

Table of Contents

| | | |
|----------|---|-----------|
| 1 | Introduction | 1 |
| 1.1 | Introduction | 2 |
| 1.2 | Technological framework of compression ignition engines | 2 |
| 1.3 | New combustion strategies..... | 10 |
| 1.4 | Document content and structure | 10 |
| | Bibliography | 14 |
| 2 | Advanced combustion strategies in compression ignition engines | 17 |
| 2.1 | Introduction | 18 |
| 2.2 | Conventional diesel emissions dilemma | 18 |
| 2.3 | Low Temperature Combustion approaches | 21 |
| 2.3.1 | Mixing-controlled LTC | 21 |
| 2.3.2 | Homogeneous Charge Compression Ignition | 24 |
| 2.4 | Strategies for expanding the HCCI operating limits | 25 |
| 2.4.1 | Charge preparation | 25 |
| 2.4.2 | Fuel stratification using direct injection | 27 |
| 2.4.3 | Fuel autoignition qualities modification | 31 |
| 2.4.4 | Spark assistance | 33 |
| 2.4.5 | Dual-fuel operation..... | 35 |
| 2.5 | Reactivity Controlled Compression Ignition | 38 |
| 2.5.1 | Description of RCCI combustion process | 38 |

| | | |
|----------|--|-----------|
| 2.5.2 | Direct comparison of RCCI vs HCCI | 40 |
| 2.5.3 | Effects of engine variables on RCCI combustion | 42 |
| 2.6 | Approach of the study | 51 |
| 2.6.1 | Motivation of the study | 51 |
| 2.6.2 | Objectives of the study | 53 |
| 2.6.3 | General methodology and research development | 53 |
| | Bibliography | 57 |
| 3 | Tools and methodology | 63 |
| 3.1 | Introduction | 65 |
| 3.2 | Experimental facilities | 65 |
| 3.2.1 | Single-cylinder research engine | 65 |
| 3.2.1.1 | Engine description | 66 |
| 3.2.1.2 | Variable valve actuation system | 67 |
| 3.2.1.3 | Fuel injection systems | 68 |
| 3.2.1.4 | Baseline fuel properties | 71 |
| 3.2.2 | Test cell characteristics | 71 |
| 3.2.2.1 | Engine speed and torque regulation | 72 |
| 3.2.2.2 | Air supply and exhaust systems | 73 |
| 3.2.2.3 | Exhaust Gas Recirculation loop | 74 |
| 3.2.2.4 | Lubrication and cooling systems | 75 |
| 3.2.2.5 | Fuel conditioning system | 76 |
| 3.2.2.6 | Data acquisition systems | 76 |
| 3.2.3 | Instrumentation and measuring equipment | 78 |
| 3.2.3.1 | Torque and engine speed measurement | 78 |
| 3.2.3.2 | Mean pressure and temperature measurement | 78 |
| 3.2.3.3 | Instantaneous pressure transducers | 79 |
| 3.2.3.4 | Mass flow measurement | 79 |
| 3.2.3.5 | Horiba gas analyzer | 80 |
| 3.2.3.6 | AVL Smoke meter | 81 |

| | | |
|----------|---|------------|
| 3.2.3.7 | Blow-by meter | 83 |
| 3.2.4 | Experimental procedure considerations | 83 |
| 3.3 | Theoretical tools | 85 |
| 3.3.1 | 0-D Combustion diagnosis model..... | 85 |
| 3.3.2 | 3-D Computational fluid dynamics model | 88 |
| 3.3.2.1 | General features | 89 |
| 3.3.2.2 | Modeling methodology | 90 |
| 3.3.2.3 | Model set-up and validation..... | 94 |
| 3.4 | Summary and conclusions | 98 |
| | Bibliography | 99 |
| 4 | Improving RCCI efficiency at low load by combining engine settings | 103 |
| 4.1 | Introduction | 104 |
| 4.2 | Operating conditions and test methodology definition | 104 |
| 4.2.1 | Baseline injection strategy selection | 105 |
| 4.2.2 | Influence of main injection timing on NOx and soot emissions | 109 |
| 4.3 | Strategy 1: Effect of oxygen concentration and gasoline fraction | 112 |
| 4.4 | Strategy 2: Effect of intake charge temperature and gasoline fraction | 117 |
| 4.5 | Comparison of both strategies..... | 122 |
| 4.6 | Summary and conclusions | 125 |
| | Bibliography | 127 |
| 5 | Piston bowl geometry effects on RCCI combustion | 129 |
| 5.1 | Introduction | 130 |
| 5.2 | Sources of heat transfer losses in RCCI combustion | 131 |
| 5.3 | Piston bowl geometries definition | 135 |
| 5.3.1 | Approaches in piston design to reduce heat transfer .. | 135 |
| 5.3.1.1 | Thermal barrier coatings | 136 |
| 5.3.1.2 | Piston geometry modification | 138 |

| | | |
|----------|--|------------|
| 5.3.2 | Description of the piston bowl geometries studied | 141 |
| 5.4 | Effect of piston bowl geometry at low load | 144 |
| 5.4.1 | Experimental results | 144 |
| 5.4.2 | Understanding the differences between geometries | 151 |
| 5.4.2.1 | Heat transfer analysis | 152 |
| 5.4.2.2 | Combustion losses | 155 |
| 5.4.2.3 | Efficiency | 156 |
| 5.5 | Evaluation of the suitable geometry for extended load operation | 157 |
| 5.5.1 | Medium load results | 157 |
| 5.5.2 | High load results | 162 |
| 5.6 | Piston bowl geometry selection | 168 |
| 5.7 | Summary and conclusions | 170 |
| | Bibliography | 172 |
| 6 | Effect of intermediate ethanol-gasoline blends on RCCI combustion | 175 |
| 6.1 | Introduction | 177 |
| 6.2 | Background and conditions of the study | 178 |
| 6.2.1 | Alternative fuels for internal combustion engines | 178 |
| 6.2.2 | Fuels used and methodology considerations | 182 |
| 6.3 | Low load study | 183 |
| 6.3.1 | Effect of low reactivity fuel properties on RCCI | 183 |
| 6.3.1.1 | Test conditions | 184 |
| 6.3.1.2 | Results | 185 |
| 6.3.2 | Gas properties modification for improved reactivity | 190 |
| 6.3.2.1 | Test conditions | 191 |
| 6.3.2.2 | Combustion development comparison | 192 |
| 6.3.2.3 | Engine-out emissions results | 197 |
| 6.3.2.4 | Discussion | 199 |
| 6.4 | Evaluation of the suitable LRF for extended load operation | 202 |
| 6.4.1 | Medium load results | 202 |

| | | |
|----------|--|------------|
| 6.4.1.1 | Test conditions | 202 |
| 6.4.1.2 | Results | 203 |
| 6.4.2 | High load results | 208 |
| 6.4.2.1 | Test conditions | 208 |
| 6.4.2.2 | Results | 209 |
| 6.5 | Low reactivity fuel selection | 214 |
| 6.6 | Summary and conclusions | 219 |
| | Bibliography | 222 |
| 7 | RCCI operating limits assessment | 225 |
| 7.1 | Introduction | 226 |
| 7.2 | RCCI operation over the whole engine map | 227 |
| 7.2.1 | Experimental procedure definition | 227 |
| 7.2.2 | Results with nominal compression ratio | 232 |
| 7.2.3 | Results with reduced compression ratio | 235 |
| 7.2.4 | Technological challenges of RCCI concept | 238 |
| 7.3 | Dual-mode RCCI/CDC capabilities | 243 |
| 7.3.1 | Engine description | 244 |
| 7.3.2 | RCCI operating limits | 246 |
| 7.3.2.1 | Low and high reactivity fuels selection | 246 |
| 7.3.2.2 | Results | 247 |
| 7.3.3 | Dual-mode engine operation approach | 249 |
| 7.4 | Summary and conclusions | 256 |
| | Bibliography | 259 |
| 8 | Conclusions and suggestions for future work | 261 |
| 8.1 | Introduction | 262 |
| 8.2 | Summary and conclusions | 262 |
| 8.3 | Suggestions for future work | 269 |
| | Bibliography | 275 |