

Contents

Foreword	xi
Acknowledgments	xiii
Introduction	xv
Chapter 1 Engine Emissions	1
1.1 Characteristics of Engine Exhaust Gas	1
1.1.1 Major Components of Engine Exhaust Gas	1
1.1.2 Units Used for Exhaust Gas Components	1
1.1.3 Concentration Variations of Exhaust Gas Components	2
1.1.4 Exhaust Gas as Fluid (Physical Characteristics)	2
1.1.4.1 Density	3
1.1.4.2 Viscosity (Coefficient of Viscosity)	3
1.1.4.3 Specific Heat	4
1.1.4.4 Temperature	4
1.2 Major Air Pollutants in Engine Exhaust	5
1.2.1 Inorganic Compounds	5
1.2.2 Organic Compounds	6
1.2.2.1 Hydrocarbons	6
1.2.2.2 Alcohols and Carbonyls	6
1.2.3 Engine Exhaust Particulates	7
1.3 Greenhouse Gases in Exhaust Emissions	7
References	7
Appendix A.1 Calculations of Engine Exhaust Gas Composition	9
A.1.1 Combustion Reaction Formula	9
A.1.2 Calculations of Gas Component Concentration	11
A.1.3 Excess Air Ratio and Gas Component Concentration	12
Chapter 2 Gaseous Emissions Measurement	13
2.1 Overview	13
2.1.1 Direct Sampling Method	13
2.1.1.1 Gas Sampling with the Direct Sampling Method	14
2.1.1.2 Equations of Mass Emission	14
2.1.2 Dilution Sampling Method	15
2.2 Constant Volume Sampler	15
2.2.1 Overview of the Constant Volume Sampler	15
2.2.2 System Structure	16
2.2.2.1 Mixing Tee	16

2.2.2.2	Flow Controller	18
2.2.2.3	Gas Sampling Bags	20
2.2.3	Calculation of Mass Emission	21
2.2.4	System Setup and System Check	22
2.2.4.1	Setting the Dilution Flow Rate	22
2.2.4.2	Calibration of the Dilution Flow Rate	24
2.2.4.3	Total System Verification	26
2.3	Measurement of Ultra-Low-Emission Vehicles by the CVS Method	27
2.3.1	Compensation of Background (Dilution Air)	29
2.3.1.1	Active Carbon Filter	29
2.3.1.2	Dilution Air Refiner	29
2.3.1.3	Proportional Ambient Sampling Method	30
2.3.2	Optimization of Dilution Ratio	31
2.3.2.1	Variable-Flow CVS	31
2.3.2.2	Heated CVS	31
2.3.2.3	Dehumidification of the Dilution Air	32
2.3.3	Preventing HC Hang-Up	32
2.3.3.1	Selection of Materials	32
2.3.3.2	Separate Sample Lines for Low-Concentration Measurement	32
2.3.3.3	Extensive Purging	32
2.3.3.4	Blank Tests	33
2.4	Bag Mini Diluter	34
2.4.1	System Configuration and Features	34
2.4.2	Mass Emission Calculation	36
2.5	Exhaust Flow Rate Measurement	36
2.5.1	Summary of Exhaust Flow Measurement	36
2.5.2	Direct Measurement Method	36
2.5.2.1	Ultrasonic Flow Meter	36
2.5.2.2	Pitot Tube Flow Meter	39
2.5.3	Indirect Measurement Method	40
2.5.3.1	Intake Air Flow and Fuel Flow	40
2.5.3.2	Intake Air Flow and Air-to-Fuel Ratio	41
2.5.3.3	Tracer Method	41
	References	43

Chapter 3 Measurement of Particle Emissions and Black Smoke 45

3.1	PM Mass Filter Weighing (Balance) Method	47
3.1.1	PM Sampling from a Tunnel	47
3.1.1.1	Full-Flow Dilution Tunnel	47
3.1.1.2	Micro Dilution Tunnel	48
3.1.2	Filter Weighing	51

3.1.3	Separate Analysis of Soluble Organic Fraction	53
3.2	Other Methods for Exhaust Particle Mass Measurement	53
3.2.1	Filter Combustion Method for Measuring Low-Mass PM	53
3.2.2	Continuous Measurement of PM Mass Concentration	55
3.3	Particle Number Measurement	56
3.3.1	Continuous Measurement of Solid Particle Number	56
3.3.2	Particle Size Distribution Measurement	57
3.4	Measurement of Black Smoke	60
3.4.1	Opacity Meter	60
3.4.2	Light Reflection	61
	References	61
Chapter 4 Evaporative Emissions Measurement		63
4.1	Outline of Evaporative Emission Regulation	63
4.2	Evaporation Test of Parked Vehicles	64
4.2.1	Outline of the Test	64
4.2.1.1	Variable Pressure Absorption System	66
4.2.1.2	Calibration and HC Retention Test	66
4.2.2	Analyzer for Evaporative Emission Measurement	67
4.2.2.1	Analyzer	67
4.2.2.2	Calculation of Evaporation Rate	67
4.3	Running Loss Evaporation Test	67
4.3.1	Evaluation of the Entire Vehicle	68
4.3.1.1	SHED Configuration	68
4.3.1.2	Fuel Temperature Profile	69
4.3.2	Evaluation of Evaporative Emission by the Point-Source Method	70
4.4	Evaporative Test After Vehicle Driving	71
	References	71
Chapter 5 Principles of Exhaust Gas Analyzers		73
5.1	Analytical Principles for Regulated Emission Components of Interest	73
5.2	Non-Dispersive Infrared Detection	74
5.2.1	Principle	75
5.2.2	Infrared Detector	76
5.2.2.1	Pyroelectric-Type Infrared Detector	77
5.2.2.2	Pneumatic Cell-Type Detector	78
5.2.2.3	Detector Using Lead Selenide	79
5.2.3	Application to Exhaust Gas Analyzers	80
5.2.3.1	Interference Compensation by AS Method	80
5.2.3.2	Adjustment of Water Concentration in Calibration Gas	81
5.3	Flame Ionization Detection	82
5.3.1	Principle of Flame Ionization Detection	82

5.3.2	Application to Exhaust Gas Analyzer	83
5.3.2.1	Separate Measurement of Methane	83
5.3.2.2	Compensation of Oxygen Interference	84
5.4	Chemiluminescence Detection	85
5.4.1	Principle of Chemiluminescence Detection	86
5.4.2	Application to the Exhaust Gas Analyzer	87
5.4.2.1	Atmospheric Pressure-Type and Vacuum Pressure-Type NO _x Analyzers	87
5.4.2.2	Options of Sample Dehumidification	88
5.5	Paramagnetic Detection	89
5.6	Zirconia Solid Electrolyte Method	91
5.6.1	Zirconia-Type Air-to-Fuel Ratio Sensor	91
5.6.2	Zirconia-Type Nitrogen Oxide Sensor	92
5.7	Fourier Transform Infrared Spectroscopy	93
5.7.1	Principle of Fourier Transform Infrared Gas Analyzer	93
5.7.2	Analyzer Configuration and Target Gas Components	94
5.8	Mid-Infrared Laser Spectroscopy	96
5.9	Gas Chromatography	97
5.9.1	Principle of Gas Chromatography	97
5.9.2	System Components and Conditions	98
5.9.2.1	Column	98
5.9.2.2	Oven Temperature	99
5.9.2.3	Detector	99
5.9.2.4	Sample Injector	99
References		100
Chapter 6 Testing Equipment for Vehicle Emissions		101
6.1	General Configuration	101
6.2	Equipment for Simulating Actual Driving Conditions	103
6.3	Equipment for Gas Component Analysis	103
6.3.1	Constant Volume Sampling System	103
6.3.2	Exhaust Gas Analyzer	104
6.4	Particle Measurement Equipment	105
6.5	Driving Aid Equipment/Automatic Driving Equipment	105
6.5.1	Driver's Aid System	105
6.5.2	Robot Driver	105
6.6	Automation System	107
6.6.1	Laboratory Automation System	107
6.6.2	Full-Automatic Unmanned Testing System	108
Chapter 7 Practical Measurement of Engine Emissions		111
7.1	Emission Measurements for Powertrain Development	111
7.1.1	Air-to-Fuel Ratio and Excess Air Ratio	111

7.1.1.1	Calculating from Exhaust Gas Concentrations.	111
7.1.1.2	Real-Time Measurement Using Zirconia Sensor	114
7.1.2	Exhaust Gas Recirculation Ratio	115
7.1.2.1	Calculation from CO ₂ Concentrations	115
7.1.2.2	Transient Measurement of EGR Ratio	116
7.1.3	Fuel Consumption	117
7.1.3.1	Vehicles Using Combustion Engine for Power Source	117
7.1.3.2	Hybrid Vehicles	118
7.1.4	Engine Oil Consumption.	120
7.1.4.1	S-trace Method.	121
7.1.4.2	Calculation of Oil Consumption.	122
7.1.5	Catalytic Converter Evaluation	124
7.1.5.1	Three-Way Catalytic Converter Evaluation	124
7.1.5.2	Evaluation of Aftertreatment System for Nitrogen Compounds	125
7.1.5.3	Evaluation of Diesel Particulate Filter	128
7.1.5.4	Evaluation of Aftertreatment Catalyst Using Model Gas	128
7.1.6	Measurement of Oxygenated Hydrocarbons	129
7.1.6.1	Quantitative Estimation of Alcohols	129
7.1.6.2	Quantitative Estimation of Carbonyl Compounds	131
7.1.6.3	Measurement of Non-Methane Organic Gases	133
7.1.7	Measurement of Greenhouse Gases.	136
7.1.8	Modal Mass Analysis	137
7.1.9	Onboard Emission Measurements.	140
7.2	Emission Test for Type Approval.	146
7.2.1	Scope of Regulation and Test Procedures	146
7.2.2	Common Test Procedure	147
7.2.2.1	Test Cycles	148
7.2.2.2	Off-Cycle Emission Tests	149
7.3	Emission Test for Production Vehicles	151
7.3.1	Random Sampling Inspection on Production Line	151
7.3.2	In-Use Vehicle Measurement	151
	References.	152

Chapter 8 Emission Regulations Around the World and Worldwide Harmonization of Technical Regulations 157

8.1	Emission Regulations Around the World.	157
8.1.1	Japanese Emission Standards	157
8.1.1.1	History and Regulatory Process	157
8.1.1.2	Recent Trend	159
8.1.2	United States Emission Standards	160
8.1.2.1	History and Regulatory Process	160

Contents

8.1.2.2	Recent Trend	161
8.1.3	European Union Emission Standards	163
8.1.3.1	History and Regulatory Process	163
8.1.3.2	Recent Trend	164
8.1.4	Other Nations and Regions.....	164
8.2	Worldwide Harmonization of Technical Regulations and Mutual Recognition of Approval.....	165
8.2.1	1958 Agreement and ECE Regulation	166
8.2.2	1998 Agreement and gtr.....	166
	References.....	167
	Index.....	169