WOODHEAD PUBLISHING N MECHANICAL ENGINEERING

HCCI and CAI engines for the automotive industry

Edited by Hua Zhao







Contents

	Contributor contact details	xiii
	Preface	xvii
Part I	Overview	
1	Motivation, Definition, and History of HCCI/CA	
	engines	3
	H ZHAO, Brunel University West London, UK	
1.1	Introduction	3
1.2	Current automotive engines and technologies	5
1.3	Historical background of HCCI/CAI type combustion	
	engines	6
1.4	Principle of HCCI/CAI combustion engines	10
1.5	Definition of HCCI and CAI combustion engines	15
1.6 1.7	Summary References	16
1.7	Kererences	16
Part II	Gasoline HCCI/CAI combustion engines	
2	Overview of CAI/HCCI gasoline engines	21
	H ZHAO, Brunel University West London, UK	
2.1	Introduction	21
2.2	Fundamentals of CAI/HCCI gasoline engines	21
2.3	Effects of use of exhaust gases as diluents	29
2.4	Approaches to CAI/HCCI operation in gasoline engines	35
2.5	Summary	40
2.6	References	40
3	Two-stroke CAI engines	43
	P DURET, IFP, France	
3.1	Introduction	43

•	<u> </u>
VI	Contents
VI .	CONTENIS

3.2	Principles of the two-stroke CAI combustion	46
3.3 3.4	How to control the two-stroke CAI combustion The potential application of the two-stroke CAI	56
	combustion	67
3.5	Future trends	72
3.6	Sources of further information and advice	74
3.7	References	75
4	Four-stroke gasoline HCCI engines with thermal management	77
	J YANG, USA	
4.1	Introduction	77
4.2	The optimized kinetic process (OKP) HCCI engine	79
4.3	Strengths and weaknesses	91
4.4	Future trends	91 97
4.5	Sources of further information and advice	99
4.6	References	101
		101
5	Four-stroke CAI engines with residual gas	
	trapping	103
	H ZHAO, Brunel University West London, UK	
5.1	Introduction	103
5.2	Principle of CAI operation with residual gas trapping	103
5.3	CAI operation in a four-stroke port fuel injection (PFI) gasoline engine	107
5.4	Effect of direct injection on CAI combustion in the	107
5.4	four-stroke gasoline engine	115
5.5	Effect of spark ignition on CAI combustion in the	115
0.0	four-stroke gasoline engine	129
5.6	Summary	132
5.7	References	134
6	Four-stroke CAI engines with internal exhaust gas	
	recirculation (EGR)	136
	A FÜRHAPTER, AVL List GmbH, Austria	
6.1	Introduction	136
6.2	Principle of CAI with internal EGR	137
6.3	Engine concepts and layout	141
6.4	Thermodynamic results and analysis of CAI with	
	internal EGR	146
6.5	Transient operation with CAI and internal EGR	155
6.6	Future trends	162

Contents	vii

6.7 6.8	Sources of further information and advice References	162 163
7	HCCI control	164
	P TUNESTÅL and B JOHANSSON, Lund University, Sweden	
7.1	Introduction	164
7.2	Control means	165
7.3	Combustion timing sensors	171
7.4	Methods	174
7.5	Summary and future trends	182
7.6	References	182
8	CAI control and CAI/SI switching	185
	N MILOVANOVIC, Delphi Diesel Systems Limited, UK and J TURNER, Lotus Engineering, UK	
8.1	Introduction about requirements for the control of the	
	CAI engine	185
8.2	Problems in controlling the CAI engine	185
8.3	Transition between operating modes (CAI-SI-CAI)	188
8.4	The 'mixed mode' CAI-SI engine in operation:	
	presentation and discussion of the experimental results	100
	obtained	192
8.5	Summary	202
8.6	References	203
9	Fuel effects in CAI gasoline engines	206
	G T KALGHATGI, Shell Global Solutions, UK	
9.1	Introduction	206
9.2	Practical transport fuels	207
9.3	Auto-ignition quality of fuels	210
9.4	The octane index and the K value	217
9.5	The auto-ignition requirement of an HCCI engine and	
	fuel effects in combustion phasing	222
9.6	Combustion limits	224
9.7	IMEP and indicated efficiency	226
9.8	Other approaches to characterising fuel performance in	220
0.0	HCCI engines	228
9.9	Fuel requirements of HCCI engines	230
9.10	Summary References	233 234
9.11 9.12	List of notations	234
9.1Z		230
	Appendix – HCCI predictor	231

Part III Diesel HCCI combustion engines

10	Overview of HCCI diesel engines	241
	J V Pastor, J M Luján, S Molina and J M García, CMT-Motores Térmicos, Spain	
10.1	Introduction	241
10.2	Conventional diesel combustion	242
10.3	Fundamentals of HCCI combustion	247
10.4	Overview of diesel HCCI engines	252
10.5	Summary	261
10.6	References	263
11	HCCI combustion with early and multiple injections	~ - ~
	in the heavy-duty diesel engine	267
	Y AOYAGI, New ACE, Japan	
11.1	Introduction	267
11.2	Experimental apparatus	268
11.3	Early injection HCCI (PREDIC) by low cetane fuel	271
11.4	Multiple injections HCCI by low cetane fuel (two-stage	074
11 6	combustion, MULDIC)	274
11.5	HCCI for normal cetane fuel	277 285
11.6 11.7	Summary Acknowledgements	285
11.7	References	280
11.0	Nomenclature	280
		200
12	Narrow angle direct injection (NADI™) concept for	
	HCCI diesel combustion	289
	B GATELLIER, IFP, France	
12.1	Introduction	289
12.2	The NADI TM concept overview	290
12.3	First results and limitations	292
12.4	Development of the concept	296
12.5	Evaluation of the concept in a multi-cylinder engine	307
12.6	Future trends	318
12.7	References	320
13	Low-temperature and premixed combustion concept with late injection	322
	S KIMURA, Nissan Motor Company, Japan	
13.1	Introduction	322
13.2	Basic concept of low-temperature and premixed combustion	323

13.3	Characteristics of combustion and exhaust emissions with	
	modulated kinetics (MK) combustion	324
13.4	Second generation of MK combustion	330
13.5	Emission performance improvement of second generation	
	of MK combustion	334
13.6	Future trends	337
13.7	References	340
14	HCCI fuel requirements	342
	T W RYAN III, SWRI, USA	
14.1	Introduction	342
14.2	Background	342
14.3	Diesel fuel HCCI	345
14.4	HCCI fuel ignition quality	350
14.5	Gasoline HCCI	354
14.6	HCCI fuel specification	358
14.7	Fundamental fuel factors	360
14.8	Future trends	361
14.9	References	362
Part IV	HCCI/CAI combustion engines with alternative fuels	
15	Natural gas HCCI engines	365
	N IIDA, Keio University, Japan	
15.1	CNG HCCI engine experiment and calculation conditions	365
15.2	CNG composition	366
15.3	Influence of equivalence ratio	369
15.4	Auto-ignition timing and combustion duration	371
15.5	Auto-ignition temperature and auto-ignition pressure	372
15.6	Exhaust emission, maximum cycle temperature and	
	combustion efficiency	374
15.7	Influence of n-butane on auto-ignition and combustion in	
	methane/n-butane/air mixtures	376
15.8	Summary of naturally aspirated natural gas HCCI engine	383
15.9	Supercharged natural gas HCCI engine setup and	
15.10	experiments	383
15.10	Performance and exhaust gas characteristics at a	205
	compression ratio of 17	385
15.11	Performance and emission characteristics at a	200
15 10	compression ratio of 21	388
15.12	Potential of natural gas turbocharged HCCI engines	389
15.13	Summary	391
15.14	References	392

Contents

16	HCCI engines with other fuels	393
	N IIDA, Keio University, Japan	
16.1	Characterization of DME	393
16.2	DME HCCI engine	394
16.3	DME chemical reaction model	394
16.4	Combustion completeness in the DME HCCI engine	396
16.5	Combustion control system for a small DME HCCI	
	engine	408
16.6	Method of combining DME and other fuels	421
16.7	Reducing pressure rise rate by introducing 'unmixed-ness'	
	of DME/air mixture	423
16.8	Summary	425
16.9	References	429
Part V	Advanced modeling and experimental techniques	
17	Auto-ignition and chemical kinetic mechanisms of	
	HCCI combustion	433
	C K WESTBROOK and W J PITZ, Lawrence Livermore National Laboratory, USA and H J CURRAN, National University of Ireland, Galway	
17.1	Introduction	433
17.2	Kinetics of auto-ignition	434
17.3	Reaction types	435
17.4	Temperature regimes of auto-ignition	437
17.5	Illustrations of auto-ignition in the rapid compression	
	machine	445
17.6	Kinetic models for HCCI ignition	451
17.7	Summary	453
17.8	References	453
18	Overview of modeling techniques and their	
	applications to HCCI/CAI engines	456
	S M ACEVES, D L FLOWERS, R W DIBBLE and A BABAJIMOPOULOS, Lawrence Livermore National Laboratory, USA	
18.1	Introduction	456
18.2	Fundamentals of HCCI ignition and combustion	457
18.3	The chemistry of HCCI	458
18.4	Prediction of ignition in HCCI engines	462
18.5	Detailed calculation of HCCI combustion and emissions	465
18.6	Prediction of operating range	468
18.7	Summary and future trends	470
18.8	References	471

	Contents	xi
19	Overview of advanced optical techniques and their applications to HCCI/CAI engines	475
	M RICHTER, Lund University, Sweden	
19.1	Introduction	475
19.2	Diagnostic approaches	476
19.3	Spectroscopic environment	481
19.4	Chemiluminescence imaging	482
19.5	Laser induced fluorescence	484
19.6	Thermographic phosphors	498
19.7	Future trends	500
19.8	References	502
Part VI	Euture directions for CAI/HCCL engines	

20 Outlook and future directions in HCCI/CAI engines 507 H ZHAO, Brunel University West London, UK

Index