

Table of contents

Nomenclature	xvii
List of figures	xxvii
List of tables	xxxiii
1 Introduction	1
1.1 General context	1
1.2 Objectives and methodology	3
1.3 About this thesis	5
2 Diesel injection systems, spray fundamentals and characterization techniques	7
2.1 Introduction	7
2.2 Diesel injection systems	8
2.2.1 Indirect injection systems	10
2.2.2 Direct injection systems	10
2.3 The common rail system	12
2.4 The common rail injector	14
2.4.1 The solenoid actuated injector	14
2.4.2 The piezoelectric actuated injector	17
2.5 Internal Flow	19
2.5.1 Nozzle morphology	19

2.5.2	Nozzle orifice	21
2.5.3	Characteristics of the flow and pressure losses	24
2.5.4	Hydraulic characterization	29
2.5.5	Cavitation	34
2.6	Diesel spray formation	36
2.6.1	Atomization and break-up processes	38
2.7	Theoretical view of the diesel spray structure and its characteristics . .	48
2.7.1	Macroscopic characterization	48
2.7.2	Microscopic characterization	55
3	Literature review	61
3.1	Introduction	61
3.2	Overview of experimental macroscopic and microscopic characterization on diesel sprays	61
3.2.1	Macroscopic technologies used for spray measurements	62
3.2.2	Microscopic technologies used for spray measurements	69
3.3	Overview of experimental macroscopic and microscopic studies in diesel sprays at very high injection pressures	73
3.4	Conclusions about the current state of knowledge	75
4	Materials and methods	79
4.1	Introduction	79
4.2	Injection system	79
4.2.1	Injectors	81
4.3	Mass flow measurement, methods and tools	84
4.3.1	Signal treatment procedure	86
4.4	Test rigs	89
4.4.1	High temperature and high pressure test rig	89
4.4.2	High density test rig	93
4.5	Tools and methodology for macroscopic experiments	93

4.5.1	Schlieren technique and set-up	94
4.5.2	MIE-Scattering technique and set-up	98
4.5.3	Image processing	99
4.5.4	Data averaging	102
4.6	Tools and methodology for microscopic experiments	102
4.6.1	PDPA system	102
5	Results and discussion: Internal flow	111
5.1	Introduction	111
5.2	Injectors geometry characterization	112
5.3	Rate of injection	113
5.3.1	Test plan definition	113
5.3.2	Electric signal effect	114
5.3.3	Multiple injections effect	116
5.3.4	Nozzle comparison and injectors behavior	118
5.3.5	Rail and ambient pressures influence on ROI	123
5.3.6	Injection duration study	123
5.4	Conclusions	127
6	Results and discussion: Microscopic characterization	129
6.1	Introduction	129
6.2	Test plan definition for PDPA measurements	130
6.3	PDPA measurements setting	131
6.4	Methodology for spray alignment and multi-hole injectors measurements	132
6.4.1	Methodology for spray of interest alignment	135
6.4.2	Preliminary measurements	138
6.5	Fuel Droplet Size and Velocity Distribution	138
6.5.1	Droplet velocities	139
6.5.2	Droplet diameters	142
6.5.3	Nozzle comparison	147

6.6	Conclusions	147
7	Results and discussion: Macroscopic characterization	151
7.1	Introduction	151
7.2	Spray development at isothermal conditions	153
7.2.1	Test Plan	154
7.2.2	Effect of ambient density and injection pressure on penetration and spray angle	156
7.2.3	Effect of gas properties on penetration and spray angle	159
7.3	Spray development at evaporative conditions	165
7.3.1	Test Plan	166
7.3.2	Effect of ambient density on evaporating diesel sprays	168
7.3.3	Effect of ambient temperature and injection pressure on vapor and liquid penetration	169
7.3.4	Liquid length summary results	171
7.3.5	Nozzle comparison	174
7.4	Conclusions	178
8	Conclusions and future work	183
8.1	Introduction	183
8.2	Summary and conclusions	183
8.3	Future works	187
	References	189