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Simulating Combustion

Simulation of combustion and pollutant formation
for engine-development

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Simulation of combustion and pollutant formation
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with 242 figures

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Preface

The numerical simulation of combustion processes in internal combustion engines, including also the formation of pollutants, has become increasingly important in the recent years, and today the simulation of those processes has already become an indispensable tool when developing new combustion concepts. While pure thermodynamic models are well-established tools that are in use for the simulation of the transient behavior of complex systems for a long time, the phenomenological models have become more important in the recent years and have also been implemented in these simulation programs. In contrast to this, the three-dimensional simulation of in-cylinder combustion, i.e. the detailed, integrated and continuous simulation of the process chain injection, mixture formation, ignition, heat release due to combustion and formation of pollutants, has been significantly improved, but there is still a number of challenging problems to solve, regarding for example the exact description of sub-processes like the structure of turbulence during combustion as well as the appropriate choice of the numerical grid.

While chapter 2 includes a short introduction of functionality and operating modes of internal combustion engines, the basics of kinetic reactions are presented in chapter 3. In chapter 4 the physical and chemical processes taking place in the combustion chamber are described. Chapter 5 is about phenomenological multi-zone models, and in chapter 6 the formation of pollutants is described. In chapter 7 and chapter 8 simple thermodynamic models and more complex models for transient systems analyses are presented. Chapter 9 is about the three-dimensional simulation of combustion processes in engines.

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Table of contents

Abbreviations and symbols	XII
1 Introduction	1
1.1 Preface	1
1.2 Model-building	1
1.3 Simulation	2
2 Introduction into the functioning of internal combustion engines	5
2.1 Energy conversion	5
2.2 Reciprocating engines	6
2.2.1 The crankshaft drive	7
2.2.2 Gas and inertia forces	9
2.2.3 Procedure	11
2.3 Thermodynamics of the internal combustion engine	12
2.3.1 Foundations	12
2.3.2 Closed cycles	17
2.3.3 Open comparative processes	25
2.4 Characteristic qualities and characteristic values	28
2.5 Engine maps	31
2.5.1 Spark ignition engines	31
2.5.2 Diesel engines	33
2.6 Charging	35
2.6.1 Charging methods	35
2.6.2 Supercharging	37
2.6.3 Constant-pressure turbocharging	38
2.6.4 Pulse turbocharging	41
3 Foundations of reaction kinetics	44
3.1 Chemical equilibrium	44
3.2 Reaction kinetics	47
3.3 Partial equilibrium and quasi-steady-state	48
3.4 Fuels	50
3.4.1 Chemical structure	50
3.4.2 Physical and chemical properties	53
3.5 Oxidation of hydrocarbons	56

4 Engine combustion	60
4.1 Spark ignition engines	60
4.1.1 Mixture formation	60
4.1.2 Ignition	63
4.1.3 The combustion process	65
4.1.4 Abnormal combustion	69
4.1.5 Controlled autoignition	70
4.2 Diesel engines	72
4.2.1 Injection methods and systems	73
4.2.2 Mixture formation	80
4.2.3 Autoignition	81
4.2.4 Combustion	83
4.2.5 Homogeneous combustion	86
4.3 Pressure trace analysis	88
4.3.1 Determination of the heat release rate	88
4.3.2 Loss distribution	92
4.3.3 Comparison of various combustion processes	95
5 Phenomenological combustion models	98
5.1 Diesel engine combustion	98
5.1.1 Zero-dimensional heat release function	98
5.1.2 Stationary gas jet	99
5.1.3 Packet models	104
5.1.4 Time scale models	111
5.2 SI engine combustion	113
6 Pollutant formation	116
6.1 Exhaust gas composition	116
6.2 Carbon monoxide (CO)	117
6.3 Unburned hydrocarbons (HC)	118
6.3.1 Limited pollutant components	118
6.3.2 Non-limited pollutant components	122
6.4 Particulate matter emission in the diesel engine	127
6.4.1 Introduction	127
6.4.2 Polycyclic aromatic hydrocarbons (PAH)	128
6.4.3 Soot development	129
6.4.4 Particle emission modeling	131
6.5 Nitrogen oxides	132
6.5.1 Thermal NO	133
6.5.2 Prompt NO	138
6.5.3 NO formed via N ₂ O	140
6.5.4 Fuel nitrogen	140

7 Calculation of the real working process	141
7.1 Single-zone cylinder model	142
7.1.1 Fundamentals	142
7.1.2 Mechanical work	144
7.1.3 Determination of the mass flow through the valves / valve lift curves	144
7.1.4 Heat transfer in the cylinder	147
7.1.5 Heat transfer in the exhaust manifold	156
7.1.6 Wall temperature models	157
7.1.7 The heat release rate	160
7.1.8 Knocking combustion	174
7.1.9 Internal energy	178
7.2 The two-zone cylinder model	187
7.2.1 Modeling the high pressure range according to Hohlbaum	187
7.2.2 Modeling the high pressure phase according to Heider	190
7.2.3 Results of NO _x calculation with two-zone models	193
7.2.4 Modeling the charge changing for a two-stroke engine	195
7.3 Modeling the gas path	197
7.3.1 Modeling peripheral components	197
7.3.2 Model building	199
7.3.3 Integration methods	200
7.4 Gas dynamics	201
7.4.1 Basic equations of one-dimensional gas dynamics	201
7.4.2 Numerical solution methods	205
7.4.3 Boundary conditions	208
7.5 Charging	214
7.5.1 Flow compressor	214
7.5.2 The positive displacement charger	224
7.5.3 The flow turbine	225
7.5.4 Turbochargers	236
7.5.5 Charge air cooling	239
8 Total process analysis	245
8.1 General introduction	245
8.2 Thermal engine behavior	245
8.2.1 Basics	245
8.2.2 Modeling the pipeline system	246
8.2.3 The cooling cycle	248
8.2.4 The oil cycle	251
8.2.5 Physical properties of oil and coolant	256
8.3 Engine friction	257
8.3.1 Friction method for the warm engine	257
8.3.2 Friction method for the warm-up	258

8.4	Engine control	261
8.4.1	PID controller	261
8.4.2	Load control	261
8.4.3	Combustion control	262
8.4.4	Control of exhaust gas recirculation	262
8.4.5	Charger aggregate control	264
8.4.6	The driver controller	266
8.5	Representing the engine as a characteristic map	267
8.5.1	Procedure and boundary conditions	267
8.5.2	Reconstruction of the torque band	269
8.6	Stationary simulation results (parameter variations)	272
8.6.1	Load variation in the throttled SI engine	273
8.6.2	Influence of ignition and combustion duration	274
8.6.3	Variation of the compression ratio, load, and peak pressure in the large diesel engine	276
8.6.4	Investigations of fully variable valve trains	277
8.6.5	Variation of the intake pipe length and the valve control times (SI engine, full load)	279
8.6.6	Exhaust gas recirculation in the turbocharged diesel engine of a passenger car	279
8.6.7	Engine bypass in the large diesel engine	283
8.7	Transient simulation results	285
8.7.1	Power switching in the generator engine	285
8.7.2	Acceleration of a commercial vehicle from 0 to 80 km/h	287
8.7.3	Turbocharger intervention possibilities	289
8.7.4	Part load in the ECE test cycle	290
8.7.5	The warm-up phase in the ECE test cycle	292
8.7.6	Full load acceleration in the turbocharged SI engine	293
9	Fluid mechanical simulation	297
9.1	Three-dimensional flow fields	297
9.1.1	Basic fluid mechanical equations	297
9.1.2	Turbulence and turbulence models	303
9.1.3	Numerics	313
9.1.4	Computational meshes	320
9.1.5	Examples	321
9.2	Simulation of injection processes	326
9.2.1	Single-droplet processes	327
9.2.2	Spray statistics	331
9.2.3	Problems in the standard spray model	343
9.2.4	Solution approaches	347
9.3	Simulation of combustion	354
9.3.1	General procedure	354
9.3.2	Diesel combustion	357

9.3.3	The homogeneous SI engine (premixture combustion)	365
9.3.4	The SI engine with stratified charge (partially premixed flames)	380
Literature		382
Index		391

Abbreviations

50 mfb	50 % mass fraction burned
bb	blow-by
BDC	bottom dead center
BTDC	before top dead center
CA	crank angle
CAC	charge air cooler
CAI	controlled auto-ignition
cc	combustion chamber
CD	combustion duration
CCBDC	charge change bottom dead center
CCTDC	charge change top dead center
CFD	computational fluid dynamics
DI	direct injection
DISI	direct injection spark ignition
DS	delivery start
dv	dump valve
eb	engine block
EGR	exhaust gas recirculation
EV	exhaust valve
EVC	exhaust valve close
EVO	exhaust valve open
EIVC	early intake valve close
FEM	finite element method
HCCI	homogeneous charge compression ignition
hrr	heat release rate
ID	injection duration
IGD	ignition delay
IND	injection delay
ip	injection pump
IP	injection process
IT	ignition time
ITDC	ignition top dead center
IV	intake valve
IVC	intake valve close
IVO	intake valve open
LES	large-eddy-simulation
LIVC	late intake valve close
mcp	mass conversion point
mfb	mass fraction burned
nn	neuronal network
oc	oil cooler
OHC-equ.	oxygen-hydrogen-carbon-equilibrium
op	oil pan

PAH	polycyclic aromatic hydrocarbons
PDF	probability density function
rg	residual gas
SOC	start of combustion
SOI	start of injection
TC	turbocharging, turbocharger
TDC	top dead center
tv	throttle valve
VTG	variable turbine geometry

Symbols

A	surface [m ²] kinematics of the Boltzmann equation variable α parameter Zacharias
	temperature difference Heider [K]
A^*	temperature difference Heider [K]
A_{id}	ignition model parameter
A_{prem}	combustion model parameter
a	Vibe heat release rate constant sonic speed [m / s] thermal diffusivity [m ² / s] gradient „crooked coordinates“ parameter knocking criterion reference opening path thermostat
B	function Heider
B_0, B_1	breakup model constants
b	breadth [m] parameter knocking criterion
b_e	specific fuel consumption [g / kWh]
C	function Lax Wendroff constant heat transfer Woschni constant
C_1	Woschni constant
C_2	Woschni constant [m / (s K)]
C_3	Vogel constant constant of the particle path
C_4	constant of the particle path
C_A	contraction coefficient
C_{gl}	Heider constant
C_v	velocity coefficient
C_w	drag coefficient
CD	combustion duration [Grad]
Cou	Courant number

c	carbon component [kg / kg fuel] spring rate [N / m] progress variable velocity [m / s] constant length [m] parameter knocking criterion specific heat [J / (kg K)]
$c_{(i)}$	species mass fraction of the species no. i
c_i	stock concentration
c_f	constant friction method fan
c_m	medium piston velocity [m / s]
c_p	piston velocity [m / s] specific heat at constant pressure [J / (kg K)]
c_u / c_m	swirl number
c_x	mixture fraction variance transport equation model constants
$c_{\varepsilon_1}, c_{\varepsilon_2}, c_{\varepsilon_3}$	ε -equation model constants
c_μ	turbulence model constant
c_v	specific heat at constant volume [J / (kg K)]
D	diffusion constant diameter [m] parameter Zacharias cylinder diameter [m]
D_R	inverse relaxation time scale of a drop in turbulent flow [s ⁻¹]
$\frac{\partial}{\partial t}$	partial differential
d	wall thickness [m] diameter [m] damping factor [kg / s]
d_f	fan diameter [m]
d_m	medium turbine diameter [m]
E	energy [J]
\dot{E}	energy flow [J / s]
E_A	activation energy
E_{id}	ignition energy [K]
E_{kin}	kinetic spray energy [J]
EB	energy balance
EGR	exhaust gas recirculation [%]
e	eccentricity, crossing [m]
F	Lax Wendroff function flexibility of the engine [Nm s] force [N] function
F_g	gas force [N]
FA	parameter Zacharias

f	general function force density [N/m ³] distribution function
f_{rg}	mass fraction of the residual gas
f_{mep}	mean friction pressure [bar]
G	formal field variable, which zeros localize the flame front position free enthalpy [J] function Lax Wendroff Gibbs function [J]
g	specific free enthalpy [J / kg]
H	enthalpy [J] heating value [J / kg]
h	hydrogen component [kg / kg Kst] specific enthalpy [J / kg] stroke [m]
h_1	parameter polygon hyperbolic heat release rate
h_2	parameter polygon hyperbolic heat release rate
h_3	parameter polygon hyperbolic heat release rate
I	impulse [(kg m) / s] current [A]
I_K	knocking initiating critical pre reaction level
ID	injection duration [Grad]
ifa	fan ratio
$imep$	indicated mean effective pressure [N / m ²]
iz	number of line sections
L	angular momentum [N m s] length scale [m]
K	combustion chamber dependent constant (Franzke)
K_d	differential coefficient
K_i	integral coefficient
K_p	proportional coefficient equilibrium constant
K_b	bearing friction constant
K_η	constant [m ³]
K_ρ	factor gap thickness
k	constant turbulent kinetic energy [m ² / s ²] heat transfer coefficient [W / (m ² K)] index
k_c	container stiffness [N / m ⁵]
k_f	velocity coefficient for the forward reaction pipe friction coefficient [m / s ²]
k_r	velocity coefficient for the reverse reaction
kp	knocking probability
L	swirl length [m]