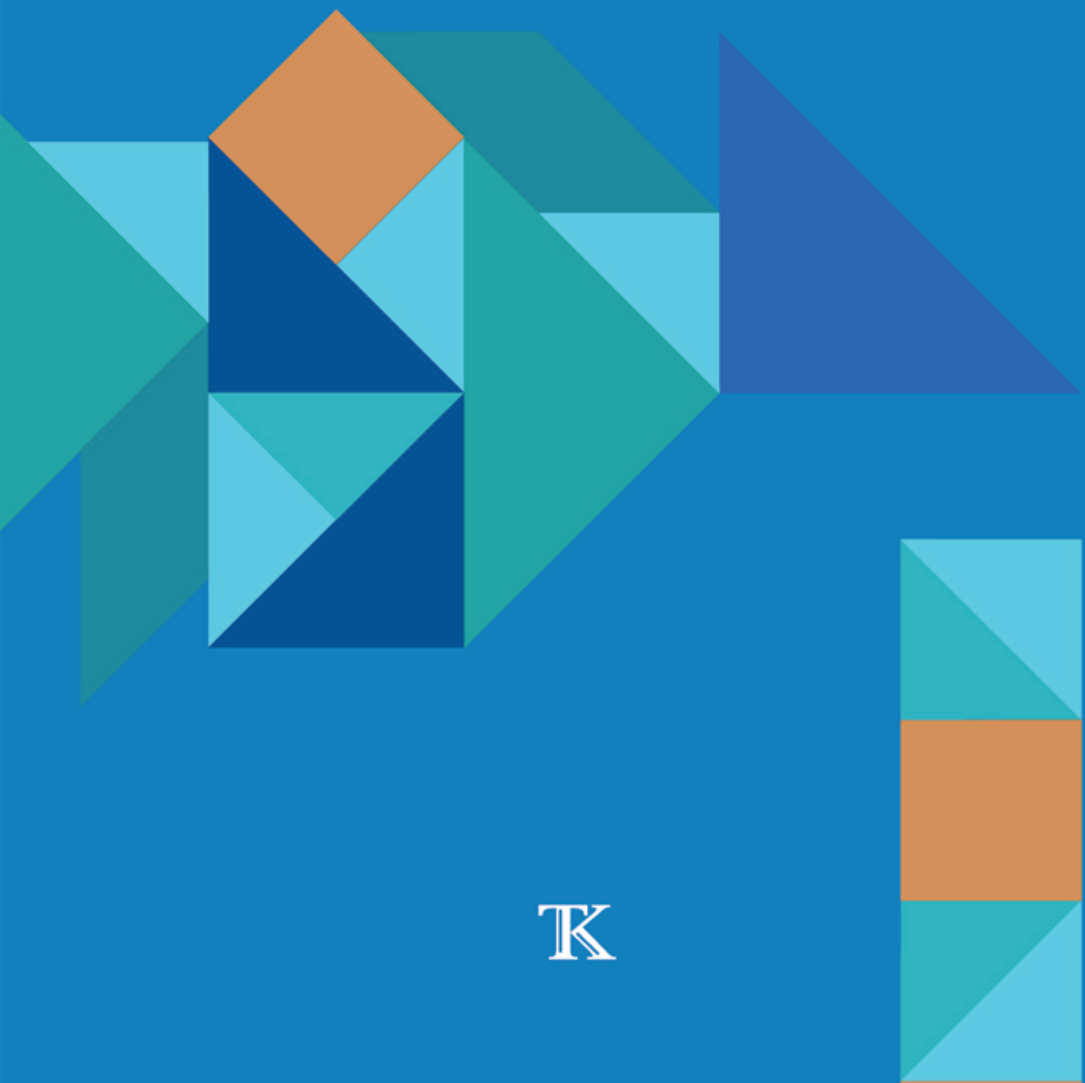
Margit Löschau

AIR POLLUTANT EMISSIONS AND THEIR CONTROL

– with the focus on waste incineration facilities –



To my parents

Margit Löschau

Air Pollutant Emissions and their Control

– with the focus on waste incineration facilities –

TK

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– with the focus on waste incineration facilities –

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Preface

After completing her doctoral studies at the Institute of Environmental Engineering of the Technical University of Berlin, Dr. Margit Löschau specialised in air pollutant emissions from thermal waste treatment processes and approaches to their control.

With this book, which is the culmination of her academic work and practical experience, she provides us with a comprehensive overview and an in-depth discussion of the problem areas associated with waste incinerator flue gases, focusing on the targeted analysis of the instruments available for tackling the air pollutants of concern.

Beginning with a detailed examination of the origin and effect of the most important atmospheric and climate-relevant pollutants, she lays the foundations for her analysis and the solution to the problems associated with flue gas treatment.

The book then presents the pertinent European and German legislation, technical guidelines and standards complete with a comparison of the emission limits applicable for air pollutants in industrialised countries.

One focus of this part of the work is the formation of pollutants and their reduction by primary measures directly in the combustion process.

The next chapter is dedicated to the chemical and physical principles of pollutant removal from gas streams. With the underlying theory thus laid out, the subsequent chapters deal with secondary measures for the control of particulate air pollutants, nitrogen oxides, organic pollutants and acid gases.

Acid gas control technologies and – to the necessary extent – waste water treatment technologies along with emission monitoring and analysis methods are dealt with exhaustively.

Liquid and solid residues from different flue gas treatment processes and their management are examined and evaluated in detail.

Based on the presentation of the underlying physical and chemical principles and pollutant-specific problem-solving approaches, the author develops and provides in-depth descriptions of overall flue gas treatment concepts.

Particular mention should also be made of the detailed references at the end of each chapter, which facilitate further investigations into individual problem areas.

This book is the first in-depth and largely complete treatise on the chief aspects of air pollution control for the protection of the atmosphere and the climate to be published in a long time.

This comprehensive work, presented by an author who has a strong academic and practical track record is a valuable resource for all those involved in air pollution control engineering, whether they are students or professionals in the field.

I therefore highly recommend this book to all students, faculty members and practitioners in the field of environmental engineering.

Neuruppin, November 2014

Professor Dr. Dr. Karl J. Thomé-Kozmiensky †



The author
Dr. Margit Löschau

Margit Löschau was born in 1978 in Berlin and studied Environmental Engineering at the Technical University of Berlin. After graduating, she worked there as a scientific assistant and in 2006 obtained her doctorate with honours at the Department of Waste Management under Prof. Dr.-Ing. Dr. h. c. Karl J. Thomé-Kozmiensky and Prof. Dr.-Ing. Vera Susanne Rotter. She then worked for eight years as a project manager and engineer for Pöyry Deutschland GmbH where she was involved in waste-to-energy projects worldwide. During that time she specialised in the field of air pollution control technology and also lectured at the Technical University of Berlin on the topic of "Air Pollution Control". Since 2014 she has been the managing director of Wandschneider + Gutjahr in Hamburg, an engineering and consulting services provider, specialising in thermal treatment facilities for solid waste, sewage sludge and biomass.

Contents

INTRODUCTION 1

1 ORIGINS AND EFFECTS OF AIR POLLUTANTS 3

1.1 Natural Composition of the Atmosphere 6
1.2 Dust 7
1.3 Carbon Monoxide 10
1.4 Organic Pollutants 10
1.4.1 Polychlorinated dibenzodioxins and furans 11
1.4.2 Polychlorinated biphenyls 13
1.4.3 Polycyclic aromatic hydrocarbons 14
1.5 Nitrogen Oxides 16
1.6 Hydrogen Halides 18
1.7 Sulphur Oxides 19
1.8 Heavy Metals 20
1.9 References 24

2 LEGAL FRAMEWORK 27

2.1 European Law 29
2.1.1 Industrial Emissions Directive 29
2.1.2 Reference Documents on Best Available Techniques 36
2.2 German Legislation 36
2.2.1 Federal Immission Control Act 36
2.2.1.1 Seventeenth Federal Immission Control Ordinance 37
2.2.1.2 Thirteenth Federal Immission Control Ordinance 43
2.2.1.3 Technical Instructions on Air Pollution Control 46
2.2.2 Greenhouse Gas Emissions Allowance Trading Act 46
2.2.3 Standards and Guidelines 48
2.2.3.1 VDI Guideline 3460 – Emission Control 48
2.2.3.2 Uniform Practice in Monitoring Emissions 49
2.2.3.3 DIN EN 15259 – Measurement of Stationary Source Emissions 49
2.3 Emission Limit values by Different Countries 51
2.4 References 51

3 POLLUTANT FORMATION IN THE COMBUSTION PROCESS AND PRIMARY CONTROL MEASURES 55

3.1 Dust 58
3.2 Carbon Monoxide and Organically Bound Carbon 60
3.3 Organic Pollutants 61
3.3.1 Polychlorinated dibenzodioxins and furans 62

3.3.2 Polycyclic aromatic hydrocarbons 64
3.4 Nitrogen Oxides 65
3.4.1 Formation mechanisms 65
3.4.1.1 Fuel NO_x 67
3.4.1.2 Thermal NO_x 70
3.4.1.3 Prompt NO_x 71
3.4.2 Primary measures for NO_x reduction 71
3.4.2.1 Air staging 72
3.4.2.2 Flue gas recirculation 73
3.4.2.3 Low-NO_x burners 74
3.5 Acid Gases 75
3.6 Heavy Metals 76
3.7 Typical Raw Gas Compositions 81
3.8 References 82

4 CHEMICAL AND PHYSICAL PRINCIPLES OF POLLUTANT REMOVAL FROM GAS STREAMS 87

4.1 Principles of Particulate Pollutant Removal 89
4.1.1 Centrifugal force 90
4.1.2 Electrostatic force of attraction 90
4.1.3 Filtration 91
4.1.4 Heterocoagulation 93
4.2 Principles of Gaseous Pollutant Removal 94
4.2.1 Homogeneous gas-phase reaction 94
4.2.2 Sorption 95
4.2.2.1 Adsorption 95
4.2.2.2 Absorption 99
4.2.3 Catalysis 102
4.3 References 104

5 SECONDARY MEASURES FOR THE CONTROL OF PARTICULATE AIR POLLUTANTS 107

5.1 Inertial Collectors 110
5.1.1 Gravity collectors 110
5.1.2 Centrifugal collectors 112
5.2 Electrostatic Precipitators 116
5.2.1 Dry electrostatic precipitators 116
5.2.2 Wet electrostatic precipitators 124
5.3 Filtering Separators 131

5.3.1 Fabric filters 132
5.3.1.1 Process principle 132
5.3.1.2 Filter types 132
5.3.1.3 Filter elements 136
5.3.1.4 Filter cleaning 140
5.3.1.5 Filter design parameters 141
5.3.2 Granular-bed filters 142
5.4 Wet Scrubbers 143
5.5 References 144

6 SECONDARY MEASURES FOR NITROGEN OXIDES CONTROL ... 147

6.1 Reagents 150
6.1.1 Ammonia water 150
6.1.2 Urea solution 153
6.2 Selective Non-Catalytic Reduction (SNCR) Process 153
6.2.1 Process principle 153
6.2.2 Injection technology 159
6.2.3 Ammonia-based versus urea-based SNCR systems 169
6.2.4 Optimisation measures 172
6.2.5 Ammonia deposition on fly ash 176
6.3 Selective Catalytic Reduction (SCR) Process 177
6.3.1 Process principle 177
6.3.2 SCR system configurations 178
6.3.2.1 High-dust SCR 179
6.3.2.2 Low-dust SCR 179
6.3.2.3 Tail-end SCR 180
6.3.3 Reagent injection 181
6.3.4 Catalyst system 182
6.3.5 Catalyst structure and geometries 184
6.3.6 Catalyst characteristics 187
6.3.6.1 Activity 187
6.3.6.2 Stability 191
6.3.6.3 Selectivity 194
6.3.7 Side reactions 194
6.3.7.1 Formation of sulphur trioxide and sulphuric acid 195
6.3.7.2 Formation of ammonium salts 195
6.3.7.3 Mercury oxidation 197
6.3.7.4 Oxidation of organic pollutants 198
6.4 Hybrid SNCR/SCR Process 199
6.5 References 200

7 SECONDARY MEASURES FOR THE CONTROL OF ORGANIC POLLUTANTS AND VAPOUR-PHASE HEAVY METALS 205

7.1 Adsorption Processes.....207
7.1.1 Physical adsorbents.....207
7.1.1.1 Carbon-based adsorbents.....208
7.1.1.1.1 Activated carbon.....208
7.1.1.1.2 Activated coke.....209
7.1.1.1.3 Safety aspects.....214
7.1.1.2 Mineral adsorbents.....217
7.1.1.2.1 Zeolites.....217
7.1.1.2.2 Bentonites.....218
7.1.1.3 Other adsorbents.....218
7.1.2 Fixed-bed and moving-bed processes.....220
7.1.3 Entrained-flow filter cake process.....226
7.2 Mercury Absorption Process.....229
7.3 Oxidation Catalyst for Polychlorinated Dibenzodioxins and Furans.....229
7.4 References.....230

8 SECONDARY MEASURES FOR ACID GAS CONTROL.....233

8.1 Sorbents.....237
8.1.1 Sodium-based sorbents.....237
8.1.1.1 Sodium hydrogen carbonate.....238
8.1.1.2 Caustic soda.....239
8.1.2 Calcium-based sorbents.....239
8.1.2.1 Limestone.....240
8.1.2.2 Quicklime.....241
8.1.2.3 Hydrated lime.....243
8.1.2.4 Enhanced hydrated lime sorbents.....243
8.1.3 Mixed sorbents.....245
8.2 Wet Processes.....246
8.2.1 Process principle.....246
8.2.2 Scrubber types.....248
8.2.2.1 Spray tower scrubbers.....251
8.2.2.2 Packed-bed scrubbers.....252
8.2.3 Flue gas conditioning.....253
8.2.4 Acidic scrubbing stage.....253
8.2.5 Neutral scrubbing stage.....255
8.2.5.1 Physical absorption of sulphur dioxide.....255
8.2.5.2 Sulphate formation.....256
8.2.5.3 Chemical absorption of sulphur dioxide.....257

8.2.5.3.1 Limestone scrubbing....257
8.2.5.3.2 Milk-of-lime scrubbing....260
8.2.5.3.3 Caustic soda scrubbing....261
8.2.5.3.4 Other neutral scrubbing processes....262
8.2.6 Co-removal of other pollutants in wet scrubbing systems....264
8.2.6.1 Removal of mercuric chloride....264
8.2.6.1.1 Absorption in the acidic scrubber....264
8.2.6.1.2 Oxidation of elemental mercury....265
8.2.6.1.3 Re-emission of elemental mercury....265
8.2.6.1.4 Adsorption on carbon-based adsorbents....265
8.2.6.2 Co-removal of sulphur trioxide....266
8.2.6.3 Co-removal of dioxins and furans....266
8.2.6.4 Co-removal of particulate pollutants and aerosols....266
8.2.6.5 Co-removal of ammonia....266
8.2.7 Flue gas reheating....267
8.2.8 Scrubber effluent handling....267
8.2.8.1 Scrubber effluent treatment....267
8.2.8.1.1 Precipitation system....268
8.2.8.1.2 Separation of precipitates from the liquid phase....270
8.2.8.2 Product recovery from liquid residues....271
8.2.8.2.1 HCl recovery....271
8.2.8.2.2 Gypsum recovery....272
8.2.8.3 Scrubber effluent evaporation....273
8.3 Semi-Dry Processes....274
8.3.1 Process principle....274
8.3.2 Flue gas conditioning....274
8.3.3 Sorption of acid gases....277
8.3.4 Reactor system....279
8.3.4.1 Spray dry absorption processes....280
8.3.4.1.1 Rotary atomiser spray dry absorbers....285
8.3.4.1.2 Dual-fluid nozzle spray dry absorbers....286
8.3.4.2 Conditioned-dry processes....287
8.3.4.2.1 Conditioning unit....288
8.3.4.2.2 Reactor types....293
8.4 Dry Processes....296
8.4.1 Process principle....296
8.4.2 Hydrated lime-based dry process....297
8.4.3 Sodium hydrogen carbonate-based dry process....298
8.4.4 Reactor types....304
8.5 In-Situ Desulphurisation....304
8.6 Hybrid Processes....308
8.7 CFD Simulation for Plant Optimisation....310
8.8 References....313

9 EMISSIONS AND EMISSION MONITORING 317

9.1 Periodic Emission Measurements 319
9.1.1 Requirements for emission measurements 320
9.1.1.1 Measurement section 321
9.1.1.2 Measurement site 322
9.1.1.3 Measurement objective 322
9.1.1.4 Sampling strategy 323
9.1.1.5 Measurement plan 323
9.1.1.6 Measurement report 323
9.1. Methods for manual periodic emission measurements 323
9.1.2.1 Sampling and analysis for particulates and particle-bound heavy metals 324
9.1.2.2 Sampling and analysis for polychlorinated dibenzodioxins and furans 325
9.1.2.3 Sampling and analysis for gaseous inorganic compounds 327
9.2 Continuous Emission Monitoring 327
9.2.1 Allowable measurement uncertainties 328
9.2.2 Quality assurance of continuous emission monitoring systems 329
9.2.2.1 Use of suitability-tested continuous emission monitoring systems (QAL 1) 330
9.2.2.2 Calibration and validation of continuous emission monitoring systems (QAL 2) 330
9.2.2.3 Ongoing quality assurance of the CEMS during operation (QAL 3) 333
9.2.3 Continuous emission monitoring methods 334
9.2.3.1 Classification of continuous emission monitoring systems 334
9.2.3.2 Measurement of particulate emissions 337
9.2.3.2.1 Optical transmission method 337
9.2.3.2.2 Scattered light method 338
9.2.3.3 Measurement of gaseous emissions 339
9.2.3.3.1 Multi-component measurement using Fourier Transform Infrared spectroscopy 339
9.2.3.3.2 Multi-component measurement by non-dispersive infrared spectroscopy 341
9.2.3.3.3 Total carbon measurement using flame ionisation detectors 342
9.2.3.3.4 Mercury measurement 342
9.2.3.4 Measurement of reference quantities 343
9.2.3.4.1 Flow measurement 343
9.2.3.4.2 Oxygen measurement 344
9.2.3.4.3 Moisture measurement 345
9.2.3.4.4 Temperature measurement 346
9.2.3.4.5 Pressure measurement 346
9.2.4 Evaluation of emission data 346
9.3 Emissions from Thermal Waste Treatment Facilities in Germany 348
9.4 References 351

10 MANAGEMENT OF SOLID FLUE GAS TREATMENT RESIDUES ... 353

10.1 Treatment Processes ... 356
10.1.1 Solidification processes ... 357
10.1.2 Washing processes ... 361
10.1.3 Sintering processes ... 362
10.1.3.1 Integrated sintering process ... 363
10.1.3.2 Downstream sintering processes ... 364
10.1.4 Vitrification processes ... 365
10.1.4.1 Oxidative melting processes ... 366
10.1.4.2 Reductive melting processes ... 367
10.1.5 Recovery processes ... 368
10.1.5.1 Metal recovery ... 368
10.1.5.2 Recovery of precursors for soda production ... 369
10.1.5.3 Phosphate recovery ... 370
10.2 Disposal ... 371
10.2.1 Utilisation as mine fill ... 371
10.2.2 Subsurface disposal ... 373
10.3 References ... 374

11 OVERALL FLUE GAS TREATMENT CONCEPTS ... 377

11.1 Selection Criteria ... 379
11.1.1 Removal efficiency ... 380
11.1.1.1 Wet/semi-dry/dry processes ... 380
11.1.1.2 Entrained-flow or fixed-bed/moving-bed adsorbers ... 382
11.1.1.3 SNCR/SCR process ... 382
11.1.2 Flue gas temperature ... 384
11.1.3 Site-specific factors ... 385
11.1.4 Economics ... 386
11.1.4.1 Wet/semi-dry/dry processes ... 386
11.1.4.2 NO_x control processes ... 394
11.2 Examples of Implemented Flue Gas Treatment Concepts ... 396
11.3 References ... 424

LIST OF ABBREVIATIONS ... 427

LIST OF FIGURES ... 435

LIST OF TABLES ... 457

ADVERTISER INDEX ... 465

KEY WORD INDEX ... 471

In the combustion of fossil and biogenic fuels, the organic substance is oxidised to produce carbon dioxide and water as the primary products of combustion. Depending on the fuel and the process conditions, combustion processes also generate air pollutants, such as carbon monoxide, polychlorinated dibenzo-p-dioxins and furans, nitrogen oxides, sulphur oxides, hydrogen halides and particulates, which are discharged from the combustion system with the flue gas stream.

Pollutant emissions to air from combustion processes are strictly regulated by the legislator to prevent adverse impacts on the environment and human health. For this reason, air pollution control measures are generally mandatory to ensure regulatory compliance. Using a feedstock with inherently high pollutant loads and operating under the watchful eyes of a suspicious public, thermal waste treatment facilities must meet exacting air pollution control standards. Strategies for reducing air pollutant emissions are based on primary and secondary measures.

Primary measures are all combustion-side measures that prevent the formation of pollutants in the first place. Typical primary measures include, for instance, upstream separation of pollutant-containing materials, adequate homogenisation of the fuel and, most importantly, optimum combustion control matched to the specific fuel and combustion technology. Optimised control of the combustion process ensures virtually complete combustion, thereby minimising the formation of carbon monoxide, total organic carbon and organic pollutants.

For most of the pollutants, primary measures alone will, however, not be sufficient to prevent their formation, as the pollutants either already exist in the fuel or are inevitably formed from the fuel constituents by chemical reactions during the combustion process. Secondary measures, i.e. a downstream flue gas treatment system, are therefore needed to remove the air pollutants forming during the combustion process. A flue gas treatment system typically comprises several unit processes arranged in series for the removal of particulate, vapour-phase and gaseous pollutants from the flue gas stream. Some unit processes remove only a single pollutant class, while others are designed for multi-pollutant removal.

Although the underlying physical and chemical principles and the basic concepts of pollutant removal apply to many fuels, the selection of an appropriate and cost-effective flue gas treatment concept and the optimum technology combination may vary with the fuel. Prime factors governing the choice of technology and the process operating parameters are the fuel pollutant load, the resulting flue gas composition, the expected peak emissions and variability of the raw gas pollutant levels as well as the maximum allowable clean gas pollutant concentrations. For the above reasons, flue gas treatment concepts for fossil-fired utility boilers are not directly applicable to thermal waste treatment facilities.

The intent of this student textbook and handbook for practitioners is to present the particularities of waste incinerator flue gas and its treatment, and to highlight the differences from flue gas treatment systems downstream of other thermal treatment processes.

The book deals with the origin and effect of combustion-specific air pollutants, their formation mechanisms in the combustion process, primary and secondary control measures and emission monitoring techniques, including the management of flue gas treatment residues. The benefits and drawbacks of the individual process technologies and their optimal combination under different scenarios are discussed.

In addition, the book features comprehensive analyses of the emission situation, reagent consumption, residue volumes generated and the cost structure of thermal waste treatment facilities as a function of the installed flue gas treatment technology along with information on current legislative, science and technology trends and their impact on flue gas treatment practice. It is rounded off by an evaluation of the status quo of waste incinerator flue gas treatment in Germany, implementation examples of the various equipment combination options as well as information on typical operating parameters from flue gas treatment practice.

Addressing students, decision makers, engineering contractors and plant operators alike, the book serves as a reference work for developing a conclusive overall treatment concept for a specific site and air pollution control task, whether for the construction of new or the optimisation of existing flue gas treatment systems.

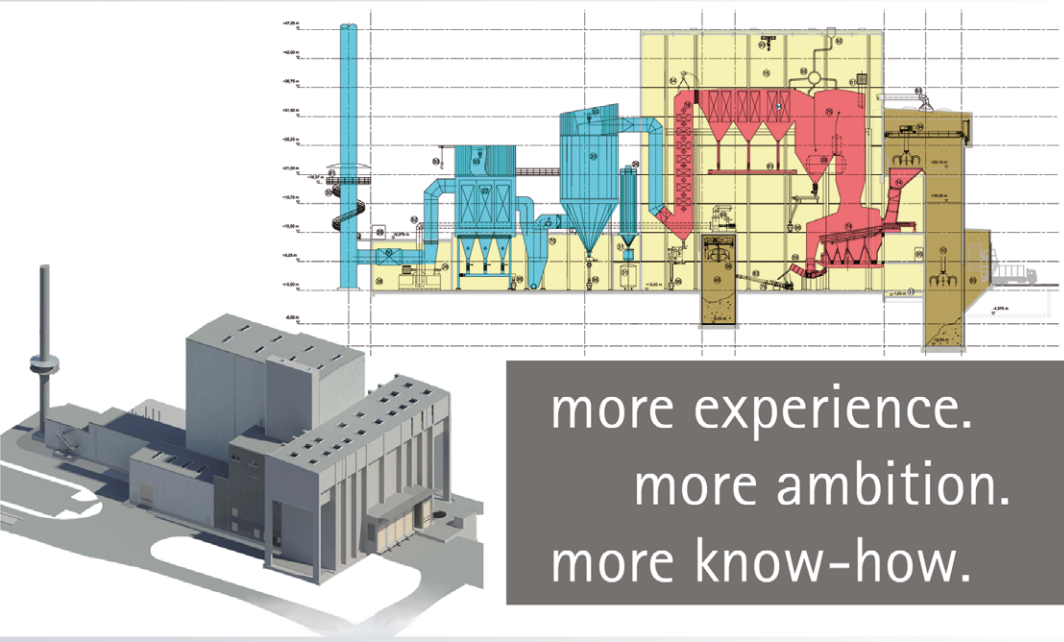
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Air pollutants are any substances foreign to ambient air that are likely to cause harmful environmental effects. According to the definition of the Federal Immission Control Act (Bundes-Immissionsschutzgesetz –BImSchG), the chief piece of legislation regulating ambient air quality in Germany, air pollutants are *changes in the natural composition of the air, especially through smoke, soot, dust, gases, aerosols, vapours or odorous substances.* Harmful effects on the environment as defined by the BImSchG are ambient air impacts w*hich, according to their nature, extent or duration, are liable to cause hazards, considerable disadvantages or considerable nuisance to the general public or the neighbourhood.*

Typical air pollutants include:

- particulate matter (dust)
- carbon monoxide (CO)
- nitrogen oxides (NO_x)
- sulphur oxides (SO_x)
- hydrogen halides (HCl, HF)
- organic pollutants (e.g. PCDD/Fs)
- heavy metals (e.g. Hg, Cd, As, etc.)

Air pollutants enter the atmosphere through both natural sources and anthropogenic sources. Natural sources of air pollutant emissions include forest fires, volcanic eruptions and soil erosion. Typical anthropogenic sources are combustion systems, industrial processes, households and transport.

Basically, a distinction is made between the emission and ambient air impact of pollutants. According to the BImSchG, emissions *are air pollutants, noise, vibrations, light, heat, radiation and similar phenomena originating from a facility.* Ambient air impacts (termed "immissions" in the German legislation), by contrast, are *air pollution, noise, vibration, light, heat, radiation and similar effects on the environment which affect human beings, animals and plants, the soil, the water, the atmosphere as well as cultural assets and other material goods.*

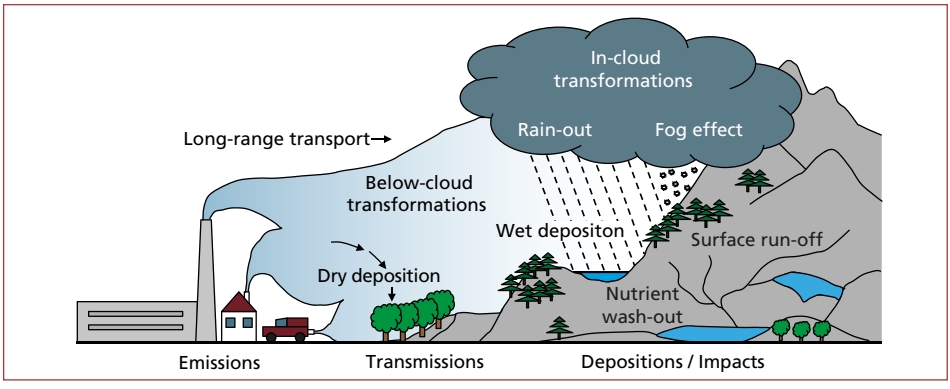


Figure 1: Relationship between emission, transmission and impacts of air pollutants

Source: Bhattacharyya, A. T.: Saurer Regen, Schwermetalle und die Aufnahme der Schadstoffe durch die Pflanzen. In: Spezielle Berichte der Kernforschungsanlage Jülich (Jül-Spez) No. 265, Jülich, 1984, adapted

Pollutants directly emitted to the air are referred to as primary pollutants. Frequently, primary pollutants chemically react with other substances in the atmosphere to form secondary air pollutants. The dispersion, transport and the chemical transformation of emitted substances in the atmosphere are subsumed under the term transmission. The impact of air pollutants on humans and the environment is due to their deposition – both wet and dry – on surfaces (Figure 1).

1.1 Natural Composition of the Atmosphere

The air quality provides information on the concentration of air pollutants relative to the natural composition of the Earth`s atmosphere. The natural composition of the atmosphere is presented in Table 1. The two main components of ambient air are nitrogen (N_2) at approx. 78 vol% and oxygen at approx. 21 vol%. Other constituents include argon (Ar), carbon dioxide (CO_2) and diverse trace gases.

Constituent	Formula	Volume fraction	Mass fraction
Main constituents		%	
Nitrogen	N_2	78.084	75.518
Oxygen	O_2	20.942	23.135
Argon	Ar	0.934	1.288
Carbon dioxide	CO_2	0.038	0.058
Subtotal		**99.998**	**99.999**
Trace gases		ppm	
Neon	Ne	18.18	12.67
Helium	He	5.24	0.72
Methane	CH_4	1.76	0.97
Krypton	Kr	1.14	3.30
		ppb	
Hydrogen	H_2	500	36
Nitrous oxide	N_2O	317	480
Carbon monoxide	CO	50 to 200	50 to 200
Xenon	Xe	87	400
		ppt	
Dichlorodifluoromethane (CFC-12)	CCl_2F_2	535	2,200
Trichlorofluoromethane (CFC-11)	CCl_3F	226	1,100
Chlorodifluoromethane (HCFC-22)	$CHClF_2$	160	480
Tetrachlorocarbon	CCl_4	96	510
Trichlorotrifluoroethane (CFC-113)	$C_2Cl_3F_3$	80	520
Methyl chloroform	CH_3-CCl_3	25	115
1,1-dichloro-1-fluoroethane (HCFC-141b)	CCl_2F-CH_3	17	70
1-chloro-1,1-difluoroethane (HCFC-142b)	$CClF_2$-CH_3	14	50
Sulphur hexafluoride	SF_6	5	25
Bromochlorodifluoromethane	$CBrClF_2$	4	25
Bromotrifluoromethane	$CBrF_3$	2.5	13

Table 1:

Natural composition of dry air at m.s.l.

1.2 Dust

Dust is the collective term for (solid) particles finely dispersed in gases. Frequently, the term dust is used synonymously with suspended dust. Suspended dust in turn is synonymous with total dust or total suspended particulates (TSP) and by definition includes solid and liquid suspended particles or mixtures of the two (aerosols). The dust emission limits mandated, for instance, by the 17th Immission Control Ordinance (17. Bundes-Immissionsschutzverordnung – 17. BImSchV), the German regulations governing the limitation of emissions from thermal waste treatment facilities, relate to total dust.

Based on its aerodynamic diameter, dust is typically classified into four categories according to the National Air Quality Standard for Particulate Matter (PM Standard) of the U.S. Environmental Protection Agency (EPA):

- coarse dust, Ø > 10 µm
- PM 10, Ø < 10 µm
- PM 2.5 (fine dust), Ø < 2.5 µm
- PM 0.1 (ultrafine particles), Ø < 0.1 µm

The aerodynamic diameter of a particle is equivalent to the diameter of a sphere with a density of 1 g/cm³ which has the same settling velocity as the particle of interest.

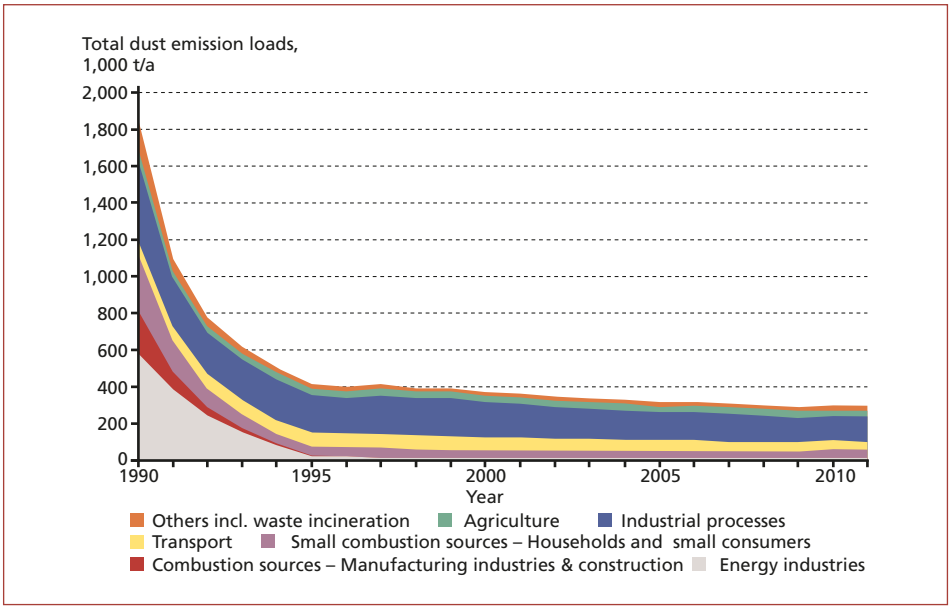


Figure 2: Total dust emissions by source sectors in Germany, 1990 to 2011

Source: Based on data published by Umweltbundesamt: National Trend Tables for the German Atmospheric Emission Reporting 1990–2011 (final version: 12 December 2012). Retrieved from http://www.umweltbundesamt.de/themen/luft/emissionen-von-luftschadstoffen

Figure 2 presents the total dust emissions by source sectors in Germany during the period of 1990 to 2011. In 2011, some 300,000 t of dust were emitted to the atmosphere, mainly by industrial processes, transport, and small combustion sources.

Of these emissions, the inhalable fraction (PM 10) of the total dust poses a particular health concern as it may lead to diseases of the respiratory system. PM 2.5, the so-called alveolar fraction, can even penetrate deep into the lungs, causing farmer`s lung disease and lung cancer. Moreover, other pollutants such as heavy metals and organic pollutants tend to sorb to the surfaces of fine particles in particular and are thus present in dust-bound form. In this way, they can enter the human organism through the inhalation of particles.

Table 2: Particle size distribution in the clean gas of the Geiselbullach/Olching MSWI (downstream of fabric filter)

Particle size	Concentration %
PM 2.5 (Class 1 as per TA Luft[1)])	91.1
PM 2.5 – 10 (Class 2 as per TA Luft)	4.4
> PM 10 (Class 3 as per TA Luft)	4.5
Total	**100.0**

1) Technische Anleitung Luft – German Instructions on Air Quality Control

Source: Samhammer, H.: Kurzbericht über die Ermittlung der Korngrößenverteilung im Reingas nach Gewebefilter an einer Linie des Abfallheizkraftwerks (AHKW) Geiselbullach/Olching. TÜV Industrieservice GmbH, München, 21 November 2006

Industrial combustion processes, being always equipped with a downstream dust control device, emit almost exclusively the more difficult-to-capture PM 10 fraction. Studies of the fly ash particle size distribution downstream of the fabric filter at a thermal waste treatment facility have even shown that more than 90 % of the residual dust still present in the clean gas accounts for PM 2.5 (Table 2).

Figure 3 displays the trend in PM 10 emissions in Germany by source sectors during the period of 1995 to 2011. Total PM 10 emissions in 2011 amounted to 208,000 t. Major emitters included industrial processes, agriculture, transport as well as small combustion sources. According to information from the German Federal Environmental Agency (Umweltbundesamt), PM 10 emissions from thermal waste treatment facilities amounted to 9.1 t, corresponding to only approx. 0.004 % of the total PM 10 emissions [22]. An evaluation of the total dust emissions from thermal waste treatment facilities and combustion plants burning refuse-derived fuels yielded a dust emission load of approx. 78 t/a (see Section 9.3) for the year 2013, corresponding to a share of 0.04 % in the total PM 10 emissions.

This contrasts with PM 10 emissions of 25,000 t/a from residential wood burning appliances (fireplaces, wood stoves), 2,870 t/a from fireworks and 1,350 t/a from barbecuing [2] [4] (Figure 4). Moreover, the consumption of 82 billion cigarettes per year in Germany (status 2012) generates additional PM 10 emissions on the order of 3,630 t/a. The side stream smoke of a cigarette alone contains some 44 mg of PM 10, while the main stream smoke contains another 15 to 40 mg which is, however, not emitted to the atmosphere, but filtered through the lungs of the smoker [3] [11]. To put this into perspective: even at total PM 10 emission levels in the vicinity of the emission limit value mandated by the 17. BImSchV (5 mg/m^3 (STP dry), the emission load generated by thermal waste treatment facilities would only amount to 650 t/a.

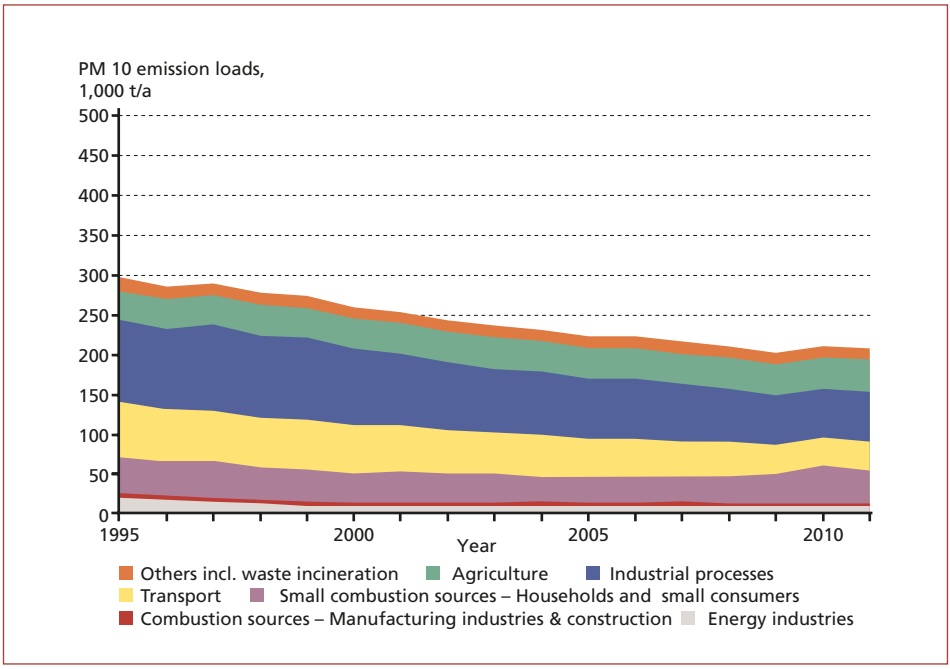


Figure 3: PM 10 emissions by source sectors in Germany, 1995 to 2011

Source: Based on data published by Umweltbundesamt: National Trend Tables for the German Atmospheric Emission Reporting 1990–2011 (final version: 12 December 2012). Retrieved from http://www.umweltbundesamt.de/themen/luft/emissionen-von-luftschadstoffen

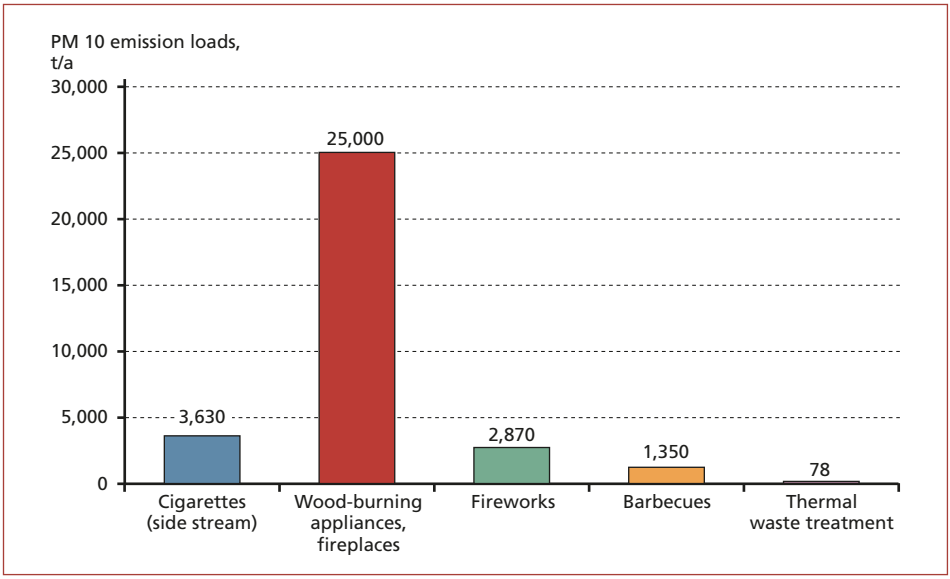


Figure 4: PM 10 emissions from cigarette consumption, fireplaces, fireworks and barbecuing in Germany as compared with thermal waste treatment facilities

Key Word Index



SprachenService Theobald

Translations by the subject matter expert

German – English English – German French – German

In the following fields of specialisation:

- **Ambient air quality and air pollution control**
  - Exhaust gas treatment
  - Emission / ambient air monitoring
  - Atmospheric dispersion modeling
- **Environmental Chemistry / Toxicology**
- **Waste water treatment**
- **Waste management**
  - Thermal waste treatment
  - Mechanical-biological waste treatment
  - Mechanical-physical stabilisation (RDF)
  - Sewage sludge incineration
  - Waste management legislation
- **Energy generation based on refuse-derived fuel, biomass, fossil fuels**
- **Material recovery, recycling technologies**
- **Hazardous waste stabilisation and solidification**
- **Cleanup of contaminated sites**

References:

Air pollution control

Translations on behalf of VDI-KRdL

VDI 3676 Inertial separators
VDI 3678–1 Electrostatic precipitators
VDI 3679–1 Wet separators for particle collection
VDI 3679–2 Waste gas cleaning by absorption (scrubbers)
VDI 3679–3 Wet separators - Mist eliminators
VDI 3927–1 Removal of sulphur oxides, nitrogen oxides and halides from combustion flue gases
VDI 3927–2 Reduction of inorganic and organic trace species in combustion flue gases
VDI 3928 Waste gas cleaning by chemisorption
VDI 3674 Waste gas cleaning by adsorption
VDI 3677 Filtering separators
VDI 2442 Thermal waste gas cleaning processes
VDI 3477 Biofilters
VDI 3460 Emission Control; Thermal Waste Treatment

Translations on behalf of Umweltbundesamt

17th Federal Immission Control Ordinance
BVT-Merkblatt Mineralöl- und Gasraffinerien
BVT-Merkblatt Zement- und Kalkindustrie
BVT-Merkblatt Chloralkalindustrie

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3R process 362
3 Ts of combustion 60

A

absorption **99**, 253, 255, 257, 264, 265
absorption coefficient 101
absorption isotherms 100, 102
accumulation filter 93, 132, 142
acid gases
  control 235
  formation 75
  measurement 339
  origins and effects 18
acid rain 17, 19
activated carbon 207, **208**, 210, 223, 226, 245, 265
activated coke 95, 140, 207, **209**, 214, 226, 245, 274, 296
activation energy 102
activator *see promotor*
active component 182, 184
activity coefficient 101, 102
activity curve 193
ADIOX process 266
adsorbents
  carbon-based 208
  costs 390
  mineral 217
  safety aspects 214
adsorption **95**, 103, 143, 184, 191, 237, 266, 269, 361
adsorption isotherms 97
adsorption processes 207
adsorption sites 97
agam. *see temperature measurement, acoustic*
air pollutants 5
air staging 72
air-to-cloth ratio 141, 142
allocation criteria 373
ambient air impacts 5
amine radicals 154
ammonia deposition 176
ammonia injection grid 181
ammonia removal 266
ammonia scrubbing 263
ammonia slip 157, 169, 172, 173, 190, 195, 199, 266
ammonia soda process 238
ammonia water **150**, 169
ammonium chloride 195
ammonium hydrogen sulphate 195
ammonium salts 177, 179, 187, 193, **195**
ammonium sulphate 176, 195
anatase 182
annual surveillance test 329, 332, 333
antimony 20, 77
arsenic 20, 77
Ash-Dec process 364, 371
atomic absorption spectroscopy 325, 339, 343
auto-ignition capability 215
automated measuring system *see continuous emission monitoring*
availability 257, 261, 333, 334, 386

B

back-corona 122
baghouse filters *see fabric filter*
BAM process 371
barrier effects 92
bentonites 218
Best Available Techniques 36
Best Available Techniques Reference Documents 36
BioCon process 371
Boudouard reaction 61
Brønsted acid sites 184

C

cadmium 20, 77
cake filtration 92
calcination 264, 305, 306
calibration 31, 49, 329, 330, 333, 346
calibration function 331
capital investment cost 221, 386, 389, 391, 393, 394
capital recovery cost 386
carbon monoxide
  formation 60
  measurement 339
  origins and effects 10, 11
  removal 229
catalysis 99, **102**, 182

catalyst
activity 187
characteristics 187
deactivation 191
poisons 192
regeneration 193
selectivity 194
side reactions 194
stability 191
structure 184
system 182
caustic soda **239**, 257, 261, 271
caustic soda scrubber 247, **261**
caustic soda solution 390
centrifugal collector 109
centrifugal force 89, 285
centrifugal separator **112**
CFD simulation 310, 313
chemisorption 95, 99, 102
chromium 20, 77
circulating fluidised-bed reactor 295
classification 346
cleanable filter 93, 132
clean gas SCR *see tail-end SCR*
CMR substances 11
coagulant aids 268
coagulants 268
cobalt 21
co-benefit removal 207
cold combustion 60
collecting electrode 116, 126
collection area 121, 122
collection efficiency
93, 109, 113, 118, 120, 142
combination process *see hybrid process*
combustibility index 214
composition of the atmosphere 6
compressed air atomisation 160
conditioned-dry processes 287
contact evaporator 181
continuous emission monitoring 327
control charts *see quality control charts*
cool-dry extractive system 337
cooled probe method 325
copper 21, 77
Coulomb's law 90
countercurrent adsorber 221
crosscurrent adsorber 221
cut size 113
cyclone *see centrifugal collector*
cylindrical filter 134

D

deactivation mechanisms 191
decarbonisation 305, 308
dehydration 305
denovo synthesis 63, 179
depth filtration 92, 137, 142
desorption 95, 96, 97, 98, 104, 223
Deutsch equation 120
diameter, aerodynamic
7, 96, 112, 115, 136, 137, 282
differential pressure sensing monitor 343
diffusion 96
dilution method 325
dioxins *see PCDDs*
discharge electrode 116, 125
dispersion 104
drift 333, 334
drift check 334, 341
drift velocity *see migration velocity*
dry processes **296**, 386
dry slaking 288, 293
dual-fluid nozzle 163, 286
dust
collection 109
formation 58
measurement 337
origins and effects 7
dust resistivity 121, 122, 124, 126

E

economics 386
electrostatic force of attraction 90
electrostatic precipitator 109, **116**
dry 116
wet 124
elemental sulphur 220
Eley-Rideal mechanism 103
emission data teletransmission systems
49, 330
emissions 5
carbon monoxide 10
continuous monitioring 327
dioxins and furans 12
heavy metals 22
hydrogen chloride 18
hydrogen fluoride 18
nitrogen oxides 17
periodic measurements 319
polyaromatic hydrocarbons 15
sulphur dioxide 19

thermal waste treatment 348
total dust 8
enhanced hydrated lime sorbents 243, 245
entrained-flow filter cake process 226, 280, 288
entrained-flow reactor 293
Eulerian-Lagrangian model 310
evaporation cooler 288
explosibility 214
extractive methods 337

F

fabric filter 93, 109, **132**, 140
characteristics 141
cleaning 140
filter elements 136
types 132
Federal Immission Control Act 36
Ferrox process 362
field ionisation *see impact ionisation*
filter bag 136
filter bag material 137
filter cake 136, 140, 270, 280, 288, 391
filter/condenser method 325
filter element 136
filter gap 93
filter head unit 324
filter medium 91
filtration **91**, 109, 131, 141, 143, 270, 361, 362
fine dust 143 *see PM 2.5*
fixed-bed-adsorber 220
fixed-bed process 220
flame ionisation detector 342
flow measurement 343
flue gas conditioning 253, 274, 288
flue gas recirculation 73
forced oxidation 258
Fourier-Transform-Infrared spectrospcopy 339
fractional separation efficiency 109, 121
fuel NO_x 67
full-cone spray pattern 165
functional test 49, 329, 330, 332, 333
furans *see PCDFs*
furnace sorbent injection *see in-situ desulphurisation*

G

gas-phase reaction 94
glow point temperature 214
granular-bed filter 93, 132, 142
gravity collector 109, **110**
Greenhouse Gas Emissions Allowance Trading Act 46
gypsum recovery 272

H

HCl recovery 271
heavy metals
chemical forms and partitioning 76
measurement 324, 342
origins and effects 20
removal 264
Henry-Dalton law 101
Henry's law 100
Henry's law constant *see absorption coefficient*
heterocoagulation **93**, 109, 125, 143, 144
high-dust SCR 179, 186, 197
high-temperature catalyst 187
hollow-cone spray pattern 165
honeycomb catalyst 186
honeycombs *see honeycomb catalyst*
horizontal-flow adsorber *see crosscurrent adsorber*
hot spots 226
hot-wet extractive system 337
humidification mixer 291
hybrid process **308**, 309, 313, 315, 379, 385, 396, 421, 422, 423
hybrid SNCR/SCR process 149, 172, 199, 200
hydrated lime 215, 228, **243**, 245, 257, 259, 260, 274, 278, 280, 291, 297, 304
hydraulic placement method 373
hydrogen evolution 360

I

impact ionisation 91, 116, 125
Industrial Emissions Directive 29
inertial collector **110**, 111, 113, 115
infrared detector 341
infrared radiation pyrometer 174
injection lances 181

injection technology 159, 181
in-situ CEMS 304, 336
in-situ desulphurisation 76, 235, 240, 243
interference 339, 340
interferogram 339
isocyanic acid 154, 171, 178
I-TEFs 12

L

landfill classes 373
Langmuir-Hinshelwood mechanism 103
lead 21, 77
lime slaker 288, 293
limestone **240**, 245, 257, 258, 390
limestone scrubbing 257
limiting oxygen concentration 214, 226, 228
loading capacity 97
long-term sampling system 49, 326
low-dust SCR 179
low-NO_x burners 74
low-temperature catalyst 187, 193

M

macro-pores 96
magnesium hydroxide scrubbing 264
manganese 77
measurement objective 322
measurement plan 323
measurement report 323
measurement section 321
measurement site 322
measurement uncertainty
323, 324, 329, 331, 346
mechanical placement method 372
melting processes *see vitrification processes*
membrane filter 137
memory effect 63, 266
mercury 79
measurement 342
origins and effects 21
oxidation 197
removal 264
meso-pores 96
Michelson interferometer 339
micro-pores 96
migration velocity 119, 120, 121, 122
milk-of-lime scrubbing 260
mine fill 371
minimum ignition energy 214
mist eliminator 255
mixed sorbents 220, 245, 390
mixing rule 31
moisture measurement 345
moving-bed adsorber 220, 226, 382, 393
moving-bed process 142
multi-component measurement 339, 341
multi-cyclone *see centrifugal collector*
multi-recycling process 362
multi-venturi stage 262, 266

N

needle felt 132, 137
nickel 22
nitrogen oxides
formation 65
measurement 339
origins and effects 16, 17
removal 145
nitrous oxide 171
NO recycle process 69

O

operating costs
310, 386, 390, 393, 394, 395
optical transmission method 337
organic pollutants
formation 62
origins and effects 10, 11, 13, 15
removal 149
sampling and analysis 325
oval filter bag 137
oxidants 247
oxidation catalyst 61, 198, 229, 230
oxyanions 77
oxygen measurement 344

P

p/T diagram 306
packed-bed scrubber
249, 251, 252, 253, 262
paramagnetic analyser 344

particles *see dust*
path temperature 173
PBT substances 11
PCDD/Fs
  formation 62
  origin and effects 11
  removal 266
  sampling and analysis 325
periodic emission measurement 319
physisorption 95, 99, 100
pitch 189, 190
plane filter head unit 324
plate-and-frame filter press 270
plate catalyst 179, 186
PM 2.5 7
PM 10 **7**, 8
polychlorinated biphenyls 13
polychlorinated dibenzo-p-dioxins
  see PCDDs
polychlorinated dibenzo-p-furans
  see PCDFs
polycyclic aromatic hydrocarbons 14, **64**
pore-radii distribution
  104, 210, 213, 217, 223, 305
pozzolanicity 357
Prandtl tube 343
precipitant 247, 265, 269
precision 333, 334
precoating 136, 139
pressure measurement 346
promoter 184
pulse-jet cleaning method 140
pumice 219

Q

quality assurance levels 329
quality control charts 333
quasi-dry (scrubbing) processes
  see semi-dry processes
quench 253
quicklime **241**, 243, 245, 280, 305, 309

R

Raoult's law 101
raw gas composition 81
recirculation 279
recovery processes 368
  metals 368
  phosphate 370
  precursors for soda production 369
rectification *see HCl recovery*
re-entrainment 118
regeneration pressure drop 141
removal efficiency 89, 158, 169, 172, 187,
  190, 199, 266, 275, 297, 302, 381
Resolest process 369
rotary atomiser 285
rotary hearth furnace coke
  see activated coke
rotatable injectors 159
RüPA process 371
rutilisation 184, 191

S

sampling strategy 323
saturator *see quench*
scattered light method 338
SCR process **177**, 382, 394
scrubber effluent evaporation 273
scrubber effluent treatment 267
scrubber types 248
seawater scrubbing 263
selective catalytic reduction *see SCR*
selective non-catalytic reduction *see SNCR*
semi-dry processes **274**, 386
SEPHOS process 371
series-connected filter 134
Seventeenth Federal Immission Control
  Ordinance 37
sieve effect 92
single-fluid atomisation 160
single-fluid nozzles 163
sinter filter 91
sintering processes 362
site-specific factors 385
smog 17
SNCR process **153**, 382, 394
  autogenous 69
sodium bicarbonate
  see sodium hydrogen carbonate
sodium hydrogen carbonate
  238, 245, 298, 369, 390
  suspension 239
  thermal activation 239, 301

sodium sulphides 219
sodium sulphite scrubbing 263
solidification processes 357
sorbents
  calcium-based 239
  costs 389
  sodium-based 237
sorption 95
space velocity 187
spray 159, 166
spray dry absorption processes 280, 309
spray dryer 247, 273
spray pattern 165
spray tower scrubber
  143, 249, 251, 259, 261
stabilisation processes 362
standard reference method 323, 331, 337
stoichiometric ratio
  158, 171, 277, 280, 297, 298, 392
sub-micropores 96
subsurface dispsoal 373
suevite 219
suitability test 49, 330, 333
sulphation 305
sulphuric acid dew point 122
supersaturation 272
support system 182
surface filtration 92, 137
suspended dust *see total dust*

T

tail-end SCR 179, 180, 186
Technical Instructions on Air Pollution Control
  46
temperature measurement 346
  acoustic 173
thermal NO_x 70
thermolysis 154, 171, 178
Thirteenth Federal Air Immission Control
  Ordinance 43
tin 22
titanium dioxide 182
total dust 7
toxic equivalency factor 11, 14
toxic equivalent 11
transfer coefficients 79, 80, 81
transmission 6, 337
trass *see suevite*
tubular electrostatic precipitator 119
tungsten trioxide 184
turnover number 187

U

ultrasonic flow sensor 343
urea solution **153**, 169

V

validation 324, 329, 330, 331, 346
vanadium 77
vanadium pentoxide 182
van-der-Waals forces 95, 99
vapour pressure 76, 79, 101, 102
variability 332
variability test 332
venturi scrubber 94, 109, 143, 144, 249, 266
Very-Low-NO_x process 72
vitrification processes 365
volatility 57, 76, 77

W

Walther process *see ammonia scrubbing*
washing processes 361
Wellman-Lord process
  see sodium sulphite scrubbing
wet processes **246**, 386
wet scrubber 109, 143
WHO-TEF 12
wire-plate electrostatic precipitator 119
wire retaining cage 138

Z

Zeemann effect 343
zeolites 217, 390
zinc 22, 77
zirconia analyser 344