LIST OF FIGURES

Plate 2.1 First Diesel Engine....10

Plate 2.2 Rudolph Diesel....11

Figure 2.1 Pressure vs. Crank Angle at 3.88mg per cycle [63]....65

Figure 2.2 Pressure vs. Crank Angle at 5 mg per cycle [63]....66

Figure 2.3 Pressure vs Crank Angle for 6.11 mg per cycle [63]....66

Figure 2.4 Pressure vs Crank Angle at 7.22 mg per cycle [63]....67

Figure 2.5 Variation of Combustion Efficiency and Exhaust Temperature with Air-Fuel Ratio [82]....68

Figure 2.6 Variation of Oxygen Concentration and CO with Air-Fuel Ratio [82]....69

Figure 2.7 Comparison of Heat Release Rates for Different Fuels [84]....70

Figure 2.8 Structure of ANN for Dual Fuel (CNG-Diesel) Operated Diesel Engine [93]....79

Figure 2.9 Flow chart for the proposed study....83

Plate 3.1 Experimental Test Rig....87

Figure. 3.1 Schematic Diagram of Experimental Test Rig....88

Plate 3.2 Variable Compression Ratio Diesel Engine....91

Plate 3.3 Rear View of the Engine....92

Figure 3.2 Principle of Tilting Cylinder Block Assembly....93

Plate 3.4 Tilting Cylinder Block Arrangement....93

Plate 3.5 Compression Ratio Setting....94

Plate 3.6 Fuel Injection Pump....95

Plate 3.7 Eddy Current Dynamometer....96

Plate 3.8 Assembly of Eddy Current Dynamometer and Engine....97

Plate 3.9 Components Connected to the Eddy Current Dynamometer....98

Plate 3.10 Load Cell....99

Plate 3.11 Dynamometer Loading Unit....100

Plate 3.12 Engine Panel Box....101

Figure 3.3 Schematic Diagram of the Loading Dimmerstat....102

Figure 3.4 Circuit Diagram of the Loading Dimmerstat....102

Plate 3.13 Piezosensor....103

Plate 3.14 The Nut Adjustment for Setting Injection Pressure....104

Plate 3.15 Location of Pressure Sensors....105

Plate 3.16 Sensors Interface Circuit....106

Plate 3.17 Assembly of Emission Measurement Systems....109

Plate 3.18 Exhaust Gas Analyzer....110

Figure. 3.5 Principle of Non-Dispersive Infra Red Technique....110

Plate 3.19 Measurement of Exhaust Gas Constituents....111

Plate 3.20 Smoke Meter....112

Figure 3.6 Principle of Folded Geometry....113

Plate 3.21 Measurement of Exhaust Smoke....114

Plate 3.22 Interface of EnginesoftLV....115

Figure 4.1 Input and Output Variables of the Engine System....122

Figure 4.2 Comparison of Variation of BTHE with Load at CR of 17.5 and IP of 200bar....123

Figure 4.3 Comparison of Variation of BSFC with Load at CR of 17.5 and IP of 200bar....124

Figure 4.4 Comparison of BTHE at Rated Load, CR of 17.5 and IP of 200bar....124

Figure 4.5 Comparison of BSFC at Rated Load, CR of 17.5 and IP of 200bar....125

Figure 4.6 Variation of HC with Load at CR of 17.5 and IP of 200bar....126

Figure 4.7 Variation of O_2 with Load at CR of 17.5 and IP of 200bar....126

Figure 4.8 Variation of NO_x with Load at CR of 17.5 and IP of 200bar....127

Figure 4.9 Variation of HC with CR at Load of 12kg and IP of 200bar....127

Figure 4.10 Variation of O_2 with CR at Load of 12kg and IP of 200bar....128

Figure 4.11 Variation of NO_x with CR at Load of 12kg and IP of 200bar....128

Figure 4.12 Variation of HC with IP at Load of 12kg and CR of 17.5....129

Figure 4.13 Variation of O_2 with IP at Load of 12kg and CR of 17.5....129

Figure 4.14 Variation of NO_x with IP at Load of 12kg and CR of 17.5....130

Figure 4.15 Comparison of Variation of BTHE with CR at a Load of 12kg and IP of 200bar....131

Figure 4.16 Comparison of Variation of BSFC with CR at a Load of 12kg and IP of 200bar....132

Figure 4.17 Comparison of Variation of BTHE and BSFC with CR at a Load of 12kg and IP of 200bar with Earlier Studies....133

Figure 4.18 Comparison of Variation of BMEP with CR at a Load of 12kg and IP of 200bar....134

Figure 4.19 Comparison of Variation of Volumetric Efficiency with CR at a Load of 12kg and IP of 200bar 135

Figure 4.20 Comparison of Variation of HBP with CR at a Load of 12kg and IP of 200bar 136

Figure 4.21 Comparison of Variation of HGas with CR at a Load of 12kg and IP of 200bar 137

Figure 4.22 Comparison of Variation of EGT with CR at a Load of 12kg and IP of 200bar 138

Figure 4.23 Comparison of Variation of EGT with CR at a Load of 12kg and IP of 200bar with Earlier Studies 139

Figure 4.24 Comparison of Variation of BTHE with Load at a CR of 18 and IP of 200bar 140

Figure 4.25 Comparison of Variation of BSFC with Load at a CR of 18 and IP of 200bar 141

Figure 4.26 Comparison of Variation of BTHE and BSFC with Load at a CR of 18 and IP of 200bar with Earlier Studies 142

Figure 4.27 Comparison of Variation of BMEP with Load at a CR of 18 and IP of 200bar 143

Figure 4.28 Comparison of Variation of Volumetric Efficiency with Load at a CR of 18 and IP of 200bar 144

Figure 4.29 Comparison of Variation of HBP with Load at a CR of 18 and IP of 200bar 144

Figure 4.30 Comparison of Variation of HGas with Load at a CR of 18 and IP of 200bar 145

Figure 4.31 Comparison of Variation of EGT with Load at a CR of 18 and IP of 200ba 146

Figure 4.32 Comparison of Variation of EGT with Load at a CR of 18 and IP of 200bar with Earlier Studies 147

Figure 4.33 Comparison of Variation of BTHE with IP at CR of 18 and Load of 12kg 148

Figure 4.34 Comparison of Variation of BSFC with IP at CR of 18 and Load of 12kg 148

Figure 4.35 Comparison of Variation of BTHE and BSFC with IP at a CR of 18 and IP of 200bar with Earlier Studies 149

Figure 4.36 Comparison of Variation of BMEP with IP at CR of 18 and Load of 12kg 150

Figure 4.37 Comparison of Variation of Volumetric Efficiency with IP at CR of 18 and Load of 12kg 151

Figure 4.38 Comparison of Variation of HBP with IP at CR of 18 and Load of 12kg 151

Figure 4.39 Comparison of Variation of HGas with IP at CR of 18 and Load of 12kg 152

Figure 4.40 Comparison of Variation of EGT with IP at CR of 18 and Load of 12kg 153

Figure 4.41 Comparison of Variation of EGT with IP at a CR of 18 and Load of 12kg of Present Study with Jindal et al. [66] 154

Figure 4.42 Comparison of Variation of CO with CR at Load of 12kg and IP of 200bar 155

Figure 4.43 Comparison of Variation of HC with CR at Load of 12kg and IP of 200bar 156

Figure 4.44 Comparison of Variation of HC with CR at a Load of 12kg and IP of 200bar Present Study with Earlier Studies 157

Figure 4.45 Comparison of Variation of NO_X with CR at Load of 12kg and IP of 200bar 158

Figure 4.46 Comparison of Variation of CO_2 with CR at Load of 12kg and IP of 200bar 159

Figure 4.47 Comparison of Variation of O_2 with CR at Load of 12kg and IP of 200bar 160

Figure 4.48 Comparison of Variation of SO_X with CR at Load of 12kg and IP of 200bar 161

Figure 4.49 Comparison of Variation of HSU with CR for at Load of 12kg and IP of 200bar 162

Figure 4.50 Comparison of Variation of NO_x and HSU with CR at a Load of 12kg and IP of 200bar with Earlier Studies 163

Figure 4.51 Comparison of Variation of CO with Load at CR of 18 and IP of 200bar 164

Figure 4.52 Comparison of Variation of HC with Load at CR of 18 and IP of 200bar 165

Figure 4.53 Comparison of Variation of NOx with Load at CR of 18 and IP of 200bar 166

Figure 4.54 Comparison of Variation of CO_2 with Load at CR of 18 and IP of 200bar 167

Figure 4.55 Comparison of Variation of O_2 with Load at CR of 18 and IP of 200bar 168

Figure 4.56 Comparison of Variation of SO_x with Load at CR of 18 and IP of 200bar 169

Figure 4.57 Comparison of Variation of HSU with Load at CR of 18 and IP of 200bar 170

Figure 4.58 Comparison of Variation of NO_x and HSU with Load at a CR of 18 and IP of 200bar with Earlier Studies 171

Figure 4.59 Comparison of Variation of CO with IP at CR of 18 and Load of 12kg 172

Figure 4.60 Comparison of Variation of CO with IP at a CR of 18 and Load of 12kg with Jindal et al. [66] 173

Figure 4.61 Comparison of Variation of HC with IP at CR of 18 and Load of 12kg 173

Figure 4.62 Comparison of Variation of HC with IP at CR of 18 and Load of 12kg of Present Study with Jindal et al. [66] 174

Figure 4.63 Comparison of Variation of NO_x with IP at CR of 18 and Load of 12kg 174

Figure 4.64 Comparison of Variation of CO_2 with IP at CR of 18 and Load of 12kg 175

Figure 4.65 Comparison of Variation of CO_2 with IP at a CR of 18 and Load of 12kg of Present Study with Jindal et al. [66] 176

Figure 4.66 Comparison of Variation of O_2 with IP for Tested Fuels at CR of 18 and Load of 12kg 177

Figure 4.67 Comparison of Variation of SO_x with IP at CR of 18 and Load of 12kg 178

Figure 4.68 Comparison of Variation of HSU with IP at CR of 18 and Load of 12kg 179

Figure 4.69 Comparison of Variation of NO_x and HSU with IP at a CR of 18 and Load of 12kg with Jindal et al. [66] 179

Figure 4.70 Variation of CP With CA at CR of 14 for Karanja Biodiesel 181

Figure 4.71 Variation of CP With CA at CR of 14 for Diesel Oil 182

Figure 4.72 Variation of CP With CA at CR of 16 for Karanja Biodiesel 183

Figure 4.73 Variation of CP With CA at CR of 16 For Diesel Oil 183

Figure 4.74 Variation of CP With CA at CR of 18 for Karanja Biodiesel 184

Figure 4.75 Variation of CP With CA at CR of 18 for Diesel Oil 185

Figure 4.76 Comparison of Variation of Peak CP with CR at a Load of 12kg and an IP of 200bar of the Present Study with that of Earlier Investigations 186

Figure 4.77 Variation of Net Heat Release Rate With CA at CR of 14 for Karanja Biodiesel 188

Figure 4.78 Variation of Net Heat Release Rate With CA at CR of 14 for Diesel Oil 188

Figure 4.79 Variation of Net Heat Release Rate With CA at CR of 16 for Karanja Biodiesel 189

Figure 4.80 Variation of Net Heat Release Rate With CA at CR of 16 for Diesel Oil 190

Figure 4.81 Variation of Net Heat Release Rate with CA at CR of 18 for Karanja Biodiesel 191

Figure 4.82 Variation of Net Heat Release Rate with CA at CR of 18 for Diesel Oil 191

Figure 4.83 Comparison of Variation of Peak Net Heat Release Rate with CR at a Load of 12kg and an IP of 200bar of the Present Study with that of Earlier Investigations 193

Figure 4.84 Variation of Rate of Pressure Rise with CA at CR of 14 for Karanja Biodiesel 195

Figure 4.85 Variation of Rate of Pressure Rise With CA at CR of 14 for Diesel Oil 195

Figure 4.86 Variation of Rate of Pressure Rise With CA at CR of 16 for Karanja Biodiesel 196

Figure 4.87 Variation of Rate of Pressure Rise with CA at CR of 16 for Diesel Oil 197

Figure 4.88 Variation of Rate of Pressure Rise With CA at CR of 18 for Karanja Biodiesel 198

Figure 4.89 Variation of Rate of Pressure Rise with CA at CR of 18 for Diesel Oil 198

Figure 4.90 Comparison of Variation of Peak Rate of Pressure Rise with CR at a Load of 12kg and an IP of 200bar of the Present Study with that of Earlier Investigations 200

Figure 4.91 Variation of Mass Fraction Burnt With CA at CR of 14 for Karanja Biodiesel 201

Figure 4.92 Variation of Mass Fraction Burnt With CA at CR of 14 for Diesel Oil 202

Figure 4.93 Variation of Mass Fraction Burnt With CA at CR of 16 for Karanja Biodiesel 203

Figure 4.94 Variation of Mass Fraction burnt with CA at CR of 16 for Diesel Oil 204

Figure 4.95 Variation of Mass Fraction Burnt with CA at CR of 18 for Karanja Biodiesel 204

Figure 4.96 Variation of Mass Fraction Burnt With CA at CR of 18 for Diesel Oil 205

Figure 4.97 Variation of Mean Gas Temperature With CA at CR of 14 for Karanja Biodiesel 207

Figure 4.98 Variation of Mean Gas Temperature With CA at CR of 14 for Diesel Oil 207

Figure 4.99 Variation of Mean Gas Temperature with CA at CR of 16 for Karanja Biodiesel 208

Figure 4.100 Variation of Mean Gas Temperature With CA at CR of 16 for Diesel Oil 209

Figure 4.101 Variation of Mean Gas Temperature With CA at CR of 18 for Karanja Biodiesel 210

Figure 4.102 Variation of Mean Gas Temperature With CA at CR of 18 for Diesel Oil 211

Figure 4.103 Variation of CP With Cylinder Volume at CR of 14 for Karanja Biodiesel 212

Figure 4.104 Variation of CP With Cylinder Volume at CR of 14 for Diesel Oil 213

Figure 4.105 Variation of CP With Cylinder Volume at CR of 16 for Karanja Biodiesel 214

Figure 4.106 Variation of CP With Cylinder Volume at CR of 16 for Diesel Oil 214

Figure 4.107 Variation of CP With Cylinder Volume at CR of 18 for Karanja Biodiesel 214

Figure 4.108 Variation of CP With Cylinder Volume at CR of 18 for Diesel Oil 215

Figure 4.109 Variation of Cumulative Heat Release With CA at CR of 14 for Karanja Biodiesel 216

Figure 4.110 Variation of Cumulative Heat Release With CA at CR of 14 for Diesel Oil 216

Figure 4.111 Variation of Cumulative Heat Release With CA at CR of 16 for Karanja Biodiesel 217

Figure 4.112 Variation of Cumulative Heat Release With CA at CR of 16 for Diesel Oil 218

Figure 4.113 Variation of Cumulative Heat Release With CA at CR of 18 for Karanja biodiesel 219

Figure 4.114 Variation of Cumulative Heat Release With CA at CR of 18 for Diesel oil 219

Figure 4.115 Variation of Cylinder and Injection Pressures with CA (150bar) 221

Figure 4.116 Variation of Cylinder and Injection Pressures with CA (200bar) 221

Figure 4.117 Variation of Cylinder and Injection Pressures with CA (250 bar) 222

Figure 5.1 Complexity of System & Precision Level of Different Models 230

Figure 5.2 Problem Definition Screen 237

Figure 5.3 Display Screen of MATLAB Program for Optimization of Thermal Performance 238

Figure 5.4 Pareto Front for Optimisation of Thermal Performance Parameters 239

Figure 5.5 Display Screen of MATLAB Program for Optimization of Emission Constituents 241

Figure 5.6 Pareto Front for Optimisation of Emission Constituents 242

Figure 5.7 Display Screen of MATLAB Program for Optimization of Thermal Performance and Emission Constituents 243

Figure 5.8 Pareto Front for Optimisation of Both Thermal Performance Parameters and Emission Constituents Giving Equal Weightages 244

Figure 5.9 MATLAB Editor 246

Figure 5.10 Layout of Simulation of Actual Engine using ANN Model for Engine Performance 251

Figure 5.11 Setting Learning Control for Training of ANN Model 253

Figure 5.12 ANN Model for Predicting Thermal Performance with Architecture 4.8.10.3 254

Figure 5.13 ANN Model Training & Error Propogation with Increasing Number of Training Cycles for the 4.8.10.3 255

Figure 5.14 Simulation of Actual Engine Using ANN Model for Exhaust Emissions 258

Figure 5.15 Setting Learning Controls for Training of ANN Model 260

Figure 5.16 ANN Model of Exhaust Gas Constituents with Architecture 4.8.9.5 261

Figure 5.17 ANN Model Training & Error Propogation Graph With Increasing Number of Training Cycles for 4.8.9.5 262

Plate I.1 Leaves and Seeds of Karanja Tree 274

Figure I.1 Biodiesel Production Process 275

Figure I.2 Esterification Reaction of Vegetable Oil 276

Figure V.1 Calibration Certificate of Multigas Analyser 294

Figure V.2 Calibration Certificate of Smoke Meter 295

Figure V.3 Calibration Certification of the Piezosensor 296

Figure V.4 Properties of Karanja Biodiesel 297

Figure VI.1 Schematic of Continuous Microwave Reactor [107] 302

Figure VI.2 Flow Diagram of Cotton Oil Soap stock Biodiesel Production Process [108] 302

Figure VI.3 Distillation Curves of Diesel Fuel, Linseed Oil, and Methyl and Ethyl Esters of Linseed Oil [110] 303

Figure VIII.1 An Objective Function with One Local Optimum and One Global Optimum 317

Figure IX.1 The Style of Neural Computation 319

Figure IX.2 Natural Neuron 321

Figure IX.3 Mathematical Model of ANN 323

Figure IX.4 Training of ANN 324