
<td>GSC</td>
<td>Gas Solid Chromatography</td>
</tr>
<tr>
<td>GHG</td>
<td>Green House Gas</td>
</tr>
<tr>
<td>HHV</td>
<td>High Heating Value</td>
</tr>
<tr>
<td>IBTS</td>
<td>Improved Biomass Technologies</td>
</tr>
<tr>
<td>IR</td>
<td>Infra Red</td>
</tr>
<tr>
<td>IGCC</td>
<td>Integrated Gasification Combined Cycle</td>
</tr>
<tr>
<td>IEC</td>
<td>International Electrotechnical Commission</td>
</tr>
<tr>
<td>IEA</td>
<td>International Energy Agency</td>
</tr>
<tr>
<td>LPG</td>
<td>Liquefied Petroleum Gas</td>
</tr>
<tr>
<td>LC</td>
<td>Liquid Chromatography</td>
</tr>
<tr>
<td>LLC</td>
<td>Liquid Liquid Chromatography</td>
</tr>
<tr>
<td>LSC</td>
<td>Liquid Solid Chromatography</td>
</tr>
<tr>
<td>LHV</td>
<td>Low Heating Value</td>
</tr>
<tr>
<td>MMW</td>
<td>Making of Modern World</td>
</tr>
<tr>
<td>MCV</td>
<td>Medium Calorific Value</td>
</tr>
<tr>
<td>MPC</td>
<td>Model Predictive Control</td>
</tr>
<tr>
<td>MIMO</td>
<td>Multi Input Multi Output</td>
</tr>
<tr>
<td>MSW</td>
<td>Municipal Solid Waste</td>
</tr>
<tr>
<td>NSESD</td>
<td>National Strategy on Ecologically Sustainable Development</td>
</tr>
<tr>
<td>NCS</td>
<td>Non-Conventional Energy Sources</td>
</tr>
<tr>
<td>PC</td>
<td>Personal Computer</td>
</tr>
<tr>
<td>PVC</td>
<td>Polyvinyl Chloride</td>
</tr>
<tr>
<td>PRDS</td>
<td>Pressure Reducing and Desuperheating Station</td>
</tr>
<tr>
<td>PCFBG</td>
<td>Pressurized Fluidized Bed Systems Either Circulating</td>
</tr>
<tr>
<td>PROINFA</td>
<td>Programme of Incentives for Alternative Electricity Sources</td>
</tr>
<tr>
<td>PI</td>
<td>Proportional- Integral</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>--------------------------------------</td>
</tr>
<tr>
<td>PID</td>
<td>Proportional-Integral-Derivative</td>
</tr>
<tr>
<td>PYR</td>
<td>Pyrolysis</td>
</tr>
<tr>
<td>SISO</td>
<td>Single-Input-Single-Output</td>
</tr>
<tr>
<td>S.T.P</td>
<td>Standard Temperature Pressure</td>
</tr>
<tr>
<td>SOC</td>
<td>System on a Chip</td>
</tr>
<tr>
<td>TCC</td>
<td>Tar Cracking Chamber</td>
</tr>
<tr>
<td>T</td>
<td>Temperature</td>
</tr>
<tr>
<td>TCD</td>
<td>Thermal Conductivity Detector</td>
</tr>
<tr>
<td>WEC</td>
<td>World Energy Council</td>
</tr>
</tbody>
</table>