Stefan Fränzle, Bernd Markert,
Simone Wünschmann

WILEY-VCH

Introduction to Environmental Engineering

Stefan Fränzle, Bernd Markert, and Simone Wünschmann

Introduction to Environmental Engineering

WILEY-VCH

WILEY-VCH Verlag GmbH & Co. KGaA

The Authors

Dr. Stefan Fränzle
IHI Zittau
Markt 23
02763 Zittau
Germany

Prof. Dr. Bernd Markert
Fliederweg 17
49733 Haren
Germany

Dr. Simone Wünschmann
Fliederweg 17
49733 Haren
Germany

Library of Congress Card No.: applied for

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at <http://dnb.d-nb.de>.

Cover Design Grafik-Design Schulz, Fußgönheim
Typesetting Toppan Best-set Premedia Limited, Hong Kong
Printing and Binding Markono Print Media Pte Ltd, Singapore
Printed in Singapore
Printed on acid-free paper

Print ISBN: 978-3-527-32981-6

Related Titles

Katoh, S., Yoshida, F.

Biochemical Engineering

A Textbook for Engineers, Chemists and Biologists

2009
Softcover
ISBN: 978-3-527-32536-8

Mihelcic, J. R., Zimmerman, J. B.

Environmental Engineering

Fundamentals, Sustainability, Design

2009
Hardcover
ISBN: 978-0-470-16505-8

Nemerow, N. L., Agardy, F. J., Salvato, J. A.

Environmental Engineering

Water, Wastewater, Soil and Groundwater Treatment and Remediation

2009
Hardcover
ISBN: 978-0-470-08303-1

Porteous, A.

Dictionary of Environmental Science and Technology

2008
Softcover
ISBN: 978-0-470-06195-4

The Authors

Stefan Fränzle

Born 1961 in Bonn, Germany; Dr. rer. nat. habil., natural scientist. Studies in inorganic and photochemistry and astronomy at the Christian-Albrechts-University of Kiel, Germany. Ph.D. in 1992 and habilitation for environmental sciences (chemical focus) in 2008 at the University of Vechta (Germany). Scientific assistant at the International Graduate School Zittau, Germany. Publications: author/co-author of about 75 scientific papers and 8 scientific books. Research interests: working with the "Biological System of Elements" (BSE), reconstruction of the conditions of chemical and biological evolution, the implication of interelement abundance correlations for biomonitoring, the theory of the dynamics of the cell cycle (cancer and chemotherapy), wastewater treatment with visible light.

***Contact:** fraenzle@ihi-zittau.de*

Bernd Markert

Born 1958 in Meppen, Germany; Univ.-Prof. Dr. rer. nat. habil., natural scientist. Studies in chemistry and biology at the Ludwig Maximilian University of Munich, Germany. Ph.D. in 1986 and habilitation for ecology in 1993 at the University of Osnabrueck (Germany). Former Director of the International Graduate School Zittau and Univ.-Prof. for Environmental High Technology. Currently structuring an "Environmental Institute of Scientific Networks" in Haren, Germany. Publications: author/co-author or editor/co-editor of about 400 scientific papers and 19 scientific books. Research interests: the biogeochemistry of trace substances in the water/soil/plant/animal/human system, instrumental analysis of chemical elements, developing the "Biological System of Elements" (BSE), eco- and human toxicological aspects of hazardous substances, pollution control by the use of bioindicators and biomonitors, development of technologies for waste management, environmental restoration and remedial action on soils, different interdisciplinary work in the fields of economic and social sciences.

***Contact:** markert@schlundmail.de*

Simone Wünschmann

Born 1967 in Heidelberg, Germany; Dr. rer. nat, natural scientist. Former scientific assistant at the International Graduate School Zittau, Germany, Department of Environmental High Technology, Working Group for Human- and Ecotoxicology. Diploma Engineer for Ecology and Environmental Protection at the University of Applied Sciences Zittau/Görlitz, Germany, Ph.D. in Environmental Sciences at the University of Vechta, Germany. Publications: author/co-author of about 40 scientific papers and 3 scientific books. Participant at more than 50 international conferences. Research interests: pollution control, human and ecotoxicology, ecology and environmental protection, environmental engineering with an emphasis on renewable energy.

***Contact:** wuenschmann@schlundmail.de*

Preface

To our students, teachers, readers and
whoever makes use of environmental technologies,

our textbook "Introduction to Environmental Engineering–Innovative Means to Clean and Protect the Environmental Compartments" is dedicated to an interdisciplinary approach toward the technical diagnosis, relief and avoidance of anthropogenic burdens on the environment by both inorganic and organic compounds as well as factors like waste heat, the diagnosis and so on being based on pieces of knowledge and methods from the natural sciences. This approach is going to be taught herein.

First of all, before even trying to remove or reduce environmental impacts by engineer's means, there must be *environmental diagnostics* to estimate the kind, extent and reasons for the damage apparently done to the environment. This is achieved by appropriate measurement methods which often include, besides the chemical analysis of pollutants and interpretation of their possible ecological and health impacts, the development of novel methods in analytical chemistry and in effect research concerning eco- and human toxicology. This latter will give more information on the actual impacts of single substances on man and ecosystems.

Only thereafter should one switch to trying to design and implement measures in environmental reclamation ("*therapy*") directly to relieve or reduce the environmental burdens or their very reasons by certain technical means or devices. During this, analytical chemistry must constantly survey the performance of these techniques.

A really big challenge–because it requires somewhat predicting the future–is *prophylactic* work against forthcoming environmental damage. Here, environmentally benign methods of production are chosen to anticipate and avoid actual environmental damages. For this aim, one must estimate the possible results and by-effects of different alternative or competing technologies to both the environment and to translate political ends–better sustainability, avoidance of public hazards, omitting some techniques or chemicals–into practical technical know-how and application in advance.

Obviously, some of these topics are quite complex to grasp. Hence we opt rather to "narrate" things, developments and options touching issues of *environmental* *diagnosis, therapy and prophylaxis* in their respective historical context, to make you understand why people selected one technology (e.g., for vehicle propulsion) rather than another, thereby accepting environmental risks. Notwithstanding this, interested readers are fully supplied with definitions of terms and causes, formulas and tasks of comprehensive environmental technologies as they are in the third millennium so much shaped by information and communication technologies. But this is not a technocratic perspective: we also address ethical issues and juridical, political implications on national and global scales when musing what could be done to achieve a more sustainable, "greener," yet responsible and libertarian way of life. Educating people with either facet of this issue (which we express; as a "dialogic education process" [DEP]) makes them familiar with the next chapter in this volume:

Starting with comparisons from general systems sciences as well as comparative planetology, features of the three environmental compartments atmosphere, water (distinguishing fresh-, sea- and groundwaters) and soil/sediment (regolith, respectively) are analyzed in terms of a chemical reactor concept (what happens, why, where?), pointing out chances and limitations put thereby on environmental sanitation. The specific chemical and biophysical properties of single environmental compartments thus logically define the levers to be used by innovative cleaning and protection methods devised and corroborated by engineering and natural sciences. Innovation criteria to be obeyed in this process include sustainability, compliance to existing and developing national and global legislation, and likewise cost-benefit calculations to come about with solutions which may later be accepted by societies as they are. But now for the more chemical part of the story: in order to understand what will or at least might happen, quite a number of basic chemical concepts must be discussed, including their messages for the Earth's environment, such as redox potentials and their representation in Pourbaix diagrams, reaction kinetics (including Hammett and Taft equations) and the very concept of chemical equilibrium and dynamical (pseudo-)equilibrium. Early in this volume we learn about the *biological system of elements* which can provide tools for numerous unsolved problems in environmental engineering, besides understanding what happens in biology and bioinorganic chemistry.

The book is completed by case studies on process engineering dealing with certain environmental compartments, kinds of pollutants, which were admittedly selected partly due to the personal research foci of the authors:

Concerning the *atmosphere*, bioindication and biomonitoring are considered most innovative methods which will still gain importance in global-scale environmental surveillance. Of course, any discussion of problems now hitting the atmosphere as an environmental compartment would be far from complete if it neglects the issue of radiative forcing, global warming and in turn the possible methods to withhold the greenhouse gas CO_2 from the atmosphere during and after combustion processes.

A way of cleaning concerning all *soil*, aquatic sediments, air and water is phytoremediation, which received more scientific and technical attention during the past years, as did bioindication and biomonitoring. There are agents which can secondarily mobilize toxic metals and other chemical species from the sediment owing to their own chemical properties, like complexation agents (ligands), among which the rather bioinert ethylene diamine tetraacetic acid and the chances to yet cleave it merit particular consideration.

Reactive barriers are a most promising method for cleaning ground-water bodies, hence their discussion in a separate case study. Another issue of growing importance and concern to fresh*water* supply and quality are residues of various pharmaceuticals. Both their environmental impact and the chances to remove them are discussed with the example of diclofenac (Voltaren™).

When (i) fossil fuels raise the problem of greenhouse gas emissions and (ii) nuclear energy poses accident hazards, in the afterwake of Chernobyl, Fukushima and less spectacular accidents, we become aware that an energy supply by other means becomes a key topic for our common future. *Renewable energies* like wind, water, solar energy and so on offer chances for increased use which are all technically feasible, affordable and sound in terms of natural sciences and engineering. To give an example, the Emsland region in northwest Germany, next to the North Sea and the Dutch border, and its features for renewable energies are discussed in one concluding case study.

This preface started with a request for global sustainability to be organized in a responsible way concerning environmental techniques and a "just" distribution of material goods and food among all mankind. While this just distribution and allocation by international trade will benefit from modern IT technologies, including the Internet, it also urges us to consider the human rights of all the others involved. Genuine citizens (citoyens) of the "global village" ought to represent mankind all the time in a manner of high responsibility, quality of behavior and statements and respect for global requirements. Theodor Heuss (1884–1963), first Federal President of the newly founded Federal Republic of Germany, maintained that "*quality means decency*".

Dear readers, we are most aware of the large task we undertook by tackling the given topic of environmental engineering, even if it is just an introduction to this vast field. Possibly you are dissatisfied with the results somehow, be it for complexity of the issues, the way we choose to present them or for other reasons. In addition, there were some limitations given by the publishers concerning the size and presentation of this volume. Nevertheless we would like to emphasize that it was only due to the (almost) unlimited support given by Wiley/VCH and many internationally renowned colleagues – in both the practical and emotional sense of this term – over years that this book could be written in this form within a reasonable time. We would specifically mention Dr. Frank Weinreich and Mrs. Stefanie Volk, both with Wiley and Mrs. J. Klinkmann for the picture of the turtles. Many thanks to ALL who were and got involved in whatever way!

As we often address issues of scientific quality, we do sincerely hope to fulfill these standards ourselves, writing and illustrating our texts in a way to give best information to be grasped reasonably. The somewhat lengthy glossary and literature references contribute to this end and give hints for further reading. We would be grateful if reminded of both mistakes and didactic shortcomings possibly still existing in this volume to overcome them in a next edition which hopefully will appear soon.

Thus, finally, we hope you enjoy reading this introductory textbook and get some information and the stimulus and encouragement for practically applying one or another of these possibilities we outline. We would be pleased to see this volume serve its (fairly ambitious) purpose in the study–and workplaces of some of you.

Zittau and Haren/Erika, Autumn 2011

Stefan Fränzle
Bernd Markert
Simone Wünschmann

Contents

1
Definition, History, Discipline

1.1
Definition of Environmental Engineering

Environmental sciences strive to analyze and understand – by chemical and other methods – the influence of radiation (electromagnetic of various wavelengths, etc.), chemical compounds and yet other organisms on living matter and on those parts of Earth (crust, soil, upper lithosphere, hydrosphere, atmosphere) in which life occurs in an active form. In contrast, environmental engineering is meant to alter or exploit (environmental biotechnology, biological parts of sewage treatment system, etc.) these interactions to the benefit of humans and/or the environment. We shall see what this means. By biological activities, the above regions are profoundly changed; just consider chemical and climate effects of biogenic atmosphere components like O_2, CH_4, or the construction of vast coral reefs by organisms. *Environmental chemistry* deals with the "more chemical" features of this interaction and of processes which take part in the environment. It is the study of the sources, reactions, transport, effects and fates of chemical species in the air, soil and water environments, and the effect of human activity on these. *Environmental technology* is more the application of the environmental science and green chemistry to conserve the natural environment and resources, and to curb the negative impacts of human involvement. Sustainable development is the core of environmental technologies. This brings about the following definition of *environmental engineering*:

Environmental engineering is the technology concerned with the reduction of pollution, contamination and deterioration of the surroundings in which humans live, including environment and management of natural resources. This integrated management – beyond purification (waste or flue gas treatments) – includes reuse, recycling and recovery measures.

Accordingly, environmental engineering occurs at the interface of technical and environmental systems, and it requires a certain size of mass turnovers, even though the single devices may be fairly small if distributed among a multitude of individual pollution sources, like with catalytic exhaust gas converters.

Understanding chemical processes in the environment of course takes a sound knowledge of the array of compounds, ions and elements which are there, and of their distribution among the environmental compartments, which in turn controls

Introduction to Environmental Engineering, First Edition. Stefan Fränzle, Bernd Markert, Simone Wünschmann.

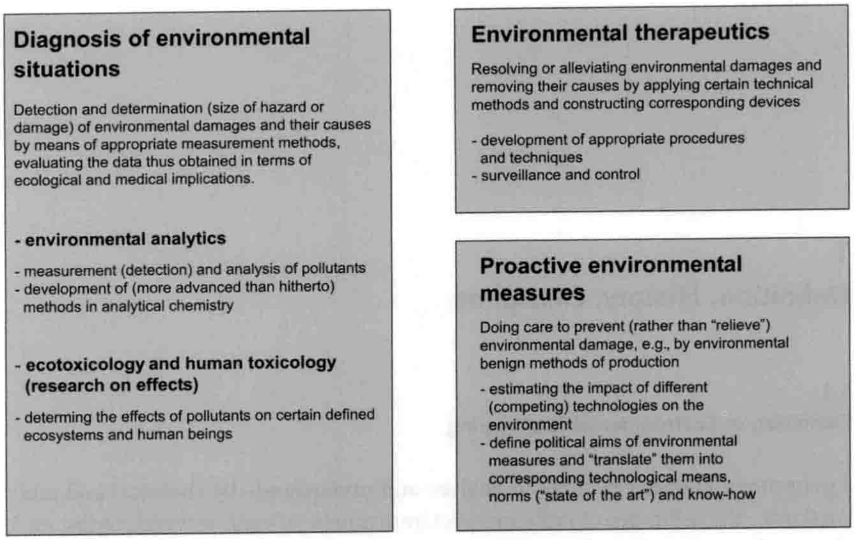

Figure 1.1 Diagnosis of envionmental situations, environmental therapeutics and proactive environmental measures.

their exposure to secondary influences (e.g., UV irradiation, activation by chemisorption to, e.g., clay minerals). To obtain the corresponding information, lots of analytical data are required, that is, environmental analysis is warranted, while the secondary effects can only be described and evaluated concerning their implications for a realistic environmental setting by simulation experiments (Figure 1.1). Taken alone, it is rather pointless to determine the environmental half-life[1] of some chemical species unless if one has sufficient additional information as to estimate whether some sink or source were apparently overlooked in modeling.

It is simple to demand more analytical data but, given the price of them, we are ever left with a pattern of sampling at rather distinct if not remote sites which must be linked by an extrapolation which fulfills the criteria of representative sampling. Expenditures for analytic data and therefore knowledge on environmental states being thus limited, we yet must go on to do "therapeutics", that is, the sanitation of obvious sources of pollution; and we must also abandon the use of substances which will cause hazards and damages only much later and at remote sites (global distillation causing PCB accumulation in the Arctic, ozone destruction, etc.). Hence proactive measures have to supplement cleaning up the more obvious mess. Surveillance and control – that is, analysis – are necessary in every stage of this development, to see whether the measures taken so far were successful.

1) The very term half-life includes the assumption that the decomposition processes are unimolecular, like photochemical decomposition via some excited state or decomposition in adsorbed state or the cleaving agent is present in large excess (which holds for O_2 but not for any radical like OH, OCl, etc.).

Ecotoxicology thereby provides information which opens the view from mere chemical interactions and aspects of accumulation due to physicochemical properties to effects on single organisms and eventually to the effects these have for entire biocoenoses, causing members of one of many species to vanish, become less vital or conversely reproduce and spread by masses. The latter also can bring about chemical effects: the algae and cyanobacteria (phytoplankton) which form in response to eutrophication deliver *inter alia* chlorinated hydrocarbons which may attack ozone and certain poisons (red tides).

So let us now have a look at how we ran into the present situation and how far environmental engineering is a convincing response to demands produced by vast socioeconomic changes, some of which started more than 10 000 years ago.

1.2 History and Development of Environmental Engineering

There is an extended prehistory of environmental engineering since people started reshaping their environs, which in turn required some measures to live so in an at least partially sustainable way.[2] The onset of agriculture in the Neolithic revolution enabled humans to gather in larger groups and to organize – now associated with agrarian areas – in correspondingly larger and less provisional settlements, distinguished by dwelling in stone houses now rather than mere wind-shelters (Koobi Fora), tents or cave entrances. The earliest of these which could be dubbed villages or even towns had a few hundred inhabitants each, like Lepenski Vir (Serbia, River Danube Iron Gate, site now inundated), Jericho (Palestinian Autonomous Territories), Çatal Hüyük (Turkey) or Poliochni (Lemnos Island, Greece; Tine and Traverso, 2001). Already then and there the increasing necessity to obtain wood, alter the landscape for agricultural purposes and later also to process ores caused damage to the local environment. In addition, people started to change their surroundings on some scale beyond felling trees, for example, when growing rice in man-made paddies – the earliest instance of "constructed wetlands" (given the first ones were located in the Lower Mekong area, beavers could not have given the idea for this innovation), with mining also dating back at least to the Mesolithic on various sites.

With larger extents of settlements and of corresponding production requirements, people had two choices:

1) Re-introducing migratory habits (slash and burn agriculture in a way replacing the former striding around with the game animals, on a somewhat longer timescale of relocation – a few years rather than months);
2) More massively using and reshaping the local and regional environments (and to defend them, using the novel skills of metal technologies). These conflicts

2) Sustainable but not forever, yet lasting much beyond the present irreproducible resources, falling short of full replacement by regenerative matter and energy supplies.