

DEPARTMENT OF  
BIOCHEMICAL  
AND CHEMICAL  
ENGINEERING

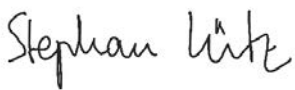
# PREFACE



## WELCOME TO THE DEPARTMENT OF BIOCHEMICAL AND CHEMICAL ENGINEERING

It is a great pleasure for me to introduce our department to you. Our department offers a unique profile and is one of the top ranking biochemical and chemical engineering departments in both Germany and Europe. It enjoys an international reputation due to its focus on cutting-edge, interdisciplinary research between engineers and scientists. We develop innovative concepts and solutions in both fundamental research as well as translation into industrial processes. Within the profile area “Chemical Biology, Drug Research and Process Engineering” of TU Dortmund University we aim to develop sustainable solutions to the big societal challenges. The numerous research projects funded by both public research agencies and industry provide ample evidence of this. In our curricula on biochemical and chemical engineering, as well as process systems engineering we educate the next generation of industrial leaders. Therefore, I am convinced you will find this brochure an interesting read, with some surprising facts about the department and some personal background on the people behind the research.

We look forward to welcoming you to this exceptional department, be it as a student, a research partner, a collaborator or a sponsor.

A handwritten signature in black ink that reads "Stephan Lütz". The signature is written in a cursive, slightly slanted style.

Stephan Lütz

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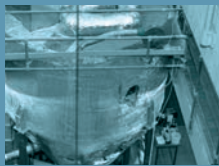


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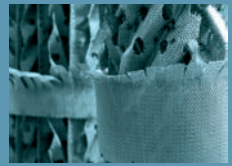


**LABORATORY  
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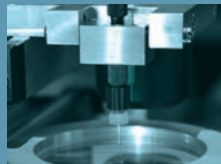


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**ISAS LEIBNIZ-  
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ANALYTISCHE  
WISSENSCHAFTEN  
– ISAS E.V.**

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**PAST – FUTURE**

- » Emeritus professors
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**IMPRINT**

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05.12.2019

Prof. Dr. Gregory Stephanopoulos received the degree of Dr.-Ing. honoris causa from TU Dortmund

19.06.2019

50th anniversary of the Department BCI



12.06.2019

Prof. Constantinos Pantelides received the degree of Dr.-Ing. honoris causa from TU Dortmund

04.10.2016

First doctorate of a master student

02.02.2012

Prof. Ignacio E. Grossmann (Carnegie Mellon University, USA) received the degree of Dr.-Ing. honoris causa from TU Dortmund



19.10.2011

Prof. Sebastian Engell and Prof. Georg Bock (University Heidelberg) receive a grant from European Research Council (ERC grant) "Model-based optimizing control from a vision to industrial reality"

16.03.2011

Gottfried Wilhelm Leibniz Prize awarded to Prof. Gabriele Sadowski



22.07.2009

BCI students council decides to establish "Ten Stars" for good teaching service

30.07.2008

First graduate of the biochemical engineering programme

2003

Restruction of the department: introduction of biochemical engineering on top to chemical engineering

2002

Introduction of biochemical engineering and international Master's programme chemical engineering

2001

First female professor Gabriele Sadowski

05.07.2000

Honorary doctorate given to Prof. Dr. Dr. Ing. h.c. Jerzy Buzek, former Prime Minister of Poland. Until today five more honorary doctorates were awarded



01.03.2000

500th Doctorate: Dr. Gregor Fernholz

17.04.1985

Renaming "Section Chemical Engineering" to "Department Chemical Engineering"

30.04.1974

First graduate in chemical engineering: Dipl.-Ing. Jürgen Sadlowski

1972

Inauguration of the experimental hall

01.10.1970

Start of teaching and studying

12.06.1969

Establishment of Chemical Engineering section as third section of Dortmund University

16.12.1968

Inauguration of the University of Dortmund

# HISTORY

In 1969 the Department of Chemical Engineering was founded as one of the first faculties of the University of Dortmund, today known as TU Dortmund.

Starting with only a small staff and a few labs, the first years saw tremendous growth of the faculty, the facilities and – most important of all – the student numbers. It was an exciting time and, despite teething problems, the first students graduated five years later. As biochemical processes came to play an increasingly important role in chemical engineering, the department was restructured in 2004, introducing a biochemical engineering syllabus to complement the chemical engineering degree.

The department takes particular pride in the high number of female students (30 – 35%) and, in 2001, the department was happy to welcome Gabriele Sadowski as its first female professor.

Moreover, the department is a truly international one, being one of the first in Germany to switch to modern BSc and MSc curricula with English language programs and courses. The considerable number of foreign students attests to the success of these endeavors.

The department is very proud that in 2011 the illustrious Leibniz prize was awarded to Prof. Gabriele Sadowski and the prestigious ERC research grant was given to Prof. Sebastian Engell, both of which are a testimony to the outstanding research environment that has been created here over the last decades.

## DEGREES AWARDED

### UP TO DECEMBER 31<sup>ST</sup>, 2020:

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<b>DIPLOMA:</b>	<b>2706</b>
<hr/>	
<b>BSC:</b>	<b>919</b>
<hr/>	
<b>MSC:</b>	<b>1031</b>
<hr/>	
<b>OTHER POST GRADUATE QUALIFICATION:</b>	<b>39</b>
<hr/>	
<b>PHD:</b>	<b>1064</b>
<hr/>	
<b>HONORARY DOCTORATES:</b>	<b>8</b>

# STUDYING BIOCHEMICAL AND CHEMICAL ENGINEERING AT THE TU DORTMUND

## Chemical Engineering at our department

The study of chemical engineering comprises courses in a broad variety of fields, starting with basic elements of mathematics and chemical, physical and engineering sciences and proceeding to classes in technical chemistry, reaction technology, engineering fundamentals, modelling as well as apparatus and plant design.

Over 7 semesters, our Bachelor program in chemical engineering provides basic knowledge in all disciplines needed in the chemical industry. The students acquire a broad background in chemistry and biotechnology, mechanical and process engineering as well as an appreciation for process safety. Additional courses are also given in business economics and technical English. The study includes an industrial internship and a group plant design project, in which a team of 8–10 students develops a basic engineering design for an entire plant within 8 weeks. This highly regarded exercise in teamwork and project management based on a concrete industrial example weaves together many of the strands that students have learnt earlier in their coursework. The syllabus is rounded off by a Bachelor research project in the final seventh semester. With their Bachelor degree, graduates are qualified to work as engineers in all kinds of capacities in the chemical industry or to proceed to a Master's degree course.

The Master program in chemical engineering focuses more on research and opens the door to a more independent scientific vocation. In three further semesters, the student has a wide choice of elective courses, on advanced reactor technology, process dynamics and control, particle technology, technical catalysis or polymer thermodynamics, for instance. The postgraduate work includes a full semester of Master thesis research, carried out in one of the faculty's laboratories chosen by the student. The Master graduate in chemical engineering is a highly qualified professional able to fill a leading position in the chemical industry or continue his academic career as a PhD candidate in one of the research groups of the faculty. An additional English language Master's degree course in Process Systems Engineering is offered for international or internationally oriented students in the specialized discipline of process engineering science.

MAIN TOPICS OF EXPERTISE	MAIN COURSES
Natural Sciences	Process and Plant Design
Mathematics	Chemical Process Engineering
Business Economics	Product Design
Chemical Engineering	Process Systems Engineering



## Biochemical Engineering at our department

Bioengineering is the fusion of engineering with biological sciences in the study and utilization of complex living systems (microorganisms, plants, animals). Bioengineering research at TU Dortmund concentrates on the development of innovative or improved biological and biotechnological concepts and techniques that can be applied to problems in the biotechnological, pharmaceutical and related industries. This includes the fundamental study of biological phenomena and the development of bio-based processes in all fields of these industries. The bioengineering program at our department is an interdisciplinary program, unique in Germany, combining engineering and natural sciences. The BSc and MSc bioengineering programs are highly innovative and flexible, providing the students with the opportunity to learn about all major aspects of biochemical engineering while retaining a strong link to classical engineering disciplines.

As with chemical engineering, the Bachelor program comprises 7 semesters, including a group project, an industrial internship and a Bachelor thesis as the final research project and provides students with all the necessary knowledge and skills to work as an engineer in the biochemical or chemical industry and related sectors, such as the pharmaceutical and food industries. The two BSc degree programs are highly compatible, so switching from chemical to biochemical engineering or vice versa for a subsequent MSc qualification presents no problems.

The Master program comprises a further 3 semesters, including a full semester Master thesis. The graduates are prepared for highly qualified scientific work and scientific managerial positions in industry. Many of our MSc graduates in biochemical engineering continue with PhD research work.

MAIN TOPICS OF EXPERTISE	MAIN COURSES
Natural Sciences	Bioengineering
Mathematics	Genetics
Business Economics	Biochemistry
Biochemical Engineering	Biotechnological Research

## OUR MISSION TO THE STUDENT

### Bachelor Programme in Chemical Engineering

Chemical Engineering is one of the key disciplines addressing the challenges arising from global megatrends, such as energy, health and new materials. Chemical engineers help to shape our world for a better life. To understand current challenges and develop creative solutions, the curriculum is a mixture of engineering and natural sciences together with mathematics and economics. Modern chemical engineers are team players: students are therefore taught how to interact in a professional environment. The Bachelor program provides an interdisciplinary study enabling one to understand new concepts and innovations for developing, optimizing and operating complex production processes and the equipment in which they are carried out. Naturally, our students come into contact with industry at the early stage of their studies. The curriculum has been carefully designed with the needs of the students in mind and to employ appropriate teaching concepts at all stages. Chemical engineering boasts a high proportion of female graduates and we actively encourage women to study this fascinating field.

### Master Programme in Chemical Engineering

The Master program provides the student with in-depth scientific expertise and techniques for the chemical engineering profession. MSc graduates are trained to conduct independent research and development work. According to individual strengths and interests, the students can choose between certain core courses and select topics from a broad range of electives. As a specialization, the department offers a Master degree in Process System Engineering, in which all compulsory courses and a large selection of electives are taught in English, including courses on modelling and computer simulation, process optimization, dynamics and control and conceptual process design.

### Bachelor Programme in Biochemical Engineering

Biochemical Engineering is an emerging discipline at the interface between the natural and engineering sciences. The undergraduate program in Biochemical Engineering offers the core Chemical Engineering syllabus together with courses in molecular and cellular biology, biochemistry, biotechnology, microbiology and the engineering analysis of systems biology and physiology. Building on these core subjects, each student takes electives and advanced engineering courses followed by the Bachelor thesis. The Bachelor program provides an interdisciplinary study on novel concepts and innovations for developing, optimizing, and operating complex production processes based on biotechnological principles.

### Master Programme in Biochemical Engineering

The Biochemical Engineering Master degree encompasses a mixture of molecular biotechnology, analytical techniques, pharmaceutical engineering, process design, process performance engineering, a variety of electives and concludes with a Master thesis research project, which can also be carried out at our partner universities. As MSc graduates in Biochemical Engineering, our students command the scientific skills and state-of-the-art techniques needed to master a multitude of engineering tasks in both industrial and academic research and development departments.

## READ WHAT OUR STUDENTS SAY ABOUT US:



### THE BACHELOR- AND MASTER PROGRAMME

*"Engineers' main task is problem solving. We learn how to do it."*

LENNART HELWES, 5. SEMESTER

*"Biochemical engineering will be the answer to numerous challenges in today's world. I like the idea of becoming an expert in this field and take up the challenge."*

LEA HERRMANN, 5. SEMESTER

*"During my internship I experienced that the TU Dortmund has established an excellent reputation among enterprises. I am proud to be a graduate of this university."*

CLAAS STEENWEG, MASTER 1. SEMESTER

*"The training is profoundly based on science and theory. However, it is completed by project work and internships. This is what appeals to me."*

TANJA STOLZKE, MASTER 1. SEMESTER

## BRINGING THE INDUSTRY TO THE UNIVERSITY:



### PLANT DESIGN PROJECT (GRUPPENARBEIT)

*All students in chemical engineering or biochemical engineering in our department have to complete a team design project. To design a chemical plant in a team is a thrilling and highly motivating experience for both the students and the supervising staff. A team, usually comprised of 10 students carries out a design project over the course of 8 weeks. The project task is devised so as to utilize much of the knowledge acquired in previous coursework, from basic engineering to sophisticated plant design. Organizing such a project helps students to gain basic managerial skills and prove themselves as useful team players. It teaches them how to meet tight deadlines and to develop a feeling for integrated and interdisciplinary work flow processes. It offers a valuable practical introduction to real life chemical and biochemical engineering and can be considered as a foretaste of the challenges in industrial plant design. The results are presented to industrial partners who both help to formulate the design tasks and provide useful feedback.*

### Doing a PhD at the BCI department

Excellent Dortmund Master students proceed to obtain a Dr.-Ing. or Dr. rer. nat. in Biochemical or Chemical Engineering with a research project on cutting-edge topics. The doctoral students are either employed by the university on faculty positions, research grants, or hold scholarships. There are no tuition fees for doctoral students. Most of the doctoral students are involved in the teaching of the faculty on the Bachelor and Master level by giving tutorials, supervising lab experiments and advising the students who are doing thesis projects. The faculty leads a structured doctorate programme on industrial biotechnology (CLIB), wherein several laboratories collaborate on modern biochemical processes.

## QUALITY ASSURANCE

### Teach 'n Tech

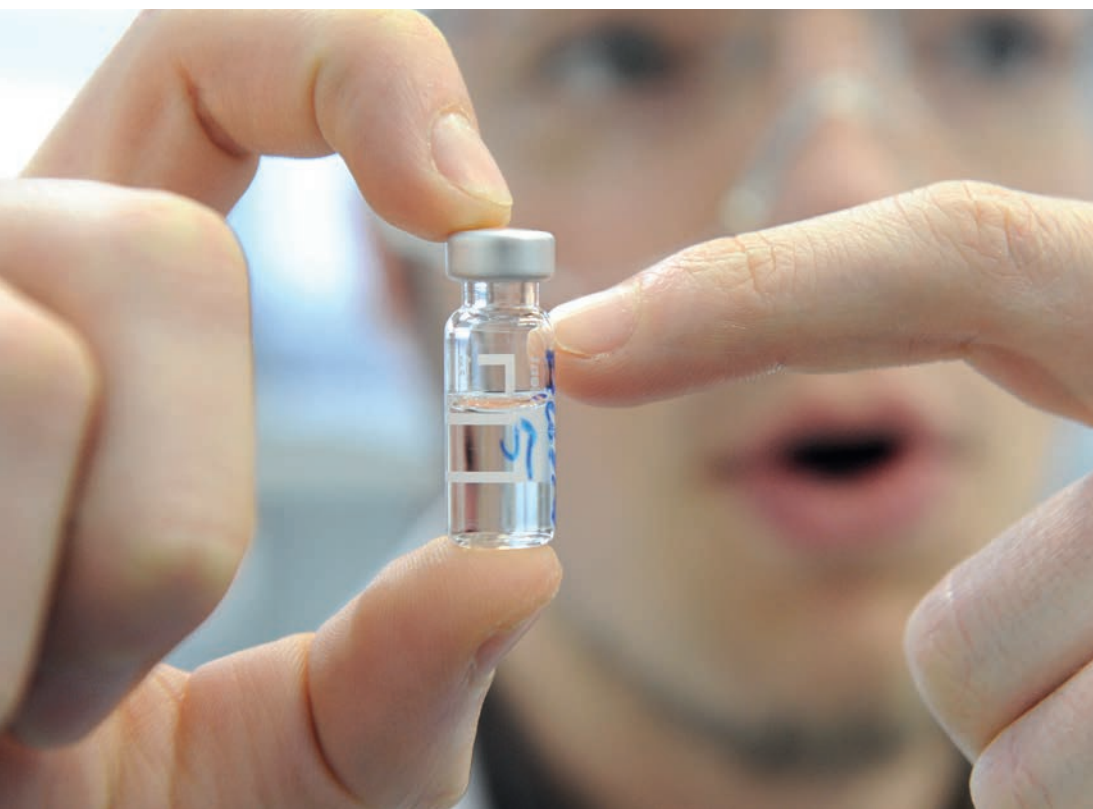
The department is committed to educating and training the students at the highest level of quality. It lives a culture of interacting with students, taking their needs and wishes seriously and implementing modern and effective teaching concepts – a strategy we refer to as “Teach ‘n Tech”.

Evaluation, benchmarking, ongoing reflection on the quality of the academic standards and disseminating best educational practices form the basis of this process, which embraces our internal and external stakeholders: students, staff, faculty, other departments and the administration of the TU Dortmund, alumni and representatives of both industry and society.

Comprehensive structures and mechanisms for quality assurance include comprehensive methods to identify areas for improvement, to foster collaboration and the exchange of best practice. Annual surveys and evaluations cover all undergraduate and graduate courses. The outcomes of these surveys and evaluations are analyzed made available to all stakeholders.

Cooperative communication with students is one of the most important aspects of quality assurance and occurs through direct meetings or within the context special events like “Teach’n Tech” workshops, an open, pari passu dialogue on teaching and learning needs. Held for the first time in 2013, this is a regular biennial event.

Outstanding teaching is honored with the “BCI teaching prize” (teaching prize) and “teaching stars” are encouraged to improve lectures and enhance learning conditions by promulgating their successful techniques.



# Axiom 0

$$u = (\sqrt{1-u^2}, u, 0, 0)$$

$$\int dx \left( \frac{\partial A}{\partial y} \right)$$

$$\delta \frac{d}{dx} = \frac{d}{dx} \delta$$

$$\sqrt{1+4^{12}} \delta y$$

$$123456789 \quad du = 0$$

$$f(x) = \sum_{i=1}^n \langle f(x), e_i \rangle$$

$$\frac{dr}{dz} = u$$

$$\int dr = \int dz u$$

$$1 + \frac{10}{n^3}$$

$$\sqrt{1+4^{12}}$$

## INTERNATIONALIZATION

Internationalization is more than just a buzzword for the BCI department, it is everyday experience in both our education and research. The department is involved in numerous international research projects, most of which are sponsored by the European Union. A recent flagship project was the F3 consortium with 27 partners that opened new horizons for future flexible continuous modularized production plants, and in which TU Dortmund was the biggest academic partner. Currently 9 collaborative EU projects are being coordinated by members of the department. International researchers, both graduates from the international Master programs at TU Dortmund and scientists and engineers with Master and doctoral degrees from other universities are an important part of the academic community in the department, and several former PhD students have become professors at foreign universities. The department encourages students to spend semesters abroad, to do their internships in an international environment, or to conduct their final thesis research projects at foreign universities. In Europe, such exchanges are organized within the framework of the Erasmus program and the department has many contracts with other universities for bilateral student exchanges. While the Bachelor courses are almost exclusively given in German,



### NORTH & SOUTH AMERICA

Brazil: Universidad Federal de Bahia

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Brazil: Universidad Federal de Rio Grande

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Mexico: Tecnológico de Monterrey

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USA: Carnegie Mellon University

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USA: Lehigh University

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USA: Princeton University

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USA: University of Pennsylvania

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### ASIA

China: China University of Mining and Technology

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China: Hong Kong University of Science and Technology

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Japan: Kyoto University

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South Korea: KAIST

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Thailand: Chulalongkorn University, Bangkok

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a significant proportion of the Master syllabus is offered in English. Indeed the specialization in Process Systems Engineering, which currently attracts 20–30 students per year, can be taken entirely in English. Under a special agreement, a group of top students is selected from CUMT, ORT, China every year. In addition, the department is responsible for the Engineering Option in the Dortmund International Summer Program, a half-semester program run from June to August having a student intake from the US, Hongkong, Mexico, Brazil and other countries. The participants attend regular courses in the department during the second half of the summer semester and are offered additional courses in the German language, culture, politics and business. The benefit for our students is that they in return can spend semesters at the home universities of the Summer Program students without having to pay tuition fees. Examples of institutions participating in this scheme are: Carnegie Mellon University, the University of Pennsylvania, Lehigh University and the University of Science and Technology, Hongkong. With Kyoto University, in Japan we have an arrangement for reciprocal industrial internships, as well as for bilateral exchanges of undergraduates, graduates and lecturers.

## **i** INTERNATIONAL COOPERATIONS amongst others:

### EUROPE

Belgium: University of Liege

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Denmark: Technical University of Denmark

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Finland: Lappeenranta University of Technology

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France: Institut National Polytechnique de Toulouse

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France: Institut National des Sciences Appliquées de Rouen

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Italy: University of Genua

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Lithuania: Vilnius Gediminas Technical University

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Netherlands: University of Twente

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Netherlands: Eindhoven University of Technology

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Poland: Jagiellonian University Medical College

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Poland: Poznan University of Medical Sciences

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Poland: Technical University of Lodz

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Poland: Warsaw University of Technology

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Portugal: Technical University of Lisboa

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Portugal: Universidade de Aveiro

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Spain: Rey Juan Carlos University

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Spain: University of Valladolid

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Spain: UPC Barcelonatech

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Sweden: University of Lund

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Slovakia: University of Technology

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Turkey: Yildiz Teknik Universitesi

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United Kingdom: University of Newcastle

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## SCIENCE IS OUR PASSION

The leitmotif of our research is the development and optimization of safe, sustainable and efficient production processes founded on a strong interaction between natural and engineering sciences. We have identified three key research areas as focal points for the research and education in the department as a whole:



### CHEMICAL PROCESS ENGINEERING

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### SUSTAINABLE BIOCHEMICAL ENGINEERING

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### PRODUCT DEVELOPMENT AND PROCESS ENGINEERING FOR SPECIALTY PRODUCTS

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#### Chemical Process Engineering

Chemical Process Engineering is the traditional strength of our department. The distinguishing feature of our approach is the integrated view of the entire process, from the chemical reaction to the separation steps and recycle streams, leading to efficient and environmentally benign production. This philosophy is imparted to the students in the group project and reflected in the large number of collaborative research projects. One of the challenges we are currently addressing is to intensify chemical production processes, by combining classical chemical engineering operations such as reaction, separation and heating/cooling or by switching to continuous operations with intensified heat and mass transfer, leading to both significant cost savings and a reduced environmental footprint. The emphasis on the chemical side has been towards processes based on renewable resources, like fats and oils. Optimization of plant designs as well as optimal operational policies are being investigated as a means to further improve plant performance.

#### Sustainable Biochemical Engineering

Our department is making an important contribution to the development and optimization of biotechnological processes for industrial applications. Typical unit operations being examined are enzymatic reactions and fermentation as well as downstream processing steps, such as technical scale chromatography. In this field, modelling and computation also play an important role when attempting to increase yield, selectivity and raw material utilization. Additionally, research work is being carried out in the field of new products and biomaterials. Methods from systems biology are being used to design and optimize biotechnological processes combining experimental data and model-based predictions.





## Product development and process engineering for specialty products

Up to now, there has been little scientific treatment of the industrial production of special compounds with complex structures exhibiting explicitly specified properties. The area of low-volume and high-value products will probably be the most profitable for the chemical industries in coming years. A research goal in this field is to model the processes and thus identify optimization potential for high conversion rates and minimal inputs of energy and materials.

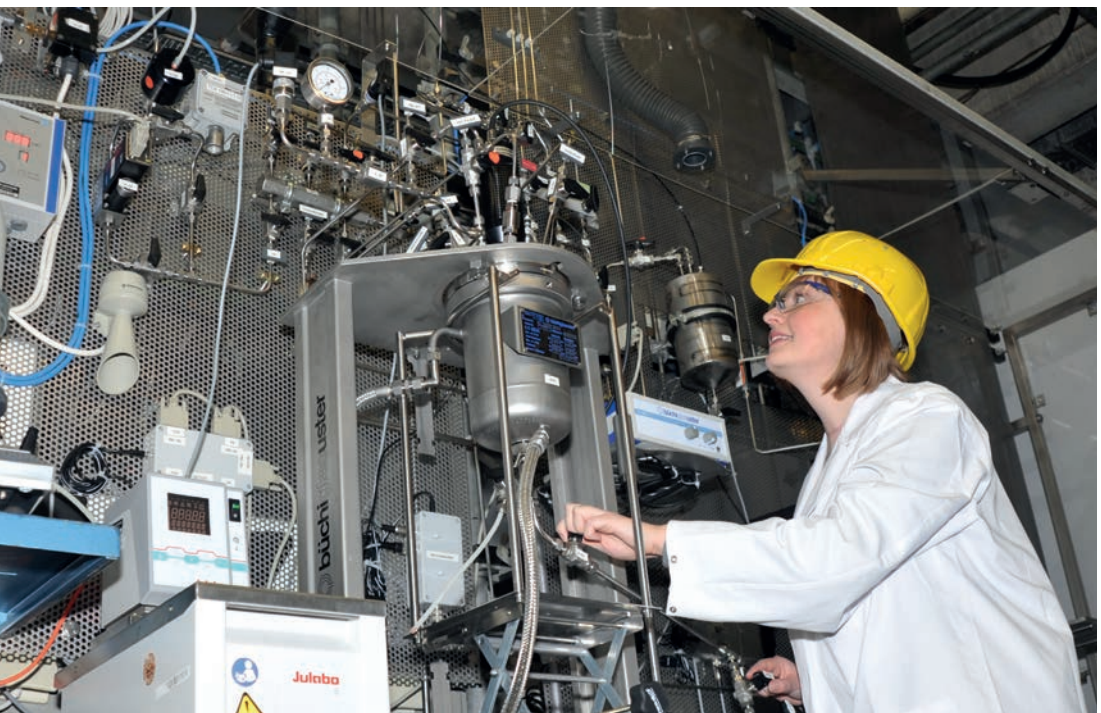
With increasingly powerful computer simulations it will be possible to model even micro-scale-phenomena and exploit the results for process and system optimization. Targeted product development is an important emerging challenge playing an essential role in such areas as pharmaceuticals, food, and agrochemicals. Most of the products of industrial processes today are solid compounds and are very often only sparingly soluble. There is a great need for “smart engineering” of these products based on particle and powder technology in general, but also for innovations with targeted applications as drugs for humans.

## WE LIVE SCIENCE

### Transregio InPROMPT

The Transregional Collaborative Research Center “Integrated Chemical Processes in Liquid Multiphase Systems“ (InPROMPT), sponsored by the DFG (German Science Research Council), is a joint research cluster between TU Dortmund, TU Berlin, Otto-von-Guericke-Universität Magdeburg, and the Max-Planck-Institut für Dynamik komplexer technischer Systeme in Magdeburg. In InPROMPT, more than 60 scientists from various disciplines work on the development of new homogeneously catalyzed chemical production processes starting from long-chain alkenes or fatty acids in multiphase systems. The research projects address the entire process chain from the chemical reaction in multi-phase systems to product separation and recycle structures in a holistic manner. The processes are transferred from lab scale to mini-plant scale and validated in sufficiently long production campaigns to study the effects of catalyst deactivation, for example. The research is broken down into three areas, fundamentals of chemical reactions and separations, unit operations, and systems engineering. In the last area, methods for rapid process development and optimization of the process flowsheets and for process control are being developed.

In InPROMPT, two innovative approaches to homogeneously catalyzed reactions are being pursued: the application of solvent systems with tuneable properties and multiphase systems with surfactants. The long-term goal is to optimize these liquid-liquid systems so as to utilize them in industrial multiphase chemical reaction processes. In the first phase, the rhodium catalysed hydroformylation of 1-dodecene was investigated as a model reaction. After a very positive project evaluation in September 2013, the Transregio has been extended for another four years. In the second phase, the range of chemical reactions will be extended to reactions with fatty acids.



## INVITE

INVITE is a joint research center, owned by TU Dortmund, University of Düsseldorf, and Bayer AG in a private-public partnership (PPP). The acronym stands for Innovation, Vision, and Technology. INVITE's research on innovative and resource efficient production focuses on modular and continuous manufacturing of chemicals and biologicals. In networks of partners from academia and industry new production technologies are developed for the chemical and pharmaceutical industry. Currently, the Drug Development Innovation Center (DDIC@INVITE) is in foundation adding pharmaceutical technologies as new research topic.

In the European Project F3, INVITE provided the test environment for the demonstration of six different containerized production processes and continues to perform research and development on modularized and intensified innovative production processes. Various modular chemical production processes were successfully developed and brought to industrial maturity. Current activities include the EU-funded project CONSENS on integrated sensors and automation, continuous manufacture of monoclonal antibodies as well as decentralized chemical production for leather processing.



*Container setup of modular, small-scale production plant for gas-liquid reactions*

The INVITE building is located on an 800 m<sup>2</sup> site at the edge of the ChemPark in Leverkusen, Germany. It comprises a technical center and pilot plant, a lecture hall, laboratories, and office space. INVITE provides a unique infrastructure to develop and test the technical performance of novel intensified production technologies. The heart of the building is the pilot plant, where three 20-foot containers can be operated in parallel. The whole pilot plant is an explosion protection zone enabling the processing of real chemicals. The pilot plant is connected to the infrastructure of the ChemPark Leverkusen, hence, INVITE can benefit from the access to the process streams and high quality support in analytics, operations, and technical services. Beside research and development activities, sponsored by research contracts with industry as well as by publicly co-funded projects, INVITE offers training courses for professionals from academia and industry. Up to now, three PhD students successfully finished their dissertation at TU Dortmund and inhabit industrial positions. Six PhD students are currently supervised by Prof. Kockmann (AD), the chief scientist at INVITE, Prof. Schembecker (APT), Prof. Thommes (FSV), and Prof. Engell (DYN) in various research projects at INVITE, with additional PhD students joining these projects while working in the department BCI.



# LABORATORY OF EQUIPMENT DESIGN

PROF. DR. KOCKMANN



## CURRICULUM VITAE

PROF. DR.-ING. NORBERT KOCKMANN

Born	1966 in Burgsteinfurt, Germany
Education	1985 – 1991 Mechanical Engineering, TU Munich
PhD	1991 – 1996 On fouling mitigation in falling film evaporators, University of Bremen
Postgraduate Qualification (Habilitation)	2001 – 2007 Research group leader at the Laboratory for Design of Microsystems, Institute of Microsystems Technology (IMTEK), University of Freiburg 2007 Habilitation, University of Freiburg
Positions	1997 – 2001 Project manager at Messer Griesheim GmbH, Krefeld 2007 – 2011 Head of research lab & microreactor specialist at Lonza AG, Visp, Switzerland Since 2011 Professor in the Department BCI of TU Dortmund

## RESEARCH INTERESTS

- » Micro process engineering
- » Microreactors and separation equipment
- » Extraction processes and equipment
- » Crystallization processes and equipment
- » Multiphase flow
- » Modular, small-scale equipment
- » Process intensification
- » Pharmaceutical processes and production

## CONTACT

### Laboratory of Equipment Design

Department of Biochemical and Chemical Engineering  
TU Dortmund  
D-44221 Dortmund/Germany

Tel.: +49-(0)231-755-8077  
Fax: +49-(0)231-755-8084  
norbert.kockmann@tu-dortmund.de  
www.ad.bci.tu-dortmund.de



# “DESIGN ENGINEERING FOR CREATIVE SOLUTIONS COMBINES SCIENCE WITH ART.”

*Prof. Dr. Kockmann*

## *What is your conception of science?*

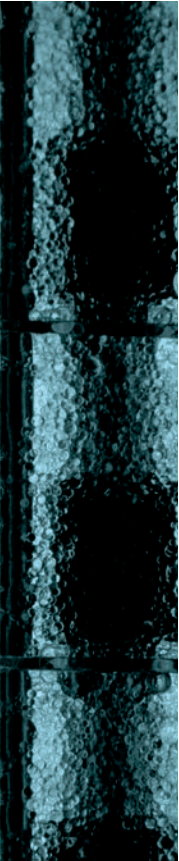
We work on novel combinations of scientific knowledge with engineering methods to get creative and smart answers for our current challenges in environmental protection, health care, and sustainable living. The goal is the effective use of raw materials and energy for higher quality products.

## *What are you and your group busy with?*

We develop modern equipment for process intensification, which enables chemical and biochemical process development in the lab and consistent scale-up into production. For example, we developed an extraction column with small internal volume, which allows for so far unmatched efficient separation of chiral molecules. We speak with industry to find opportunities for our research activities getting a fundamental understanding of the complex underlying processes. This understanding is essential for us to develop answers and solutions for our future challenges.

## *Where do you see the department in the future?*

Biochemical and chemical engineering sciences are key elements in shaping our modern life. Our department will train a substantial number of well-prepared engineers leaving the university as solution finders. The department will integrate novel technologies and new product solutions and will bind closer ties to the other faculties to broaden the scientific fundament.



## TEACHING

Chemical engineering is a cross-sectional area including natural sciences as well as engineering disciplines. In teaching first year students the introductory course, I want to motivate them for the new episode in their life. Some topics are self-explaining; however, the combination of pure mathematics with real-life problems gives momentum for deeper digging, necessary for studying at the university. In progressing, the students get familiar with safety concepts and their responsibility for later activities in their job. The final course in the Bachelor curriculum is on equipment technology and design, embracing fundamentals of mechanical stability, norms, and engineering design basics. This prepares the students for their

final works as well as for more challenging tasks in their following career.

Showing graduate students to apply their knowledge to solve real-life problems is enlightening and starts creative processes. Modern technology is taught by our chair in courses on micro process engineering, pharmaceutical process technology, GMP and quality assurance. The historical development of chemical technology is taught in the course on Technical and Innovation History, including student's presentations on special historical topics. However, most challenging is to work with PhD students to develop their own solutions for scientific questions.

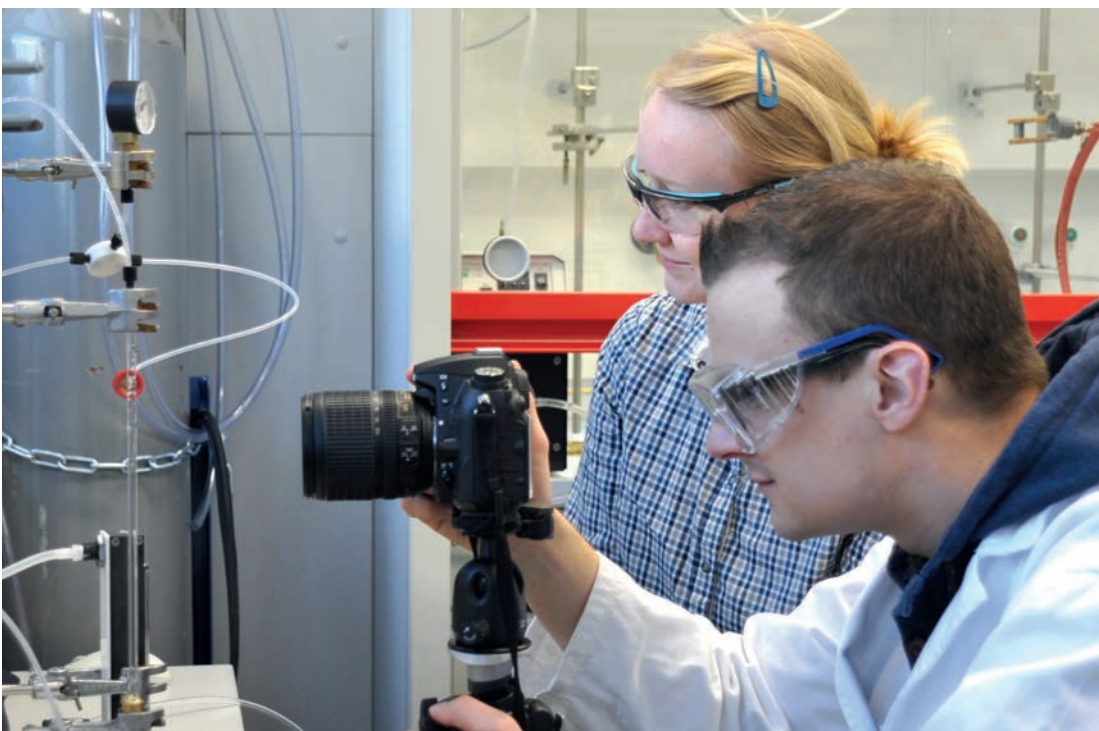
## RESEARCH

Research in our group is guided to find new solutions on intensified processes. Miniaturized equipment allow for improved observation of transport phenomena and, with a better understanding, a directed intensification and better control. Multiphase flow with mass and heat transfer as well as complex chemical reactions are investigated on lab scale with the potential to scale-up.

Liquid-liquid flow is deployed in microchannels as well as in small extraction columns for a broad range of applications, e.g. the reactive extraction of chiral molecules. Gas-liquid dispersion processes in a nozzle are optimized and transferred to a modular microchannel reactor setup. Further fabrication techniques are investigated to broaden this technology. Solid formation in small channels is challenging, but offers unique opportunities to learn about their formation and growth mechanisms. Short helical alternating reactor capillaries are investigated for narrow residence time distribution and high heat transfer beneficial for rapid, exothermic chemical reactions, and continuous crystallization.

Modular equipment and continuous-flow processes are corner stones to bring our research results into larger application. Robust and scalable equipment help to gain valuable process information already in the lab. With a platform strategy, the process developed in the lab can be transferred to pilot or even production scale. Chemical, process and engineering know-how is stepwise build-up accompanying the flexible development process and can be re-used for other processes

The main connection with industry is the role as chief scientist at the research platform INVITE, which is a private public partnership (PPP) between TU Dortmund, BCI, HHU Düsseldorf and Bayer in Leverkusen. Within the ENPRO consortium, energy- and resource-efficient processes and related modular equipment is developed for small-scale production. Close collaboration between industrial and academic partners is an important way for successful innovation. Open innovation is a new way for industry to generate solutions to their challenges.





# LABORATORY OF PLANT AND PROCESS DESIGN

PROF. DR. SCHEMBECKER





## CURRICULUM VITAE

PROF. DR.-ING. GERHARD SCHEMBECKER

Born	1963 in Wadersloh, Germany
Education	1983 – 1988 Chemical Engineering study, TU Dortmund
PhD	1988 – 1992 PhD Thesis at the Laboratory of Technical Chemistry A, TU Dortmund, Germany
Postgraduate Qualification (Habilitation)	1992 Laboratory of Technical Chemistry A, TU Dortmund 1999 Habilitation, TU Dortmund
Positions	1998 – 2005 Managing director of Process Design Center GmbH, Dortmund 1999 – 2003 Managing director of Process Design Center B.V., Breda, Netherlands 2003 – 2005 President and CEO of Process Design Center Inc., Santa Barbara, CA, USA Since 2005 Full Professor in the Department BCI of TU Dortmund Since 2013 President of University Alliance Ruhr Inc., New York, NY, USA

## RESEARCH INTERESTS

- » Conceptual Design, Simulation and Optimization of Integrated Biochemical Processes
- » Centrifugal Partition Chromatography
- » Tunable Aqueous Polymer Phase Impregnated Resins
- » Foam Fractionation
- » Crystallization and Product Design

## CONTACT

### Laboratory of Plant and Process Design

Department of Biochemical and Chemical Engineering  
TU Dortmund  
D-44221 Dortmund/Germany

Tel.: +49-(0)231-755-2338

Fax: +49-(0)231-755-2341

gerhard.schembecker@tu-dortmund.de

www.apr.bci.tu-dortmund.de



# “THERE ARE NO PROBLEMS, ONLY CHALLENGES AND SOLUTIONS!”

*Prof. Dr. Schembecker*

*Prof. Dr. Schembecker, what is your vision in science?*

The final goal of our research is to drastically improve efficiency in process development and design. In order to achieve this goal we need to understand the underlying chemical, biological and physical principles of each single process step enabling us to develop new and innovative process technology.

*Can you explain me in short what you and your group are busy with?*

Our research aims at methodologies and technologies for an optimal design and operation of biochemical plants. On the one hand we work on new technologies for the separation of complex mixtures produced e.g. by biochemical reactions. On the other hand we develop new manufacturing concepts for a most optimal integration of up and downstream.

*What moment in your life triggered you to become a scientist?*

For quite some time I ran my own company supporting clients in optimizing their chemical production processes. During our projects I learned that production companies rather go for small step innovation than for breakthrough ideas. Game-changing innovation is possible only in a research environment which is not fully economically driven. Such a working environment allowing out-of-the-box thinking is offered by a university.



## TEACHING

Plant and process design covers all aspects necessary to transfer a process idea from laboratory into a production plant. Knowledge from numerous disciplines is needed to develop a resource efficient process capable to manufacture the desired product in the most economical way.

The main lecture „Plant and Process Design“ in the bachelor program addresses key knowledge elements enabling our students to perform process design projects in industry. These include process development aspects like reactor and separation technology selection or energy integration. Plant design covers pumps and compressors, piping and layout. Different operating concepts are presented for batch and continuous operation, including Good Manufacturing Practice aspects. An introduction to static and dynamic investment calculations completes the

course. Parallel to the main lecture an introduction to simulation technologies presents state-of-the-art mass and energy balancing techniques and software.

The master course „Conceptual Design“ provides a more detailed view on the design of an overall process concept. One area is the design and operation of multiphase reactors, another one a knowledge based procedure to develop separation sequences for highly complex mixtures.

Additional elective courses offer a deeper insight into some special areas of interest. The latter include: Steady-State, Dynamic, and Bioprocess Simulation, as well as Technical Chromatography, and Crystallization. Moreover, external experts give elective courses in industrial biotechnology.

## RESEARCH

The Laboratory of Plant and Process Design aims at developing methodologies, tools and technologies for the development and implementation of resource efficient biochemical production processes based on a sound understanding of the driving biochemical and physical phenomena.

### Biochemical Process Design

Prof. Dr.-Ing. Gerhard Schembecker

This group concentrates on the development of systematic methods for process development following the idea of adapting approaches applied in chemical industry to the needs of biochemical processes. Expert knowledge is transferred into heuristics for the generation of alternative process options. Models which are built into the bioprocess simulation software INOSIM are used to evaluate these options and Key Performance Indicators (KPIs) help to rank them. Model parameters are determined by intelligent experiments performed automatically on a robotic platform.

Of special interest is the development of the bio manufacturing facility of the future. Current research targets at the optimal integration of up- and downstream as well as continuous manufacturing. Together with INVITE GmbH - the joint research organization of Bayer and TU Dortmund University in Leverkusen - new operating concepts are implemented like the first of its kind fully continuous plant for the manufacture of monoclonal antibodies using disposable equipment.

### High Gravity Technology Center Dortmund (ROTOR)

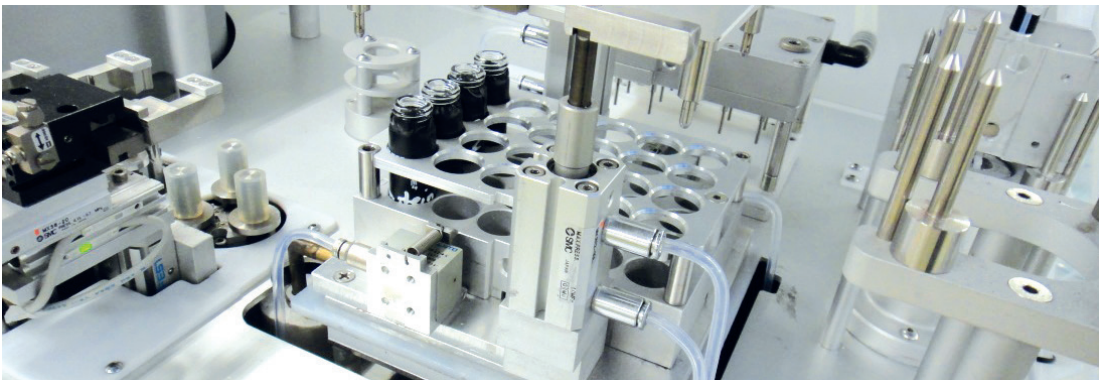
M.Sc. Jörg Koop

High gravity (Higee) technology replaces gravity with centrifugal force, which can be adjusted to values higher than gravity by orders of magnitude. That leads to intensified gas-liquid contacting in Rotating Packed Beds (RPB), used for distillation, absorption or, stripping processes. On the other hand, Centrifugal Partition Chromatography (CPC) and Continuous Centrifugal Extraction (CCE) offer great potential for the purification of valuable bioproducts from fermentation broths. Thus, Higee technology provides solutions for some of the modern chemical industry's challenges, like more restrictive regulations for off-gases, limited space on offshore plants, or the increasing demand for bioproducts in the pharmaceutical industry.

### Crystallization and Product Design

Dr.-Ing. Kerstin Wohlgemuth

Most of the products of the chemical or pharmaceutical industry are produced as solid. The related production processes comprise not only the crystallization step itself but also downstream processes like washing and drying. Understanding the fundamental phenomena of complex multi-step particle formation from molecular up to industrial scale is essential for designing the product. One research objective is the development of robust and scalable processes from first crystals to the final solid product to reveal constant product quality, namely crystal size distribution, mean crystal size, crystal habit and purity. E.g. one important question is the identification of the process steps in which agglomeration takes place. In the context of process design the transfer from batch to continuous processes is in focus of our research activities.





# LABORATORY OF BIOMATERIALS AND POLYMER SCIENCE

PROF. DR. TILLER



## CURRICULUM VITAE

PROF. DR. RER. NAT. JÖRG C. TILLER

Born	1971 in Jena, Germany
Education	1990 – 1995 Chemistry, Friedrich-Schiller-University Jena
PhD	1996 – 1999 Biosensor Technologies and Cellulose Chemistry, Jülich Research Centre and Friedrich-Schiller-University Jena
Postgraduate Qualification (Habilitation)	1999 – 2001 Biomaterials Research, Massachusetts Institute of Technology (MIT), Cambridge, USA 2002 – 2006 Emmy Noether Young Research Group leader, Albert-Ludwigs-Universität Freiburg 2006 Habilitation, Albert-Ludwigs-Universität Freiburg
Positions	Since 2007 Full Professor in the Department BCI of TU Dortmund

## RESEARCH INTEREST

- » Design of advanced materials with specific properties due to their functional designs

## CONTACT

**Laboratory of Biomaterials and Polymer Science**  
Department of Biochemical and Chemical Engineering  
TU Dortmund  
D-44221 Dortmund/Germany

Tel.: +49-(0)231-755-2479  
Fax: +49-(0)231-755-2480  
joerg.tiller@tu-dortmund.de  
www.ls-bmp.de





## TEACHING

The manufacture, properties and applications of the most important metallic, ceramic and polymeric materials are taught in the lectures “Materials Science”. In particular structure-property relationships for alloys and hybrid materials are covered. Selected processes for preparation and characterisation are dealt within a practical course. The lecture of “Biomaterials” encompasses the concepts of natural materials and its use advanced synthetic materials. The synthesis and characterisation of polymers together with their physicochemical properties are presented in various “Polymer Science” lectures. Reaction mechanisms, industrial syntheses and structure-property relationships, polymer physics, applications and advanced polymer characterization are covered in these lectures.

## RESEARCH

The emphasis of the current research is on the design of materials that interact with biological systems. The synthesized mostly polymerbased hybrid nanomaterials possess antimicrobial properties, are activating carriers for enzymes, can be biodegraded, provide unique mechanical properties, and/or react intelligently to environmental stimuli.

### Polymer Synthesis

Polymers are prepared using a whole variety of syntheses, including anionic and cationic living polymerisation, free and controlled radical polymerisation, polymer analogue reactions as well as emulsion and suspension polymerisation.

### Antimicrobial Polymers and Materials

Materials that prevent biofouling are attracting great interest at present. Environmentally friendly materials are being developed that kill microbes, such as bacteria and fungi, on contact without releasing a biocide. Antimicrobial polymers are currently considered as alternatives to common disinfectants and even antibiotics. We work on such macromolecules that are fully hemocompatible, combine several working mechanisms in one molecule, make biocidal polymers bioswitchable in their activity, and investigate antibiotic-polymer-conjugates regarding their potential to build up fewer resistances.

## Biocatalytic Polymers

Biocatalysis in organic solvents is an important field of white biotechnology. Unfortunately, enzymes exhibit very low activities in these media. Amphiphilic co-networks are nanomaterials designed to yield increased activation of entrapped enzymes. The same is achieved by making the biocatalysts organosoluble upon polymer-conjugation. The latter systems can be rendered into organosoluble artificial metalloenzymes that catalyze untypical reactions with very high selectivity. Enzymes in polymer hydrogels are also used to induce mineralization within the gels to achieve fully transparent ultrastiff and tough hybrid materials with advanced properties.

## Smart Materials

Materials that react to environmental signals by changing shape, stiffness, or inducing force are considered as smart materials, most successfully shown on the example of shape memory natural rubber (SMNR). We are interested in preparing such materials by cross-linking commercial and in house synthesized polymers at the borderline of elastomer and melt. This way the maximal performance with respect to stretchability, crystallinity, and sensitivity is achieved. We also recently introduced a new class of smart materials, the “Predictive Materials”, which can react to the rate of environmental changes, e.g., overheating of a device, and prevent them.

## Equipment

Besides a variety of polymer syntheses and processing facilities, standard investigation methods (e.g. thermal, mechanical, structural analysis (q.v. ZEMM)) are available for designing and testing novel, tailor-made materials.



# LABORATORY OF BIOPROCESS ENGINEERING

PROF. DR. LÜTZ





## CURRICULUM VITAE

PROF. DR. RER. NAT. STEPHAN LÜTZ

Born	1976 in Hannover, Germany
Education	1995 – 2000 Chemistry, University of Bonn
PhD	2000 – 2004 Process Development for the Electroenzymatic Sulfoxidation with Chloroperoxidase, Research Centre Jülich
Postgraduate Qualification (Habilitation)	2004 – 2008 Group Leader „Technical Biocatalysis“, Research Centre Jülich 2012 Habilitation, University of Bonn 2013 Umhabilitation, University of Basel
Positions	2009 – 2016 Manager and Senior Investigator, Bioreactions Group, Novartis Pharma AG, Basel, Switzerland Since 2016 Full Professor in the Department BCI of TU Dortmund

## RESEARCH INTERESTS

- » White Biotechnology
- » Biocatalysis for the synthesis of value added products
- » Natural Products Biotechnology
- » Enzyme Technology
- » Fermentation & Biotransformation Process Engineering

## CONTACT

### Laboratory of Bioprocess Engineering

Department of Biochemical and Chemical Engineering  
TU Dortmund  
D-44221 Dortmund/Germany

Tel.: +49-(0)231-755-4764

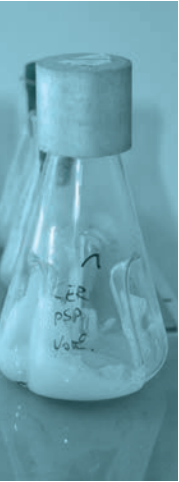
Fax: +49-(0)231-755-7382

[stephan.luetz@tu-dortmund.de](mailto:stephan.luetz@tu-dortmund.de)

[www.bpt.bci.tu-dortmund.de](http://www.bpt.bci.tu-dortmund.de)



# “ENZYMES ARE PROTEINS, THINGS OF BEAUTY AND A JOY FOREVER.” *R.N. Perham*



## *What does Bioprocess Engineering mean for you?*

The Laboratory of Bioprocess Engineering focusses on biotechnological processes for the production of chemicals by exploiting the synthesis capability of biocatalysts. The biocatalyst-based conversion of simple raw materials into value-added and/or bioactive compounds is especially interesting for reactions where chemical synthesis is restricted in selectivity or unfavorable in terms of reaction conditions.

Modern Bioprocess Engineering is based on a solid foundation in the natural sciences. The biological catalysts are understood on a molecular level and are no longer black boxes. Enzyme Technology and Systems Biotechnology are key methods in this area. These approaches – from fundamentals to process applications – will be explored both in teaching and research.

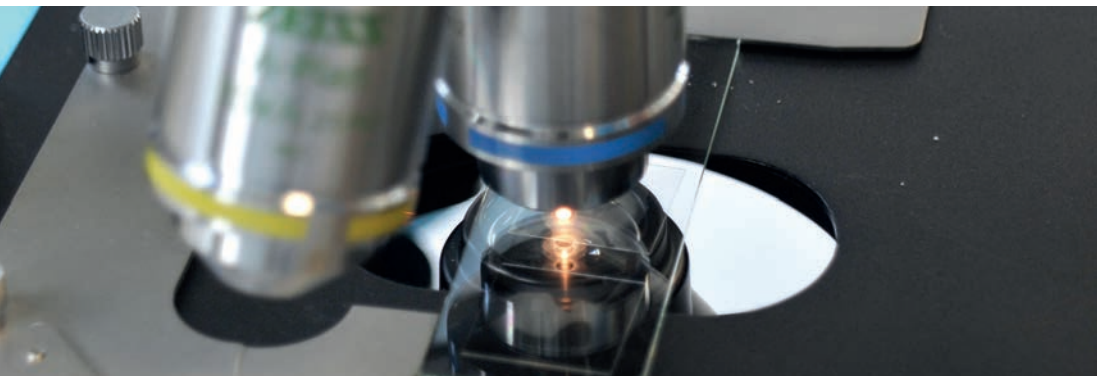
## TEACHING

The Laboratory of Bioprocess Engineering is covering all stages of bioprocess design. First-year students are introduced into the broad field of biochemical and chemical engineering by the lecture “Introduction into Biochemical and Chemical Engineering”. The lectures “Systems Biotechnology” aim on connecting typical engineering strategies such as modelling and mass balancing to biological systems. Hands-on application of these methods can be gained in Bachelor and Master theses, which are closely coupled to up-to-date research projects and can be part of any stage of bioprocess design from biocatalyst selection and characterization up to large scale fermentations. A “Virtual practical

course on Bioprocess Technology” allows the simulation and comparison of various bioprocesses and offers the possibility to investigate the direct impact of important process parameters. The lecture “Industrial Biotransformations” finally gives an overview of important industrially relevant bioprocesses and highlights the importance of integrated bioprocess engineering.

## RESEARCH

The Laboratory of Bioprocess Engineering is currently active in 3 areas: Enzymes & *in vitro* Technology, Whole Cells & Biotransformations, and Natural Products Biotechnology.



## Enzymes & *in vitro* Technology

Enzymes are used *in vitro* for reactions that are difficult to carry out by chemical means. These can be redox reactions, like the insertion of oxygen into C-H-bonds, which can be carried out selectively by enzymes. Another example is the synthesis of nucleotides in a single enzymatic step under mild reaction conditions without the need for protecting groups typically used in chemical synthesis. The enzymes are either synthesized with *in vitro* expression systems for screening purposes or produced in recombinant expression hosts.

## Whole Cells & Biotransformations

The research area Whole Cells & Biotransformations focusses on oxidative, mostly cofactor dependent processes for the production of valuable products, mainly based on renewable substrates. Genome mining and high-throughput screening is applied to detect and characterize promising new host strains and enzymatic

activities. Rational and integrated biocatalyst engineering strategies (e.g. metabolic engineering and reaction engineering) are exploited to set up biocatalyst platforms for the development of sustainable and industrially feasible bioprocesses.

## Natural Products Biotechnology

Many secondary metabolites and other natural products possess pharmaceutical relevance, for example, as antibiotics, cytostatic agents or immunosuppressants and are therefore beneficial to humans. Biotechnological approaches in the area of genetic, metabolic, and reaction engineering are pursued to produce natural products, which are difficult to obtain by isolation from their natural sources or chemical synthesis. The identification and activation of silent gene clusters of bacteria using bioengineering approaches is investigated in order to find new secondary metabolites with pharmaceutical interest.





# LABORATORY OF CHEMICAL REACTION ENGINEERING

PROF. DR. AGAR



## CURRICULUM VITAE

PROF. DR. PH.D. DAVID W. AGAR

Born	1956 in Danbury, Essex GB
Education	1974 – 1977 BSc Biochemical Engineering, University of Wales, GB
	1978 – 1980 Chemical Engineering, University of Houston, USA
Positions	1981 – 1995 BASF SE, Research, Production, Technical Support, Ludwigshafen/Rh., Germany
	Since 1997 Full Professor in the Department BCI of TU Dortmund

## RESEARCH INTERESTS

- » Process intensification
- » Microreactors
- » Reaction engineering for energy and environmental applications

## CONTACT

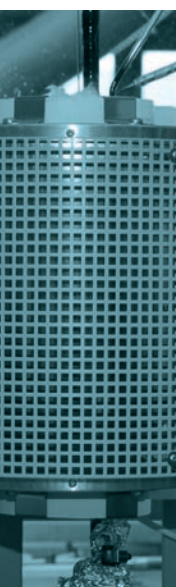
**Laboratory of Chemical Reaction Engineering**  
Department of Biochemical and Chemical Engineering  
TU Dortmund  
D-44221 Dortmund/Germany

Tel.: +49-(0)231-755-2697  
Fax: +49-(0)231-755-2698  
david.agar@tu-dortmund.de  
www.cvt.bci.tu-dortmund.de



# “THE FIRST THINGS THAT COME TO MIND WHEN THINKING ABOUT THE DEPARTMENT ARE COMPETENT GRADUATES WITH A SOLID SCIENTIFIC AND ENGINEERING EDUCATION.”

*Prof. Dr. Agar*



## *Why is heterogeneous catalysis so important for the chemical industry?*

As solids, heterogeneous catalysts can easily be recovered from the fluid reaction medium and re-used. Catalysis enables one to carry out reactions in smaller volumes, at lower temperatures and, most importantly, with high selectivities from the feedstock to the desired products. The downside of heterogeneous catalysis – that activities may be constrained by diffusive mass transfer – can be ameliorated by appropriate catalyst design.

## *What are microreactors?*

Microreactors are characterised by channel dimensions in the millimeter to sub-millimeter range and fabricated by special lithographic or other techniques. Heat and mass transfer processes can be enhanced to the point where the asymptotic chemical performance is achieved. Furthermore, microreactors eliminate the unwanted performance-diminishing stochastic phenomena present in many macroscale reactors.

## TEACHING

The (bio-)chemical reactor lies at the heart of every (bio-)chemical production unit. Its performance dictates both the choice of upstream and downstream processing steps and the overall plant efficiency. The need to understand both the complex chemical and physical phenomena taking place together with their highly non-linear behavior make chemical reaction engineering a particularly challenging discipline. Core courses in reaction engineering at the undergraduate level are offered separately for chemists, biochemical and chemical engineers. Emphasis is placed on the detailed analysis of reaction systems and reactors using mass and energy balances. After consideration of the underlying physical and chemical processes and their

quantification, the selection, design and optimization of idealized reactors is treated. The final section of the course deals with the application of these principles to industrial reactors. In the advanced reaction engineering Master's coursework multiphase chemical reactors and the modelling and simulation of complex reactions and reactors are dealt with. Electives available include heterogeneous catalysis, multifunctional reactors, computational fluid dynamics for reactors, industrial chlorine chemistry and electrochemistry. This selection is intended to cover key areas of chemical reactor engineering such as the design of chemical reactors, topical research, complex reaction systems and integrated production networks.

## RESEARCH

The research work carried out is divided into two main categories: process intensification and reaction engineering for energy and environmental applications. The effective evaluation of such systems entails a balanced combination of theoretical analysis, numerical simulation and experimental measurements together with an appraisal of the technical alternatives, economic and environmental aspects. The reaction systems examined, for example in hydrogen production and carbon dioxide recycle, are chosen on the basis of their technical and ecological relevance.

### Process Intensification

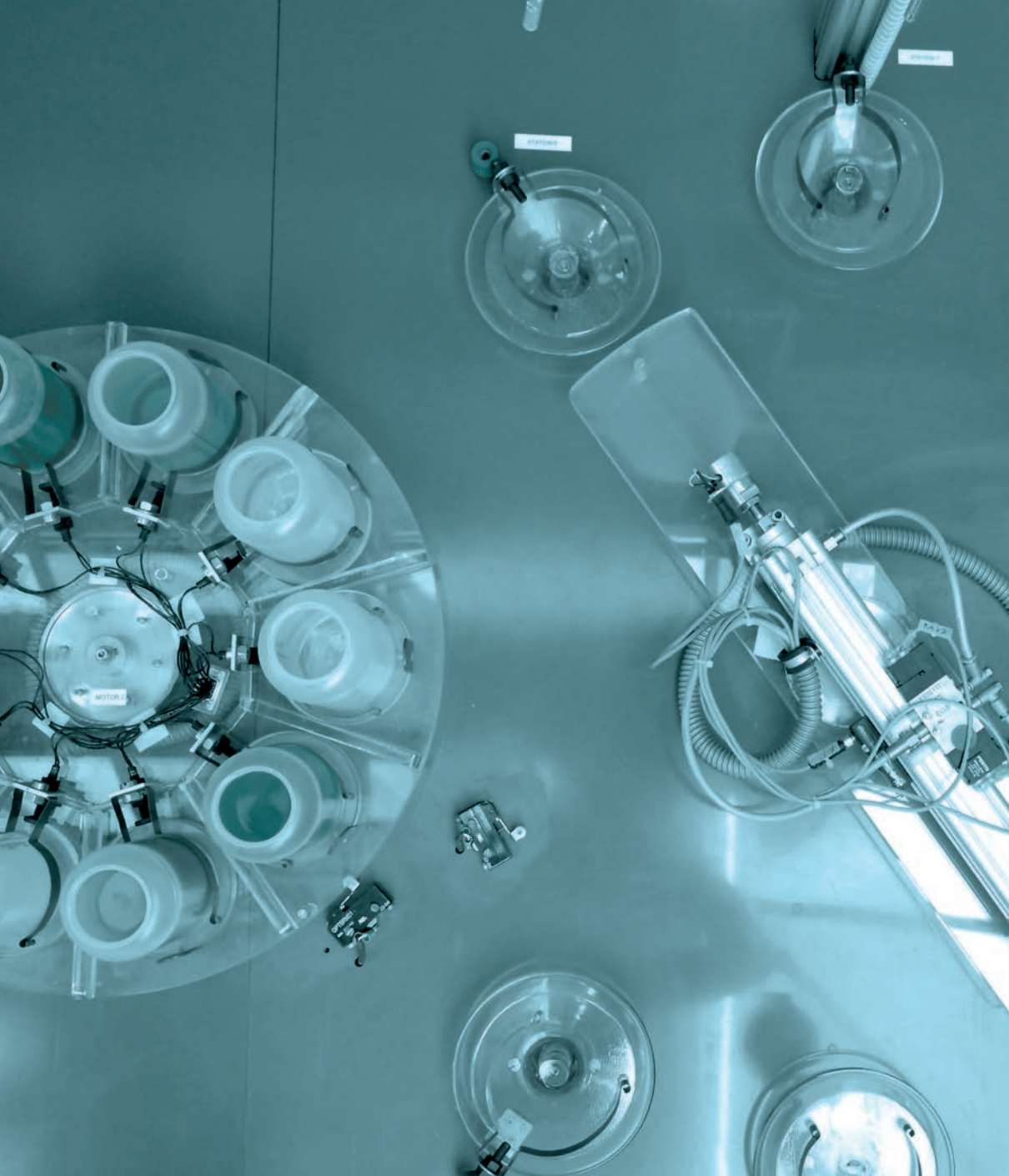
Process intensification seeks to improve reactor performance by enhancing heat and mass transfer in catalytic and multiphase reactions. Projects in this area include capillary microreactors, desorptive reactor cooling and adsorptive reaction enhancement and the use of 3D printers to devise novel multiphase microstructures. In the case of microreactors, liquid-liquid slug flow systems are being evaluated

for applications in extraction and suspension catalysis. A detailed analysis of the underlying forces and heat and mass transfer phenomena is being carried out and the challenge of numbering-up microchannels for highly parallelized industrial-scale plant addressed.

### Reaction Engineering for energy and environmental applications

Averting climate change by drastically reducing humanity's CO<sub>2</sub> footprint is one of the major challenges presently facing mankind. We have developed innovative biphasic solvents for recovering CO<sub>2</sub> from flue gases and are working on the adsorptive capture of CO<sub>2</sub> from both cement process waste gas and air. The functionalization and utilization of CO<sub>2</sub> as a raw material for the chemical industry is the subject of ongoing investigations in collaborative industrial research projects. Finally, we are engaged in several externally funded projects on the CO<sub>2</sub>-free manufacture of hydrogen and generation of energy via thermal non-catalytic methane pyrolysis.





# LABORATORY OF PROCESS DYNAMICS AND OPERATIONS

PROF. DR. ENGELL





## CURRICULUM VITAE

PROF. DR.-ING. SEBASTIAN ENGELL

Born	1954 in Düsseldorf, Germany
Education	1973 – 1978 Electrical Engineering, Ruhr-Universität Bochum
PhD	1981 On filtering from the point of view of optimal transmission of information, Department of Mechanical Engineering, University of Duisburg
Postgraduate Qualification (Habilitation)	1982 – 1986 University of Duisburg and McGill University, Montréal, Canada 1987 Habilitation, University of Duisburg
Positions	1986 – 1990 Group Leader Automation in the Process Industries, Fraunhofer-Institut IITB Karlsruhe  Since 1990 Full Professor in the Department BCI of TU Dortmund

## RESEARCH INTERESTS

- » Performance optimization by advanced process control
- » Management of complex dynamic systems
- » Design and validation of automation software
- » Scheduling
- » Optimization-based support for process design

## CONTACT

### Laboratory of Process Dynamics and Operations

Department of Biochemical and Chemical Engineering  
TU Dortmund  
D-44221 Dortmund/Germany

Tel.: +49-(0)231-755-5126

Fax: +49-(0)231-755-5129

sebastian.engell@tu-dortmund.de

www.dyn.bci.tu-dortmund.de



# “THE CHALLENGE OF OPERATING CHEMICAL AND BIOCHEMICAL PLANTS IS THE COMPLEXITY AND LIMITED PREDICTABILITY OF THEIR BEHAVIOUR.” *Prof. Dr. Engell*



## *What benefit has the society from your research?*

Our goal is that chemical or biochemical transformations are performed with minimum consumption of resources and energy and reliably meeting quality constraints so that re-work or disposal of waste is avoided.

## *Where do you see the department in ten years?*

In the top 10% in Europe, as today, probably with an even stronger focus on the development and operation of biotechnological processes.

## *What makes most fun teaching students?*

To demonstrate that by transforming real-world problems into a mathematical formalism and applying mathematical results, one obtains firm statements and important insights that cannot be obtained by trial and error or heuristic arguments. So an implicit element of our teaching is to enhance the capabilities of the students to represent problems formally and to use mathematical and computational tools for their solution.

## TEACHING

Process control and operations deals with the problem how to use the degrees of freedom that are available in the operation of a chemical or biochemical plant (flow rates, temperature settings etc.) such that the plant exhibits the best possible performance while fulfilling safety and environmental constraints. The presence of variations in the feeds and utilities, of ageing, and of not precisely predictable behaviors of the units necessitates feedback control to meet product specifications and to ensure efficient operation.

The group provides courses for the students in Biochemical and Chemical Engineering as well as for the students of the Master Program Automation and Robotics. Most courses are taught in English. Compulsory courses for Bachelor students are Introduction to Programming,

Process Dynamics and Control and Process Automation. We make sure that all graduates from TU Dortmund in Biochemical and Chemical Engineering have a basic understanding of plant dynamics and control so that they can grasp the essential aspects of plant operation and automation in their professional work. Courses offered on the Master level include Process Performance Optimization, Control Theory and Applications (Master A&R), Logic Control, Dynamic Models, Data-based Modelling, Multivariable Control, Advanced Process Control, and Batch Process Operations. Several prominent experts from the chemical industry, Dr. Stefan Krämer (INEOS Cologne), Dr. Guido Dünnebier (BTS) and Dr. Norbert Kuschnerus (former Head of the Division of Operation Support and Safety of BTS and Chairman of NAMUR) contribute to our teaching.

## RESEARCH

### Optimizing Process Control

The key idea behind our research in the control of processing plants is to use feedback control to optimize the performance of the plants rather than tracking predefined set-points. Plant limitations and quality parameters are included in the optimization as constraints. Applications include chromatographic separations, reactive distillation, and polymerization reactors where we have developed such a strategy for a real industrial reactor in cooperation with industry. A critical issue in model-based control and optimization is that the inevitable discrepancy between the behaviour of the model and that of the real plant leads to suboptimal results and can even cause instability. We are developing two approaches to cope with this problem, multi-stage nonlinear model-predictive control and iterative optimization based on modifier adaptation.

### Modelling and control of biochemical processes

Biochemical production processes are difficult to model and to control because of the complexity of the biochemical reaction networks and the lack of measurements. We have developed a novel approach to modelling which is based on elementary modes of the reaction network, thus bridging between full biochemical models and formal kinetics.

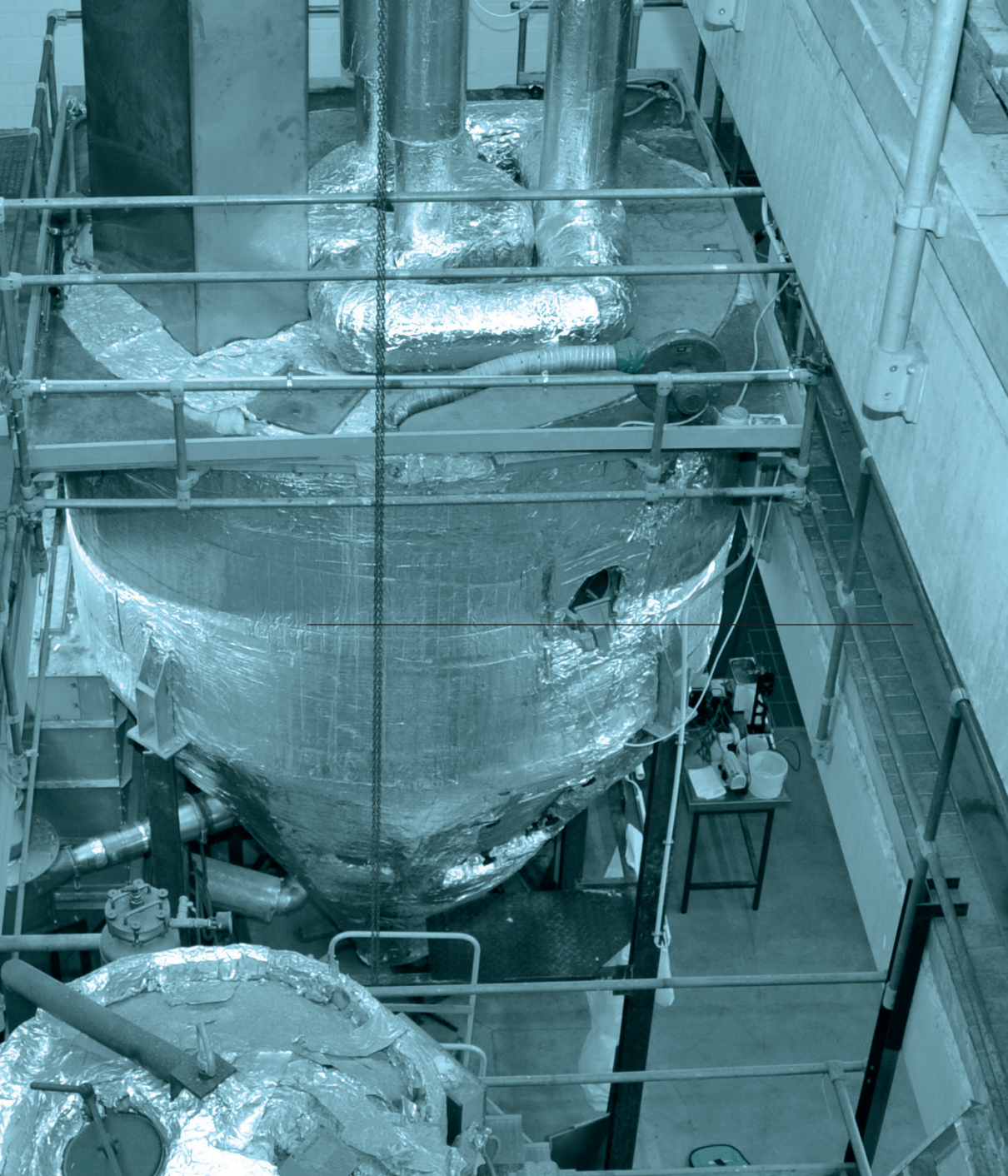
### Plant management and scheduling

Our work concerns two aspects of plant management: coordination between different plant units to achieve a globally optimal operation of a production site, and scheduling of plant operations. In site-wide optimization, we develop distributed algorithms that mimic the behaviour of markets. This has the advantage that convergence to the site-wide optimum can be achieved without exchanging information about the internal behaviour and cost structures of the different units. Mathematical programming, evolutionary algorithms and reachability analysis of timed automata are employed to solve scheduling problems. Special attention is paid to the handling of uncertainties, e.g. varying demands or product yields.

### Process development

We develop new tools for the support of the design of chemical processes along two lines: New algorithms for the solution of the optimization problems that arise in design optimization and exhibit many local optima by combination of mathematical programming and evolutionary algorithms, and methods and tools for optimization based support in early design phases when only limited and uncertain information is available.





# LABORATORY OF SOLIDS PROCESS ENGINEERING

PROF. DR. THOMMES

# CURRICULUM VITAE

PROF. DR. RER. NAT. MARKUS THOMMES



Born	1978 in Magdeburg, Germany
Education	1997 – 2001 Pharmacy, Martin-Luther-University Halle-Wittenberg
PhD	2006 Institute of Pharmaceutics and Biopharmaceutics, Heinrich-Heine-University Düsseldorf, Germany
Postgraduate Qualification (Habilitation)	2006 Senior Postdoctoral Researcher at the Institute of Pharmaceutics and Biopharmaceutics Heinrich-Heine-University Düsseldorf 2007 Postdoctoral Researcher at the Department of Industrial and Physical Pharmacy Purdue University, West Lafayette, Indiana, USA 2008 – 2014 Assistant Professor at the Institute of Pharmaceutics and Biopharmaceutics Heinrich-Heine-University Düsseldorf
Positions	Oct. 2014 Interim Professorship for Particle Technology in the Department BCI of TU Dortmund Since 2015 Full Professor in the Department BCI of TU Dortmund

## RESEARCH INTERESTS

- » Product design by spray drying
- » Spray formation, design of nozzles and spraying devices
- » Gas cleaning by particle removal using electrostatic precipitators and wet scrubbers
- » Determination of electrical properties of solid materials
- » Granulation for pharmaceutical applications
- » Formulation and process development of solid dosage forms

## CONTACT

### Laboratory of Solids Process Engineering

Department of Biochemical and Chemical Engineering  
TU Dortmund  
D-44221 Dortmund/Germany

Tel.: +49-(0)231-755-6088

Fax: +49-(0)231-755-3961

markus.thommes@tu-dortmund.de

www.fsv.bci.tu-dortmund.de



# “ARTIFICIAL INTELLIGENCE WILL COME UP IN THE NEAR FUTURE.”

*Prof. Dr. Thommes*



*Can you explain me in short what you and your group are busy with?*

I have been working for many years in the area of pharmaceutical product design. Pharmaceutical products have many unique and very specific design requirements. My focus is on formulation optimization and process design in the field of solids particle engineering. Granulation, Extrusion, and Spray Drying are unit operations I am currently investigating. We developed several pharmaceutical products currently on the market for increasing the quality of a patient's life.

*What makes Dortmund so special for you to be here?*

I enjoy working at the intersection of Biology, Chemistry, Engineering, and Pharmacy. I am convinced that most of the future challenges in Life Sciences will be interdisciplinary in nature. The Department of Bio- and Chemical Engineering here at Dortmund provides the perfect infrastructure for my research, because of the diversity of their research groups. It is a very unique place in Europe for this type of work.

*Is teaching and doing research a conflict for you?*

Teaching and research are opposite sides of the same coin. At the university level, as Wilhelm von Humboldt pointed out, there is no research without teaching and vice versa.

## TEACHING

Process engineering is one major aspect in the education of biochemical and chemical engineers. It describes the transformation of raw materials into a final product. Mechanical process engineering is focused on the mechanical unit operation rather than the thermal and chemical processes.

The course “Mechanical Process Engineering Part 1” is obligatory for biochemical and chemical engineering bachelor students. It imparts knowledge about the properties of compounds such as size, interfacial tension and density, as well as the methods used to determine these properties. An overview about the most relevant unit operations like blending, milling and granulation is given. The students gain knowledge about a wide field of process conditions, material properties as well as different types of equipment. This course sets the base for the course “Mechanical Process Engineering Part 2”, which is mandatory for the biochemical and

chemical engineering graduate students. In this course, selected topics from the bachelor course are discussed more in detail.

The course “Pharmaceutical Process Engineering” deals with the particular requirements to pharmaceutical products. To help the students understand the requirements for pharmaceutical product design, this course includes basic lectures of human anatomy and physiology. General concepts of manufacturing solid, liquid and semisolid dosage forms are introduced.

The course “Particle Technology” is designed for students of the Process System Engineering program. The course is provided in English language and is an elective for biochemical and chemical engineering students. It covers some aspects of Mechanical Process Engineering with particular focus on solid particle properties and processing.

The courses “Polymer Processing” is an elective for biochemical and chemical engineering students in the master’s program. It is offered in close collaboration with representatives from different industries and gives insights into state of the art polymer processing science from an industrial point of view.

“Dust Removal Technology” is a recent challenge in many industrial applications. This elective for biochemical and chemical engineering students of the master’s program deals with general concepts and recent developments. Wet scrubbers as well as electrostatic precipitators are introduced in more detail.

## RESEARCH

The research topics at the Laboratory of Solids Process Engineering can be classified into the focus groups dispersing, dust removal and granulation / extrusion. While those projects dealing with fundamental research are mainly funded by public grants, other projects that are funded by industrial partners deal with applied research.

### Dispersing

Submicron particles are an important part in chemical, food and pharmaceutical applications. The design of a robust and simple spray system for these particles is one of our research aims. A spray system developed in our group combines a new pneumatic nozzle

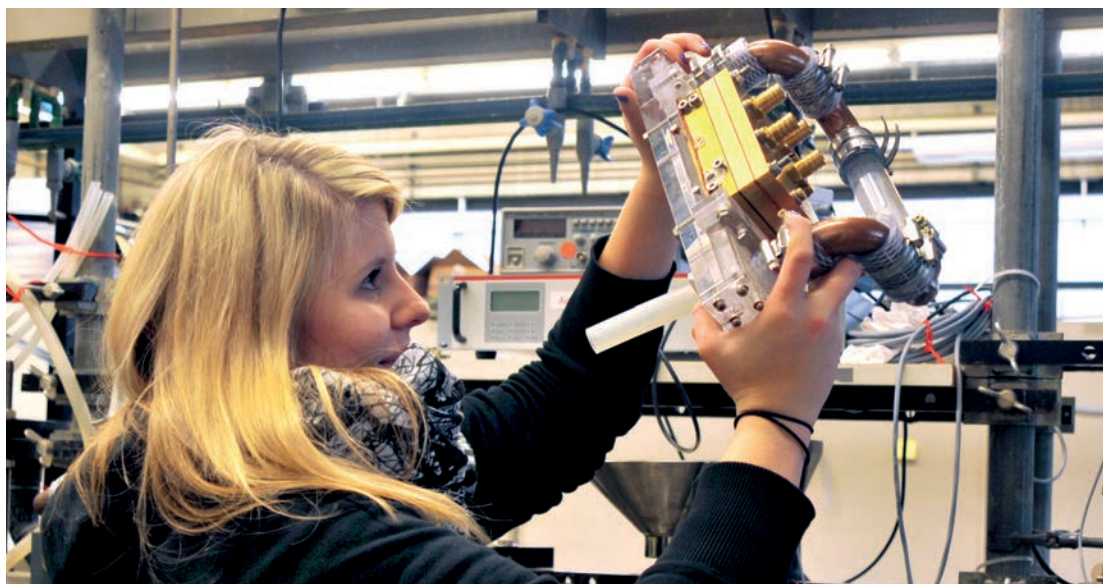
to generate small droplets and an adapted droplet separator in order to control the droplet size distribution. This system enables the continuous generation of fine droplets of a desired size without the need of a later classification step.

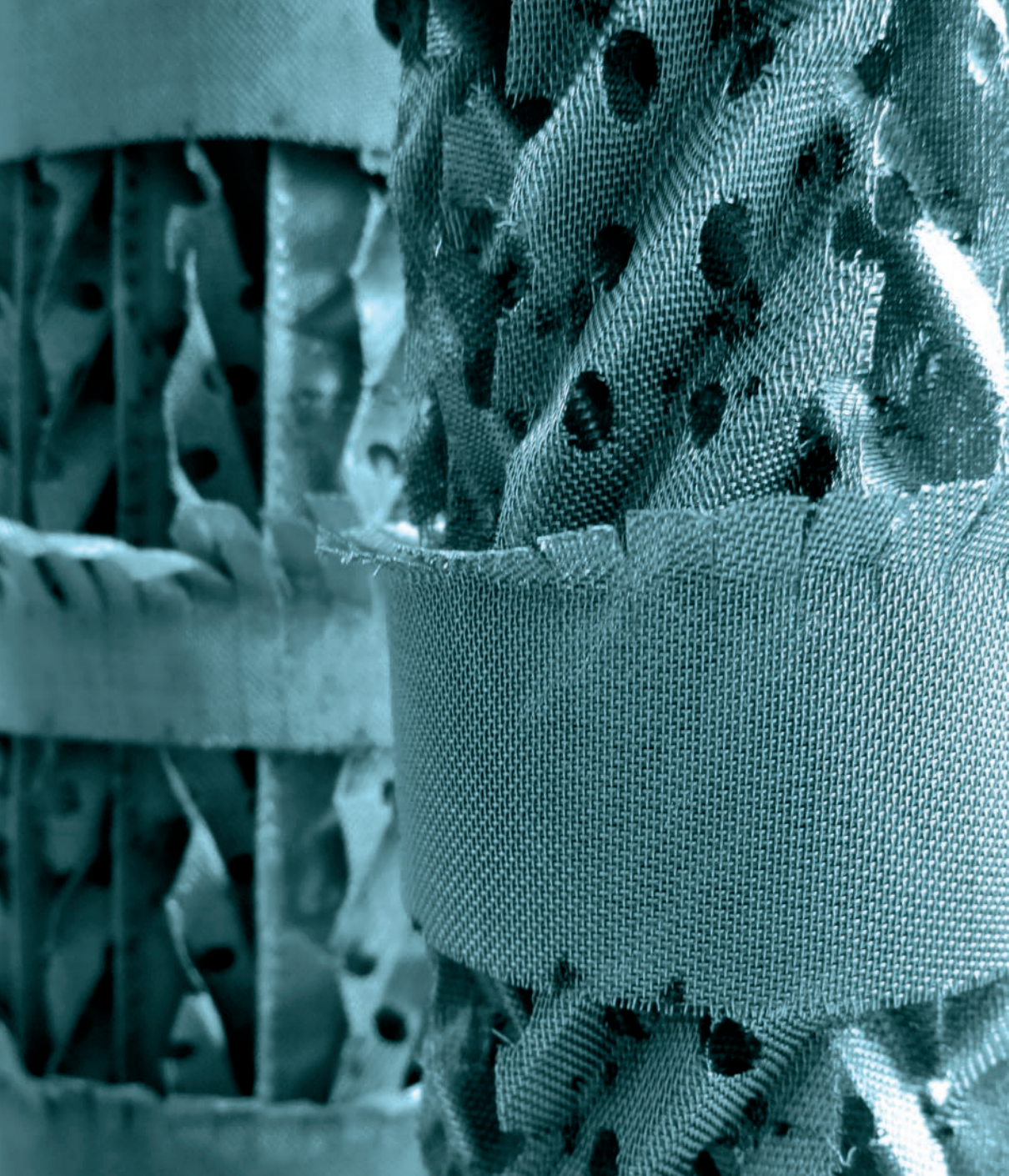
### Dust removal

The collection of particles out of gas streams is not only interesting for combustion processes. In order to produce uniform particles, spray dried solids can be efficiently separated by means of electrostatic precipitation. Until now, the electrostatic separation cannot be fully described mathematically. Therefore, examinations of the electrostatic behavior of particles in the electrostatic precipitator are necessary for designing models. Finally, these models can help increase separation efficiency and help predict separation effects.

### Granulation

The granulation process is an important unit operation and crucial for powder handling. Different granulation techniques are investigated in order to tailor the material properties like particles size, shape and porosity. One focus lies in the twin screw extrusion process as an advanced continuous manufacturing technique. Advantages of this technique include the combination of several unit operations in one machine, that would otherwise be done sequentially. Due to its efficiency and versatility, it is becoming more and more relevant in many industries.





# LABORATORY OF FLUID SEPARATIONS

PD DR. HELD





## CURRICULUM VITAE

PD DR. HELD

Born	1980 in Bogen
Education	2001 – 2007 Chemical Engineering, TU Dortmund
PhD	2012 Laboratory of Thermodynamics, TU Dortmund
Postgraduate Qualification (Habilitation)	2012 – 2017 Thermodynamics of Bioreactions, TU Dortmund
Positions	2017 - 2020 Akademischer Oberrat at the Laboratory of Thermodynamics at TU Dortmund and Group leader of the group “Biothermodynamics”  Since 2020 Substitute Professor and head of the Laboratory of Fluid Separations at TU Dortmund and Group leader of the group “Biothermodynamics”

## RESEARCH INTERESTS

- » Biothermodynamics and Bioreactions
- » Electrolytes
- » Energy Storage
- » Thermodynamic Modelling
- » Process Intensification
- » Membrane Separations

## CONTACT

**Laboratory of Fluid Separations**  
Department of Biochemical and Chemical Engineering  
TU Dortmund  
D-44221 Dortmund/Germany

Tel.: +49-(0)231-755-2086  
Fax: +49-(0)231-755-3035  
christoph.held@tu-dortmund.de  
www.fvt.bci.tu-dortmund.de



# “THE SECRET OF SUCCESS IS A DEEP UNDERSTANDING“ *PD Dr. Held*

*Dr. Held, what is your key to success and what is your vision in science?*

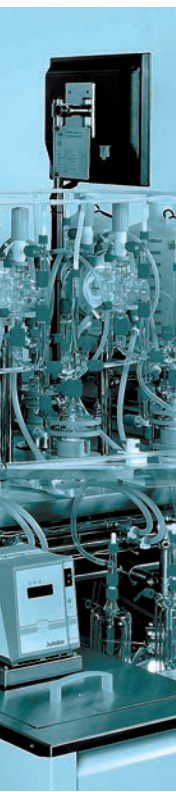
The objective of science is to deeply understand the phenomena from natural sciences and to transfer this knowledge to respective needs. Such needs could be solving engineering and social problems, teaching students, or establishing cooperation. I believe that different research fields more and more grow together, and this overlap will bring our research to the next level.

*What benefit has the society from your research?*

In my mind biochemical and chemical engineering will experience a golden age. Why? Because some of the key social needs can be solved by technologies that already exist in engineering and that needs further adaption and development. The most prominent example is the climate change, which forces us to contribute to a net-zero CO<sub>2</sub> emission society in the future. Our research promotes the development of innovative separation technologies, thus contributing substantially to a reduction of CO<sub>2</sub> footprint, a reduction of energy consumption and an increase of raw material efficiency.

*Do we need live lectures in the future?*

Sure! It is beneficial to use digital methods to support teaching nowadays. However, digital teaching cannot be the single solution to educate and train students from the BCI. Our students are young, motivated, and – diverse! Most important – they are still humans, individuals, who require physical interactions as well as face-to-face discussion. Lectures, exercises, group work, lab courses – all these needs live discussions to teach students what fluid separations are about. Certainly, future teaching will benefit from the advances of both – digital and live events. I believe that hybrid teaching is the future. Thus, the amount of work that goes into teaching will definitively not decrease.



## TEACHING

Fluid separation processes are essential in the chemical, petrochemical and pharmaceutical industry. Most industrial processes apply unit operations such as distillation, absorption and extraction for purification.

The Laboratory of Fluid Separations offers various possibilities for students to learn more about fluid separation processes, starting from the basic understanding of mass and heat transfer up to a detailed view on specific separation processes. For example, the lecture “Introduction to fluid separations” deals with basic topics of thermal separation processes such as balancing, design, dimensioning and theoretical stages. The lecture “membrane separations and hybrid separation processes” covers the fundamentals of

innovative membrane separations and hybrid separations as well as the computer-aided modeling. The lecture “Column design for thermal separation processes” deals with the fundamentals of dimensioning columns for (reactive) distillation and absorption.

## RESEARCH

### Process optimization

Process optimization is the pinnacle of a process analysis and design. We are working on optimization-based frameworks for process synthesis and intensification. In the area of conventional separations, we have proposed a methodology for an automatic synthesis of distillation-based separations, which minimizes the energy demand for separation of azeotropic mixtures. An

automatic procedure for finding best solvents for extractive processes has been developed as well. It screens conventional and innovative sustainable solvents and evaluates their use in a defined process, seeking for a potential we might oversee otherwise. We also work on optimization-based frameworks tailored for specific types of innovative integrated processes. Recent projects in that area deal with dividing wall columns, pervaporation-based hybrid separations and membrane reactors. These methodologies aid decision-making by proving the applicability of the process, generating and evaluating most promising process configurations and finally helping to choose the best process design.

### Research on membranes

Our research on membranes focuses on process intensification by combining membrane separations with chemical reactions or conventional separation methods such as distillation or extraction to achieve efficient hybrid separation processes. In this approach, we use experimental investigations to establish detailed mass transfer models for the membranes and combine these with models for other separation processes. For this purpose, we are equipped with sophisticated hardware and software tools for modeling, simulation and optimization as well as a wide variety of equipment to perform membrane separations such as reverse osmosis, organic solvent nanofiltration and pervaporation in lab scale. Furthermore, state-of-the-art

analysis techniques are available in our laboratories. Current topics are the separation of homogenous catalysts from complex reaction mixtures and the recovery of rare earth metals from seawater.

### Research on Rotating Packed Beds

Rotating Packed Beds (RPBs) apply a centrifugal field to improve the performance of mass transfer processes; thus, RPBs have high flexibility due to the adjustable rotational speed which can be easily adopted to varying mass streams (e.g., of liquid stream and vapor stream). The scientific activities of our RPB group are focusing on the unit operations absorption, stripping, and distillation at pilot scale. The RPBs are investigated regarding operation parameters like rotational speed and design parameters like packing types. This helps to define the process window (pressure drop) and to understand transport behavior (e.g., mass transport coefficients). It is the vision of RPBs to replace technical apparatuses with huge amount of required space, to increase dramatically the mass transport and therewith kinetics of hybrid separations, and to increase the operational window towards fluid mixtures with high viscosity. Furthermore, tailor-made packings are manufactured at our laboratory with the help of 3D-printing technology and characterized concerning their performance. Besides the university research on RPBs and the connection to other labs within BCI, work closely together with other universities and with the chemical industry.





# LABORATORY OF PROCES AUTOMATION SYSTEMS

PROF. DR. SERGIO LUCIA



## CURRICULUM VITAE

PROF. DR. SERGIO LUCIA

Born	1987 in Zaragoza, Spain
Education	2005 – 2010 Electrical Engineering, University of Zaragoza
PhD	2010 – 2014 Robust Multi-stage Nonlinear Model Predictive Control, TU Dortmund
Postgraduate Qualification	2015 – 2017 Postdoctoral researcher at the Otto-von-Guericke University Magdeburg 2016 Postdoctoral Fellow at Department of Chemical Engineering, Massachusetts Institute of Technology, USA 2017 – 2020 Assistant Professor at the Department of Electrical Engineering and Computer Science of TU Berlin
Positions	Since 2020 Professor in the Department BCI of TU Dortmund

## RESEARCH INTERESTS

- » Advanced process control
- » Optimal operation of complex dynamic systems
- » Data-based modeling
- » Machine learning for chemical engineering

## CONTACT

**Laboratory of Process Automation Systems**  
Department of Biochemical and Chemical Engineering  
TU Dortmund  
D-44221 Dortmund/Germany

Tel.: +49-(0)231-755-5341  
Fax: +49-(0)231-755-5129  
sergio.lucia@tu-dortmund.de  
www.pas.bci.tu-dortmund.de



# “UNDERSTANDING COMPLEX MATHEMATICAL CONCEPTS IS VERY USEFUL – BUT IT CAN ALSO BE FUN!”

*Prof. Dr. Sergio Lucia*

*Can you explain me in short what you and your group are busy with?*

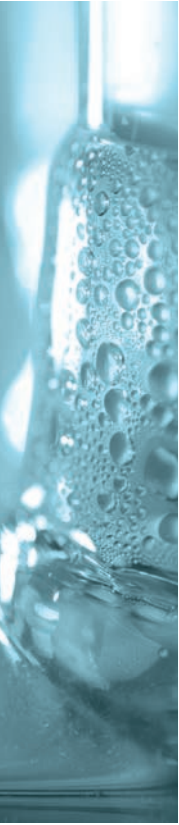
The main goal of our research is to develop new ideas and methods to operate and monitor complex chemical and biochemical processes systematically, while requiring the minimum possible amount of resources and strictly meeting all quality and safety restrictions. To achieve these goals, we work at the intersection between the research fields of automatic control, numerical optimization and machine learning.

*What makes most fun teaching students?*

Being able to transmit the enthusiasm for mathematical tools to engineering students. It is really motivating to see how the initial skepticism towards the abstract concepts that are usually part of my teaching transforms in many cases in a deep interest and understanding.

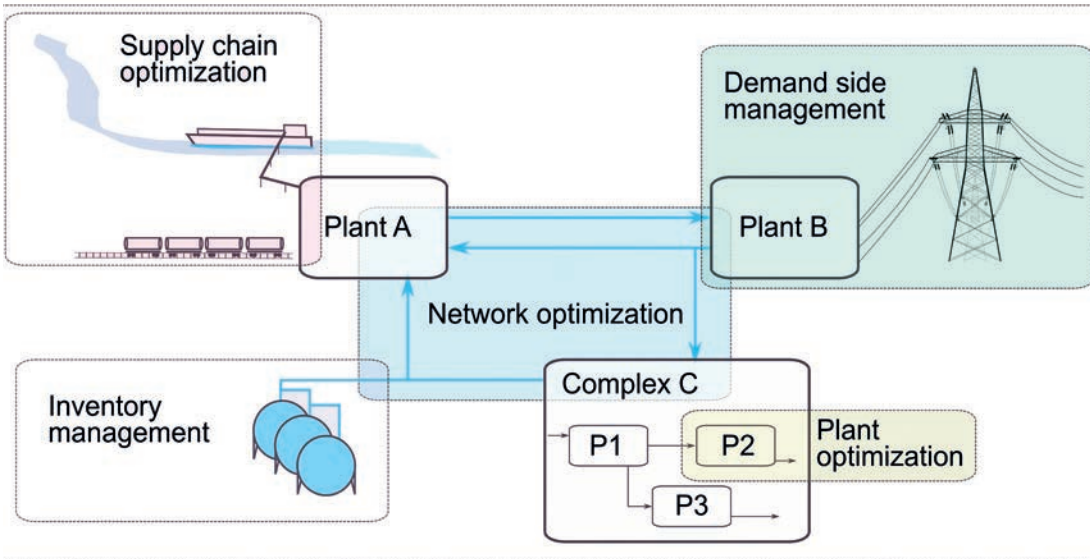
*What makes TU Dortmund so special for you to be here?*

I spent at TU Dortmund four great years between 2010-2014 to obtain my PhD at the BCI Department. Before coming back as a Professor in 2020, I was teaching and researching for six years in several universities and could see from firsthand that the BCI Department has very high-quality standards. Now it is my turn. I am very excited to contribute to make BCI an even better place both for students and researchers.



## TEACHING

Together with the laboratory of Process Dynamics and Operations, the teaching of our group is focused on the field of process control and dynamical systems. We mainly cover the topics of how to simulate, monitor and control complex systems, such as a chemical or biochemical plant, in a systematic manner. To achieve this goal, different mathematical and computational tools ranging from linear control systems theory, numerical optimization or advanced control techniques are covered in several courses at the bachelor's and master's level. Our teaching also includes notions of artificial intelligence and machine learning that are of increasing importance for the future



chemical and biochemical engineers. The new module Machine Learning Methods for Engineers covers basic concepts and includes the realization of a small project to gain first hands-on experience on a machine learning task in the chemical and biochemical engineering field.

## RESEARCH

### Model-based control

One of the core ideas of our research is to develop intelligent control and operation strategies based on models of the plants under study. These models can be used to make predictions of the expected behavior and to optimize the performance of the plant, subject to strict quality and safety restrictions. Since the available models are never perfect, our research focuses on new ideas that can deal with uncertainty in models and still compute automatic control strategies that are safe and lead to improved performance when compared to traditional techniques.

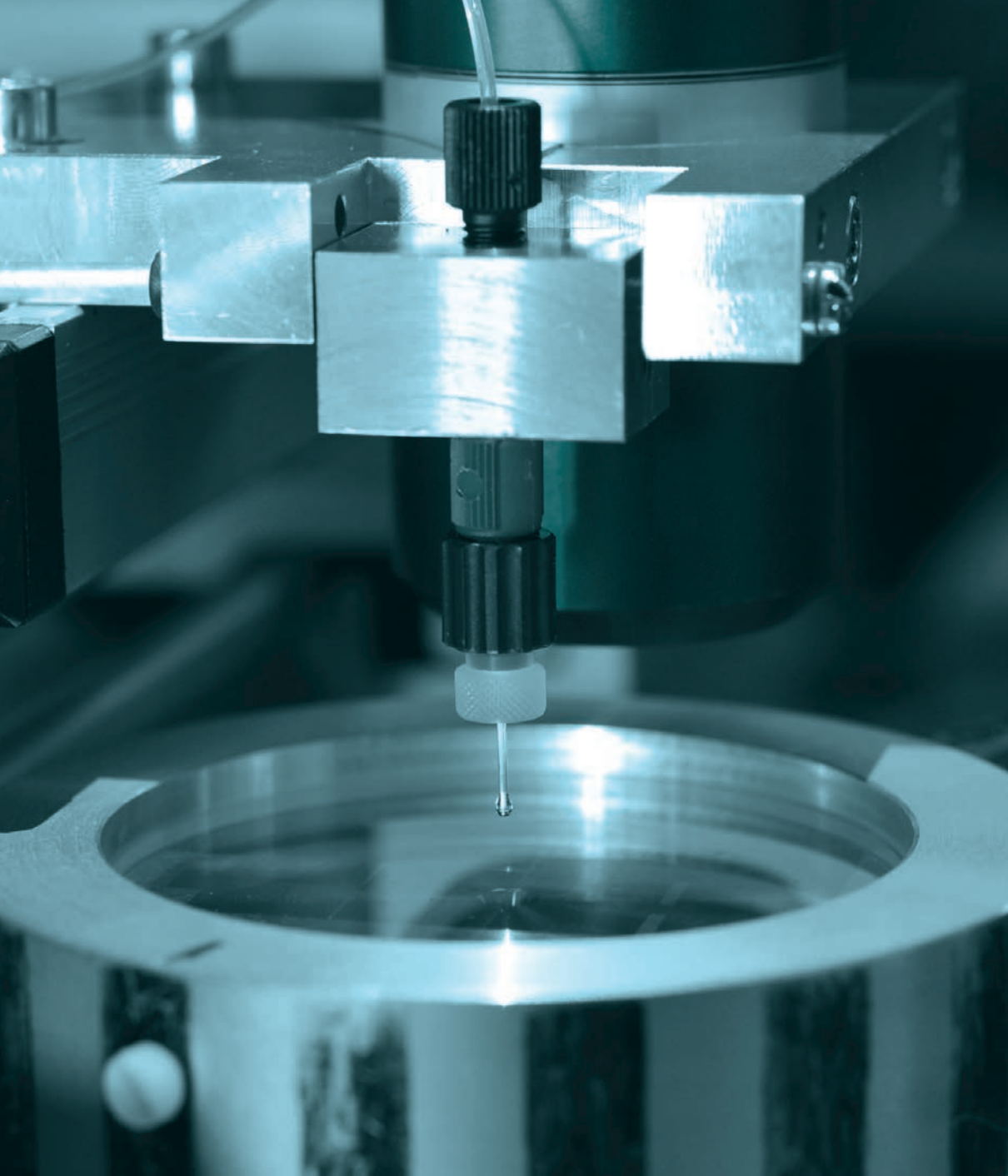
### Machine learning and control

Large amounts of process-related data are increasingly being available, either in the form of actual measurement information in industrial plants or in the form of artificial data, which can be generated with detailed models that accurately describe a chemical or biochemical process. To take advantage

of the available data and achieve better control and operation of complex processes, we develop new ideas that combine control theory and machine learning. For example, we use machine learning techniques to develop hybrid models that combine physical knowledge and measurement data of a process, leading to more accurate predictions, which can then be used in model-based control. Machine learning can also help to simplify the computations of complex controllers, which otherwise could not be applied in practice to control a process in real time. Finally, ideas from the field of reinforcement learning can help to continuously improve and adapt the model-based controllers that have been designed, helping to the maintainability of advanced controllers.

### Advanced analytics in the loop

Last years have witnessed the development of new advanced process analytics technology. While traditionally they have been used for offline analysis, recent developments in computational methods make it possible to apply advanced quantitative techniques to precisely control a process with a level of detail that was not previously possible. In our future research, we plan to study how new advanced analytics techniques can be integrated in advanced operation algorithms to realize the full potential of intelligent control.



# LABORATORY OF FLUID MECHANICS

PROF. DR. EHRHARD





## CURRICULUM VITAE

PROF. DR. -ING. PETER EHRHARD

Born	1956 in Heidelberg, Germany
Education	1984 Mechanical Engineering, University of Karlsruhe
PhD	1988 Fluid Mechanics, University of Karlsruhe
Postgraduate Qualification (Habilitation)	1988 – 1989 Postdoc at Engineering Sci. & Appl. Math., Northwestern University, USA 1995 Habilitation, University of Karlsruhe 2002 Prof. of Fluid Mechanics, Mechanical Engineering, University Karlsruhe
Positions	1984 – 1988 Researcher, Research Centre Karlsruhe 1990 – 1994 Head of Basic Research Group, Research Centre Karlsruhe 1995 – 2000 Head of Fluid and Heat Technology Division, Research Centre Karlsruhe 2000 – 2006 Head of Micro Fluid Dynamics Division, Research Centre Karlsruhe Since 2006 Professor in the Department BCI of TU Dortmund

## RESEARCH INTERESTS

- » Flows in presence of free interfaces
- » Flow and transport phenomena in micro-channels
- » Interaction of flow and particles
- » Stability of flows
- » Convective transport of heat and mass in flows

## CONTACT

### Laboratory of Fluid Mechanics

Department of Biochemical and Chemical Engineering  
TU Dortmund  
D-44221 Dortmund/Germany

Tel.: +49 (0)231-755-3252  
Fax: +49 (0)231-755-3209  
peter.ehrhard@tu-dortmund.de  
www.sm.bci.tu-dortmund.de



# “NEW VISIONS CAN NEVER BE REALIZED WITHOUT A BASIC UNDERSTANDING OF THE PHYSICS INVOLVED.”

*Prof. Dr. Ehrhard*



*I heard that you have set up a micro-flow laboratory. Can you tell me more about it?*

When I came to Dortmund in 2006, I started to set up our micro-flow laboratory, which was essentially completed in 2009. The reason for this rather lengthy gestation was mainly due to funding questions. Its core component is a high-resolution optical microscope, which not only allows us to look into micro-channels of as little as  $50\mu\text{m}$  width, but also enables us to measure two components of the velocity field and height-averaged temperature or concentration fields within such micro-channels. For this purpose, two pulsed lasers are employed to illuminate the micro-channel at two well-controlled points in time. As a consequence of the pulsed (or continuous) illumination, we receive from small fluorescent particles, or from dissolved fluorescent dyes within the fluid, fluorescence light emissions which are registered by a CCD camera. From these images, the information sought can be inferred by means of statistical and image-processing techniques. These methods are termed micro-particle-image velocimetry ( $\mu\text{PIV}$ ) and micro-laser-induced fluorescence ( $\mu\text{LIF}$ ). In addition to these measuring techniques, syringe pumps, precision scales, and electrical units for the temporal control of multiple electrodes within the micro-channels are needed to implement well-defined flows within such channels.

*Please complete this sentence: The first thing in my mind when thinking about the department is...*

...related to the familiar atmosphere between the faculty and between the students. I still find it amazing that most of the students in a given year not only know their whole peer group, but are even acquainted with a large number of students in the preceding or following years. It is a great pleasure to work in such an atmosphere.

## TEACHING

The undergraduate course in fluid mechanics imparts the basic principles of fluid flow. The fundamentals are presented at various levels of complexity, dictated by the technical applications. Several elective courses are subsequently offered in the Bachelor and the Master programs for both Biochemical and Chemical engineers, which deal with:

- » Numerical methods in fluid mechanics (CFD),
- » Measuring techniques in fluids,
- » Free-interface and multiphase flows,
- » Flow and transport in micro-channels,
- » Energy process technologies

## RESEARCH

Two examples of research projects are described below. Further projects in the fields of (electrokinetic) micro-flows, various interfacial flows, the interaction of flows and particles, and energy technologies are conducted using similar theoretical and experimental methods.

### Measurement of spreading droplets on rotating substrates

For various coating technologies, the spreading of liquids on a substrate is of great importance. One example of such a coating process is the so-called spin coating, where a liquid droplet is placed on a resting substrate, which is subsequently rotated to accelerate liquid spreading. In his Ph.D. thesis, K. Boettcher has developed a sophisticated model for this spreading flow, which now needs to be validated. For this purpose, a highly instrumented version of the spin-coating set-up has been developed and installed in our laboratory. A parallel optical arrangement, the so-called Schlieren technique, is used to measure the footprint of the droplet on the substrate. This allows one to ascertain the wetted area (and diameter) of the spreading droplet with high precision. Likewise instabilities in the spreading process can be detected and correlated with the transition from a rotationally-symmetric to a fully-three-dimensional droplet. All this may be inferred from the images generated by this Schlieren system.

Furthermore, the automated deposition of a droplet with a defined volume can be realized by means of a syringe pump and an injection needle, in conjunction with a control unit. The deposition unit is mounted on a linear translation bed, and is moved to the center of the substrate prior to droplet deposition and then withdrawn immediately after deposition, to allow an undisturbed birds-eye-view onto the droplet with the Schlieren system during the

entire spreading process. Finally, the blue cylinder represents the measuring head of a confocal chromatic distance sensor. This sensor is also traversed (radially) across the spreading droplet at particular times, the traversal taking less than a second. During this traversal, the sensor takes 2000 measurements of the distance between the optical head and the liquid/air interface with an accuracy of greater than 2 microns. These data yield precise information on the droplet contour and on the contact angle – information not available from the Schlieren system.

### Measuring techniques for flow and concentration fields in micro-channels

Models developed for the simulation of flow and transport processes in lab-on-a-chip applications need to be verified by direct measurements of the simulated quantities. Important parameters in micro-mixers, for example, are the flow velocity and the concentration of a dissolved species. The micro-measuring system uses the movement of suspended micro-spheres to deduce the complete velocity field in the focal plane of a microscope. This technique is called micro-particle-image velocimetry ( $\mu$ PIV). A similar set-up can also be used to measure the concentration of a dissolved fluorescent dye, and hence its height-averaged concentration field, with so-called micro-laser-induced-fluorescence intensity measurements ( $\mu$ LIF). Both quantities can be captured in a very short time interval, i.e. quasi instantaneously. The spatial resolution in such measurements can be as good as 5 microns, depending on the microscope lens used.



# LABORATORY OF TECHNICAL BIOCHEMISTRY

PROF. DR. KAYSER



## CURRICULUM VITAE

PROF. DR. RER. NAT. OLIVER KAYSER

Born	1967 in Recklinghausen, Germany
Education	1986 – 1991 Pharmacy, Westfälische Wilhelms-Universität Münster 1991 – 1992 Predoctoral Fellow, University of Florida, Gainesville, USA
PhD	1997 Institute of Pharmaceutical Biology, FU Berlin
Postgraduate Qualification (Habilitation)	1998 – 2003 Institute of Pharmaceutical Technology, Biopharmacy and Biotechnology, FU Berlin, Germany
Positions	2004 – 2010 Professor for Natural Product Biosynthesis, University of Groningen, the Netherlands Since 2010 Full Professor in the Department BCI of TU Dortmund

## RESEARCH INTERESTS

- » Biosynthetic pathways of secondary natural products in plants
- » Metabolic engineering
- » Metabolomics
- » Synthetic biology
- » Medicinal plant biotechnology
- » Applications for white biotechnology and pharmaceutical biotechnology

## CONTACT

### Laboratory of Technical Biochemistry

Department of Biochemical and Chemical Engineering  
TU Dortmund  
D-44221 Dortmund/Germany

Tel.: +49-(0)231-755-7487  
Fax: +49-(0)231-755-7489  
oliver.kayser@tu-dortmund.de  
www.tb.bci.tu-dortmund.de



# “THE DEPARTMENT HAS A UNIQUE PROFILE.” *Prof. Dr. Kayser*

## *What is your vision in science?*

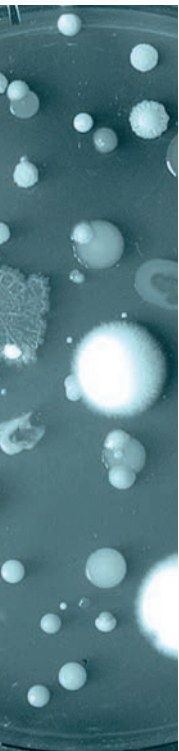
Pushing forward the frontiers of sciences or to quote Goethe, so that I may perceive what ever holds the world together in its inmost folds.

## *Can you explain me in short what you and your group are busy with?*

We identify secondary natural product pathways in plants which we can reassemble in a heterologous host. In detail, we want to rebuild the pathway for the drug THC from Cannabis sativa in *Saccharomyces cerevisiae*. By the use of sophisticated analytical and genetic techniques like LC-MS, NMR, PCR and gene sequencing we identify important enzymes and to express them functionally in a new biological environment.

## *What makes Dortmund so special for you to be here?*

The department has a unique profile, where engineers and natural scientists work together. A smart integration in bioscience and bioengineering has been set up in the past, and I am proud to join this department and to cooperate with my colleagues. Here, everyone is expanding his scientific mindset and constraints in his discipline. Sometimes I have the feeling that TU Dortmund is considered under value and the high potential must be explored.



## TEACHING

Biotechnology is one of the key industries of the 21st century. An increasing number of chemical and pharmaceutical compounds will be produced using genetically engineered microorganisms and cell cultures. To familiarize students with the biosynthetic power (and limits!) of microbial and plant cells our laboratory offers lectures in biochemistry, microbiology, pharmaceutical biotechnology and bioengineering. The lecture “Technical Biology” gives a introduction to biological concepts and strategies: how do cells and organisms work, reproduce as organisms and interact in ecosystems? Evolution, genetics and physiology are also covered.

The biochemistry lecture focuses on basic principles of energy- and carbon metabolism, regulation and secondary metabolism: how do cells degrade substrates, generate energy and synthesize all compounds required for a living cell,

growth and reproduction. The second part covers the secondary metabolism which produces a vast number of pharmaceutical useful compounds.

The lecture “Bioengineering for Chemical Engineers” presents the principles of bioengineering: how does a living cell work and reproduce? What are the components of microbial cells, how to feed and grow microorganisms and which bacteria and fungi are used for important production processes?

The lecture “Principals of Pharmaceutical Biotechnology” is an introduction to research, development and biotech production of recombinant proteins as pharmaceutical compounds. Drug screening, bioanalytical methods, formulations, production and pharmacokinetics of recombinant proteins, vaccine development, gene therapy

and registration of biotech drugs will be discussed as well. The cell biology lecture covers industrial applications of relevant plants, fungi and bacteria used in white and red biotechnology.

## RESEARCH

The living cell as a factory for pharmaceutically relevant compounds is the central theme of the Laboratory of Technical Biochemistry, focusing on two main objectives:

- » the cell as a producer of pharmaceuticals and
- » the biosynthetic network in plant cells as a target for drug and gene discovery.

The plant biotechnology research line is focused on the production of bioactive compounds of natural origin using plant cell cultures and whole plants. Next to phytochemical analysis, molecular-biological techniques are applied to gain insight into biosynthetic routes and to control the formation of bioactive compounds (pathway engineering).

### Metabolic Profiling and Metabolomics

The metabolome research concentrates on biotechnologically produced low molecular

natural products like secondary natural products using genetically engineered microorganisms. Biological systems are applied to generate molecular diversity, which is of utmost importance in drug discovery. Both natural diversity, e.g. plant cells and directed diversity, e.g. directed evolution, are investigated.

Pathway engineered plants and microorganisms are analyzed for metabolic flux of relevant precursors to design strategies for precursor redirection, detection of metabolic bottlenecks and optimal direction of precursors in *in vitro* bioreactor systems. Metabolic profiling and metabolome analysis is carried out by LC-MS, HPLC-NMR and 2D-H-NMR.

### Metabolic Engineering and Combinatorial Biosynthesis

A second research line is established to support research in the field of biochemistry and biosynthesis of medicinally used natural products. Here, of combinatorial biosynthesis of biosynthetic pathways of rare and expensive natural products (like tetrahydrocannabinol, paclitaxel and artemisinin) are biosynthesized in heterologous organismus. The basic concept is to combine metabolic pathways in different organisms on the genetic level.





# LABORATORY OF TECHNICAL BIOLOGY

PROF. DR. NETT





## CURRICULUM VITAE

PROF. DR. RER. NAT. MARKUS NETT

Born	1977 in Bad Neuenahr, Germany
Education	1997 – 2001 Pharmacy, University of Bonn
PhD	2002 – 2006 On isolation and structure elucidation of natural products, Institute for Pharmaceutical Biology, University of Bonn
Postgraduate Qualification (Habilitation)	2007 – 2008 Postdoctoral Fellow, Scripps Institution of Oceanography, Center for Marine Biotechnology and Biomedicine, San Diego, USA 2009 – 2016 Junior Research Group Leader, Leibniz Institute for Natural Product Research and Infection Biology, Jena 2014 Habilitation, Friedrich-Schiller-University Jena
Positions	2014 Guest Professor in the Department of Pharmacognosy, University of Vienna, Austria Since 2016 Professor in the Department BCI of TU Dortmund

## RESEARCH INTERESTS

- » Microbial secondary metabolism
- » Genetic engineering
- » Natural product biotechnology
- » Biosynthetic assembly lines
- » Genome mining

## CONTACT

**Laboratory of Technical Biology**  
Department of Biochemical and Chemical Engineering  
TU Dortmund  
D-44221 Dortmund/Germany

Tel.: +49-(0)231-755-4742  
Fax: +49-(0)231-755-7382  
markus.nett@tu-dortmund.de  
www.tbl.bci.tu-dortmund.de



# “OUT-OF-THE-BOX THINKING IS THE KEY TO SOLVE THE BIG QUESTIONS.” *Prof. Dr. Nett*



## *What is your vision in science*

My vision is not only to copy Nature, but to devise independent solutions, that have not evolved (yet). An example would be the design of a fully artificial pathway for a desired conversion instead of transferring an existing pathway into different hosts.

## *What benefit has the society from your research?*

We develop new solutions for the sustainable production of natural products, many of which are used as antibiotics or anticancer agents in medicine.

## *What makes most fun teaching students?*

Students often come up with creative, unconventional ideas to solve problems. Together with my group, I am trying to foster this out-of-the-box thinking by offering courses, in which the students are encouraged to tackle problems using a combination of chemical, biological and engineering methods.

## TEACHING

The integration of living cells or enzymes in industrial production processes is a rapidly emerging field. Our aim is to endow our students with both the knowledge and skills to utilize biological systems and their components for the development of usable, economically viable products or technologies. For this, we offer a series of complementary lectures as well as laboratory courses:

The basic concepts of biology are introduced in the lecture “Technical Biology”. In addition to the architecture and physiology of cells, the students become familiarized with a working knowledge in genetics. A special emphasis in this course is placed on the recognition of biological structure-function relationships and their possible technical applications. The lecture “Genetic Engineering” covers the biotechnological methods for the analysis and manipulation

of an organism’s genome in order to create cells that are tailored to industrial needs. Participants of the advanced course “Applied Genetics” have the opportunity to further extend this knowledge and to put it into practice. While the seminar in “Applied Genetics” covers recombinering, advanced cloning techniques and genetic circuits, the accompanying laboratory course deals with the design and generation of recombinant organisms for the production of fine chemicals. Principles of laboratory- and industrial-scale cell cultivation are presented in the lecture “Cell-Biological Systems”, which also includes topics such as tissue engineering and clean-room technology. Lastly, the course “Interdisciplinary Science Communication” delivers the fundamental skills for the presentation of multidisciplinary and cross-sectional projects.

## RESEARCH

Our research program is focused on the analysis and engineering of microbial pathways that are involved in the biosynthesis of medically relevant natural products. The availability of these compounds is often limited due to low production levels in the native producer organisms and the lack of economically feasible synthetic routes. Using a combination of genetic and chemical methods, we devise new fermentation-based concepts to afford ready access to these molecules as well as analogs with altered properties.

### Engineering of Molecular Assembly Lines

The knowledge about how natural products are assembled provides a number of opportunities to manipulate the biosynthesis in a rational way in order to expand the naturally occurring structural diversity. Our main efforts are directed towards unraveling the programming and plasticity of modular biosynthetic enzymes, i.e., polyketide synthases and nonribosomal peptide synthetases. The long-term objective is to utilize these megaenzymes in a combinatorial fashion for the production of custom molecules.

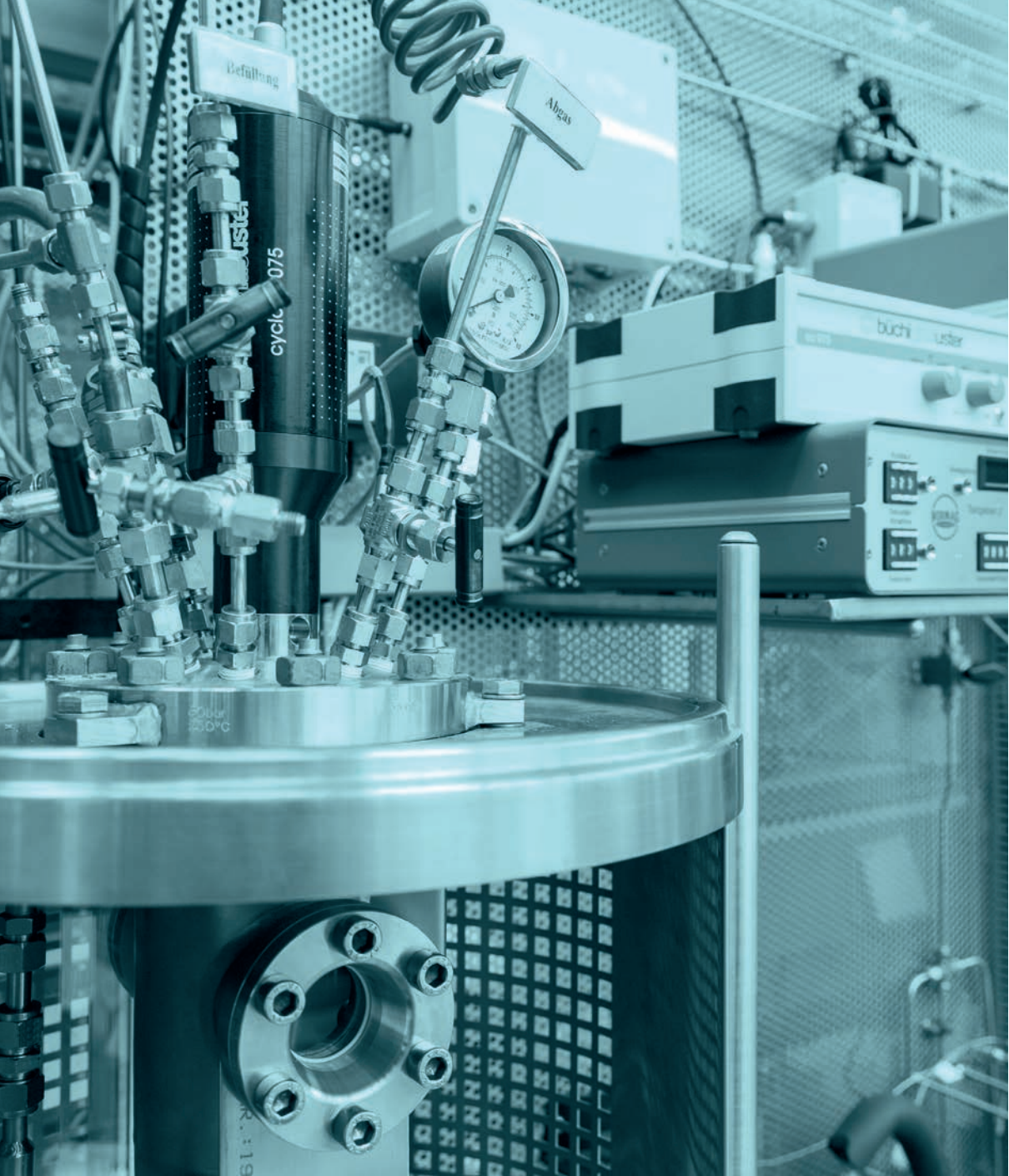
### Design of Platform Organisms

Mankind has used microbes and their metabolisms for centuries. In contrast, the fine-tuning of the metabolic network through rationally designed gene constructs is a relatively new concept. While the use of genetically modified organisms has already been successfully implemented for the production of commodity chemicals, the reconstitution of pathways to bioactive natural products is still facing a number of challenges. Our group is engaged in the engineering of new platform organisms, which facilitate the refactoring of such complex systems.

### Genome Mining

In recent years, genomic analyses have illuminated the proficiency of microorganisms and plants for the production of bioactive molecules - underappreciated for years based on conventional isolation programs - and have set the foundation for a new paradigm in natural product discovery based on genome mining. We exploit this strategy for the identification of novel producer organisms and enzymes that may have applied value as biocatalysts.





# LABORATORY OF TECHNICAL CHEMISTRY

PROF. DR. VOGT



## CURRICULUM VITAE

PROF. DR. RER. NAT. DIETER VOGT

Born	1962 in Heinsberg/Unterbruch, Germany
Education	1982 – 1988 Chemistry, Universität GHS Essen, RWTH Aachen
PhD	1992 Zur selektiven Insertion von Kohlendioxid in Epoxide, RWTH Aachen
Postgraduate Qualification (Habilitation)	1998 Habilitation, Institute of Technical Chemistry, RWTH Aachen
Positions	1999 – 2012 Chair of Inorganic Chemistry and Coordination Chemistry, Eindhoven University of Technology 2001 – 2011 Director of the Institute of Inorganic Chemistry and Catalysis 2012 - 2017 Chair of Industrial Chemistry, School of Chemistry, University of Edinburgh Since 2017 Full Professor in the Department BCI of TU Dortmund

## RESEARCH INTERESTS

- » Homogeneous transition metal catalysis
- » Ligand and catalyst design and mechanistic studies
- » Feedstock diversification and renewables
- » Process development in continuously operated miniplants

## CONTACT

Laboratory of Technical Chemistry  
(Chemical Process Development)

Department of Biochemical and Chemical Engineering  
TU Dortmund  
D-44221 Dortmund/Germany

Tel.: +49-(0)231-755-2310  
Fax: +49-(0)231-755-2311  
dieter.vogt@tu-dortmund.de  
www.tc.bci.tu-dortmund.de



# “COMBINING THE SPECIFIC SKILLS OF CHEMISTS AND CHEMICAL ENGINEERS WITHIN ONE RESEARCH TEAM CREATES SYNERGY, THAT...” *Prof. Dr. Vogt*



*Why do you think is homogeneous catalysis so significant for industrial chemistry?*

Homogeneous catalysts offer unique features such as high intrinsic activity and selectivity, which are tunable by ligand design. This implies relatively mild reaction conditions as compared to heterogeneous catalysis, an advantage that becomes even more important when converting renewable feedstocks, which are often highly functionalized molecules. However, highly efficient catalyst recovery and reuse are a prerequisite for application.

*And how do you achieve or improve the recycle of homogeneous catalysts?*

If you review the industrial applications of homogeneous catalysts you will find that in almost all cases individual solutions have been developed. These make use of extraction, rectification and filtration after catalyst decomposition. We are open to all options in our work but strive to develop methods that are non-destructive and have a low energy consumption. These include 2-phase or multiphase catalysis, the use of the thermomorphic solvent mixtures, and membrane filtration combined all with molecular weight enlargement of the catalyst. Proof of principle is gained in lab experiments and then transferred up to the miniplant level. In this chain of knowledge approach “from molecules to processes; from understanding to sustainable production” chemists and chemical engineers work hand-in-hand.



*Can you describe us in some more detail what do you mean with the term “miniplant”?*

As the name suggests, a miniplant is just a miniature version of a future production plant. Ideally it shows all units and operations including fully closed recycle loops for example of unreacted feeds, solvents and of course of the homogeneous catalysts. But of course there can be varying levels of complexity. Typical product streams are in the range of 10 to 100 g/h. In such a miniplant we can investigate all issues arising under real production conditions such as long-term catalyst stability, accumulation of byproducts, etc., which will never show up in simple batch experiments. The great advantage of miniplants is that they can be constructed rapidly and at relatively low cost using commercial equipment or devices constructed in our workshops. Computer-controlled systems permit continuous operation and good reproducibility.

## TEACHING

Technical Chemistry at TU Dortmund takes a very special role, educating both, students in chemistry and in chemical engineering. This is a particularly challenging task, as both studies often require a related but nevertheless distinct approach. The chemist considers more the chemical reactions and mechanisms, while the engineer is more interested in process development and in the optimal combination of possible unit operations. However, both groups benefit tremendously from a joint education, as they learn each others “language” and the immanent way of thinking within the other field. Both must be aware of new raw materials and energy sources, of safety and environmental considerations and of economic issues. In lectures and exercises these subjects are discussed in detail and illustrated by important examples taken from actual (large scale) industrial processes.

## RESEARCH

Our slogan is “Homogeneous Catalysis: From molecules to processes; from understanding to sustainable production”. Since 1999 the group has been active in the field of applied catalysis, with the main focus being on homogeneous transition metal catalyzed organic reactions and a strong focus on technical applications. As shown in Box 1 we investigate both, reactions based on major petrochemicals like alkenes and dienes derived from the major steam cracker fractions, but also renewables like fats and oils, terpenes and carbohydrates. Further fields of interest are the activation of carbon dioxide via transition metal catalysis and catalytic tandem reactions (see Box 2).

### 1 Applied Catalysis and Process Development

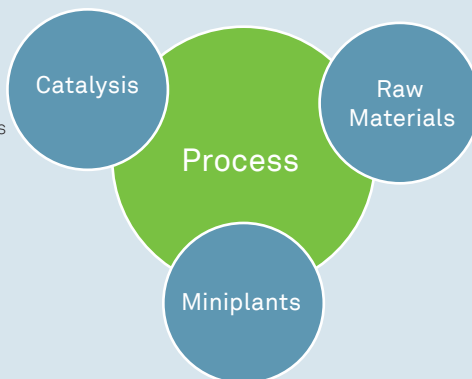
Prof. Dr. rer. nat. Dieter Vogt

#### Homogeneous Catalysis

- » mechanistic investigations
- » ligand design
- » exploration of new reactions
- » optimisation of processes
- » catalyst recycling (multiphase approach and membrane separation)
- » tandem catalysis

#### Heterogeneous catalysis

- » Metal nanoparticles
- » Selective hydrogenation
- » Selective oxidation



#### Industrial Chemistry

- » petrochemicals (alkenes, dienes, ...)
- » syngas chemistry (hydroformylation, carbonylation, hydroaminomethylation, ...)
- » renewable feedstocks (oleochemicals, terpenes, carbohydrates, ...)
- » carbon dioxide (carboxylic acids, lactones, org. carbonates, formic acid, ...)

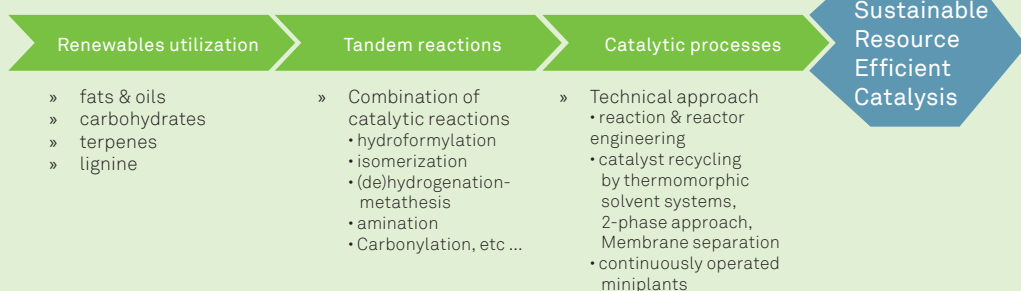
#### Process Development in Miniplants

- » continuously operated lab-scale plants
- » closed-loop operation
- » high-throughput investigations

### 2

## Sustainable & Resource Efficient Catalytic Processes

Prof. Dr. rer. nat. Dieter Vogt





# LABORATORY OF THERMODYNAMICS

PROF. DR. SADOWSKI





## CURRICULUM VITAE

PROF. DR. RER. NAT. GABRIELE SADOWSKI

Born	1964 in Kleinmachnow, Germany
Education	1982 – 1987 Chemistry, Technical University Merseburg
PhD	1991 On physical chemistry, Technical University Merseburg
Postgraduate Qualification (Habilitation)	2000 Habilitation, Department Process Engineering, TU Berlin
Positions	Since 2001 Full Professor in the Department BCI of TU Dortmund

## RESEARCH INTERESTS

- » Modeling thermodynamic properties of complex systems
- » Thermodynamics of biological systems
- » Thermodynamics of pharmaceutical systems
- » Energy conversion

## CONTACT

### Laboratory of Thermodynamics

Department of Biochemical and Chemical Engineering  
TU Dortmund  
D-44221 Dortmund/Germany

Tel.: +49-(0)231-755-2635

Fax: +49-(0)231-755-2672

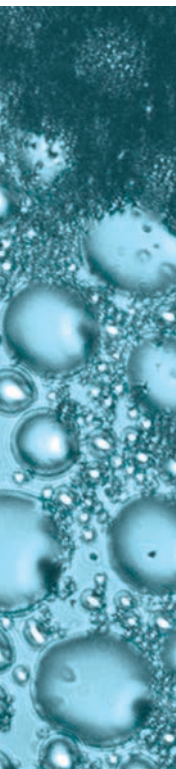
[gabriele.sadowski@tu-dortmund.de](mailto:gabriele.sadowski@tu-dortmund.de)

[www.th.bci.tu-dortmund.de](http://www.th.bci.tu-dortmund.de)



# “THE DEPARTMENT WILL BE A LEADING ONE IN LIFE-SCIENCE ENGINEERING.”

*Prof. Dr. Sadowski*



*Can you explain me in short what you and your group are busy with?*

We measure the mutual solubility of various components (gases, liquids, solids) as function of concentration, pressure and temperature and develop models to predict conditions at which these components mix or demix.

*What benefit has the society from your research?*

Knowledge of the solubility behavior allows to develop pharmaceutical drugs with improved bioavailability in the human body or to design energy-efficient separation processes in biotechnology and chemical industry.

*What makes most fun teaching students?*

It's fun to see the new generation of engineers growing and to see that they are as curious and enthusiastic about science as we are.

*Is teaching and doing research a conflict for you?*

Not at all! We do not want to just provide facts about a certain field of knowledge but we also teach the students how to work scientifically. For that, we integrate them into our research projects where they can contribute already today. It's a win-win situation!

## TEACHING

The laboratory is responsible for the Bachelor courses “Technical Thermodynamics” and “Phase-Equilibrium Thermodynamics”. The Master course “Biothermodynamics” for students of Biochemical Engineering focuses on bioreactions and thermodynamic properties of systems containing biomolecules such as electrolytes, amino acids, sugars, and proteins depending on temperature and pH.

Moreover, several electives for Bachelor and Master Students impart additional knowledge in thermodynamics, such as “Calculation of thermodynamic properties and phase equilibria with Aspen Plus”, “Efficient Use of Energy in Process Engineering”, “Energy Conversion Processes”, “Polymer thermodynamics”.

## RESEARCH

### Bioreactions and Biothermodynamics

The thermodynamic properties, phase equilibria, and reaction equilibria of systems containing biological molecules (e.g. proteins, amino acids, electrolytes) is of interest for processes in the life-science industry and biotechnology. These properties are measured and modeled to understand the complex interactions and phenomena on molecular level. Moreover, the influence of salts, buffer, pH, cofactors, or enzymes on phase behavior and reaction equilibria in biological systems is investigated experimentally as well as by modeling.

## Bioprocess Separations

Within state-of-the-art bioprocesses the total production costs are dominated by the cost for the downstream processing by up to 80 %. This is based on the fact, that often cost-intensive workup steps such as chromatographic separations are used. Therefore the Laboratory of Thermodynamics aims for investigating the potential of other unit operations such as extraction in aqueous-biphasic systems, crystallization, precipitation or supercritical extraction to enhance the downstream processing.

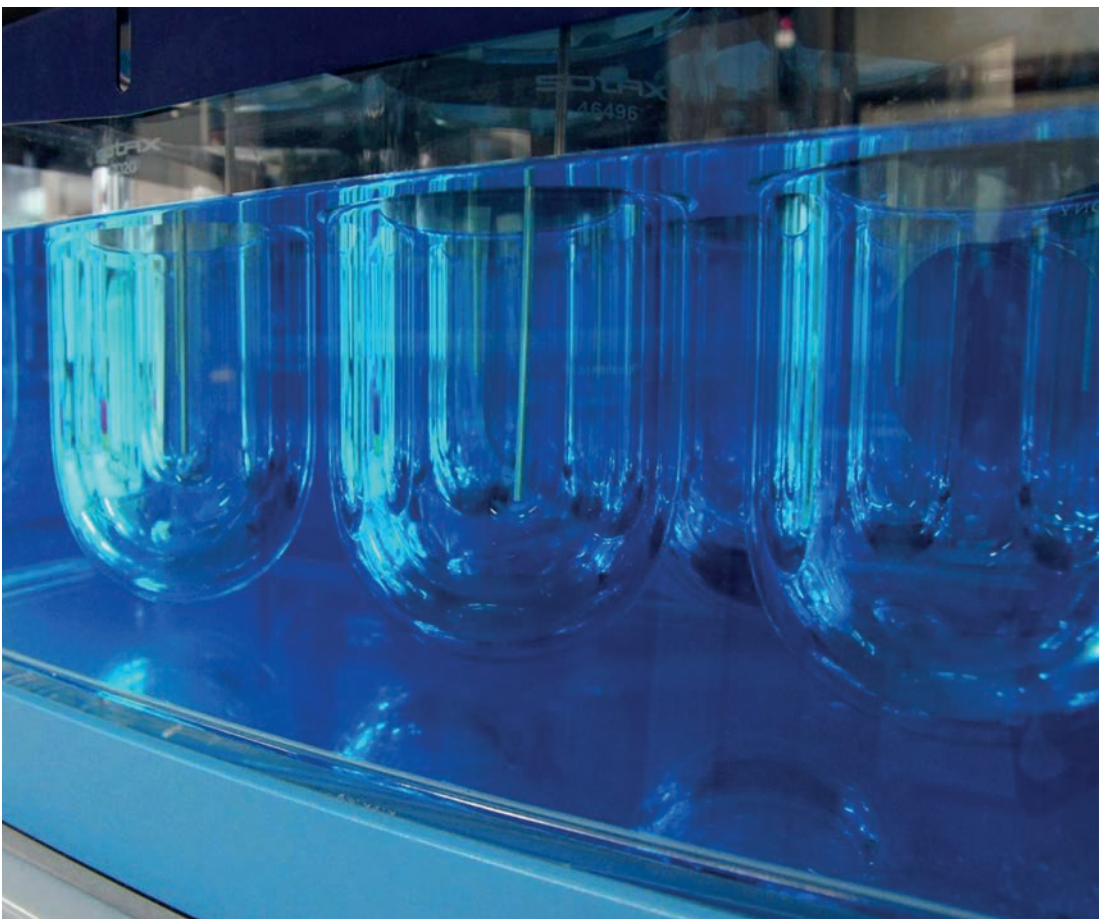
## Thermodynamics of Pharmaceutical Systems

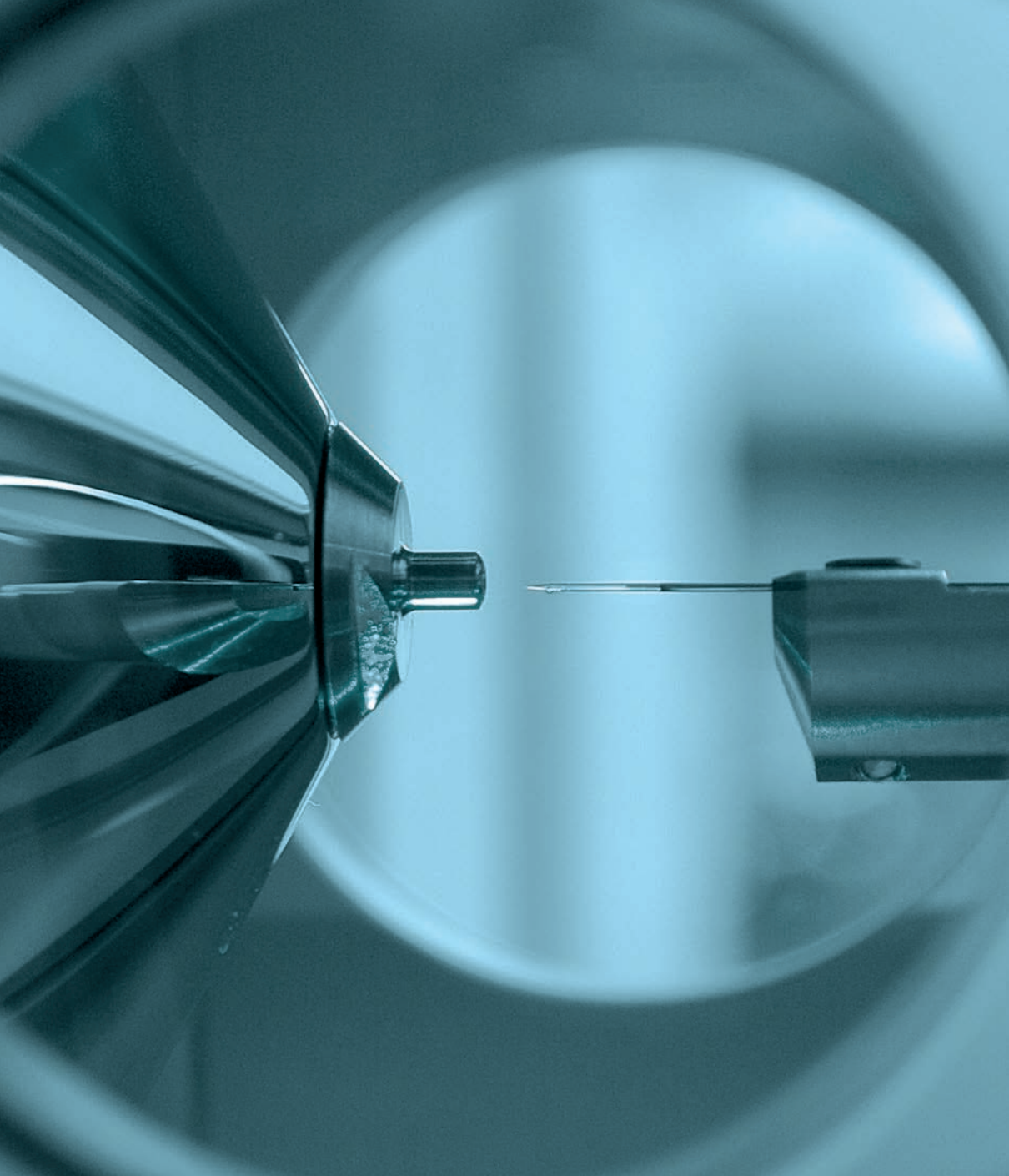
Pharmaceuticals are complex compounds often exhibiting very low bioavailability which is caused by very low solubilities as well as very slow release kinetics in the body. Therefore, the laboratory applies various thermodynamic approaches to increase the solubility and/or the dissolution kinetics of pharmaceutical compounds, e.g. by salt

formation, embedding of pharmaceuticals into polymer matrices, and formation of co-crystals. Thermodynamic models are applied to describe the phase behavior of pharmaceutical systems and to predict the influence of pH, additives and humidity.

## Decentralized Energy Conversion by Regenerative Gas Cycles

Regenerative cycles allow for efficient decentralized energy conversion without major constraints to the operating temperatures. The well-known Stirling engine can be used for cogeneration purposes, whereas the Vuilleumier cycle may operate as a thermally driven heat pump or refrigerator, possibly driven by biomass, solar power, or waste heat. Current research aims at an improved modeling of these cycles and a better understanding of the major loss mechanisms as well as convertible machine designs that can be toggled between various operating modes depending on current demands.





# ISAS

LEIBNIZ-INSTITUT FÜR  
ANALYTISCHE WISSENSCHAFTEN – ISAS – E.V.

PROF. DR. SICKMANN



## CURRICULUM VITAE

PROF. DR. RER. NAT. ALBERT SICKMANN

Born	1974 in Bad Driburg, Germany
Education	1994 – 1998 Biochemistry, Ruhr University, Bochum
PhD	2001 Chemistry Department, Ruhr University, Bochum
Postgraduate Qualification (Habilitation)	2001 – 2002 Group leader at the “Medizinisches Proteomzentrum“ (MPC), Ruhr University, Bochum
	2002 – 2003 Junior Professor for Protein function and Proteomics, Ruhr University, Bochum
	2003 – 2007 Group leader at the DFG Research Centre for Experimental Biomedicine, University of Würzburg
Positions	2007 – 2008 Professor for protein mass spectrometry at the University of Würzburg
	since 2008 Professor for Bioanalytics at ISAS, Dortmund
	since 2009 Member of the ISAS Board of Directors
	since 2011 ISAS President
	since 2011 President of the German Proteomics Society

## RESEARCH INTERESTS

- » Micro characterization of proteins
- » Mass spectrometry based proteomics
- » Post translational modification of proteins
- » Systems biology

## CONTACT

Leibniz-Institut für Analytische Wissenschaften – ISAS – e.V.  
Bunsen-Kirchhof-Str. 11  
D-44139 Dortmund/Germany

Tel: +49-(0)231-1392-0  
Fax: +49-(0)231-1392-200  
info@isas.de  
www.isas.de



# “OBVIOUSLY THE SOCIETY WILL BENEFIT FROM THIS RESEARCH WITH STRONG FOCUS ON THE DEVELOPMENT OF NOVEL DIAGNOSTIC TOOLS FOR INDIVIDUAL THERAPY OF CVD.”

*Prof. Dr. Sickmann*



## *What is your vision in science?*

I like to cite Lord Kelvin, a British physicist born in Ireland and working in Scotland:

“I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science, whatever the matter may be” (May 3rd, 1883).

This is an early statement that technology development is a driving force for science and innovation.

## *Can you explain me in short what you and your department are busy with?*

In the Bioanalytics department, we focus on the complex processes in living cells. We develop analytical methods and strategies to investigate these processes with modern “OMICS” technologies and interpret the resulting data leading to a systems understanding (also called systems biology) of biological processes. This is a young and revolutionary branch of science providing a more holistic perspective compared to the traditional, hypothesis-driven approaches in biological and biomedical research. It synergistically fuses quantitative experimental data of dynamic processes obtained from bioanalytical chemistry, cell biology, molecular biology, and medical research with mathematical methods and models from the fields of stochastic, statistics, computer and systems science. Such interdisciplinary generation and interpretation of big and multidimensional data allows the deciphering, modeling and understanding fundamental dynamic concepts of the cellular function: Quantitative information obtained from the molecular level (genes/transcripts/proteins/metabolites/lipids) to higher levels of organization such as organelles, cells, tissues or even complete organisms will deliver an integrative snapshot of life. Given the current and prospective technical progress, systems biology holds an enormous potential to fundamentally change and lift lifesciences and biomedical sciences to the next level of research.

Our research mainly focuses on molecules of biological or medical importance: e.g. glyco- and phosphoproteins, certain metabolites or synthetic biomolecules. Furthermore, lab-on-a-chip technologies and the miniaturization of devices for biological and chemical analysis play an important role in our research.

My own research is dedicated to the understanding of activation and inhibition mechanisms of platelets in health and disease. Platelets combine major roles in the development and progression of cardiovascular diseases (CVD), and have emerged as one of the most important cellular therapeutic targets since they are now considered key mediators of thrombosis, inflammation, and atherosclerosis.

### *What benefit has society from your research?*

Cardiovascular diseases (CVD) are the world wide leading cause of death – in 2011 31% worldwide, 40% in Germany. As mentioned platelets play a key role in normal and pathological hemostasis due to their ability to rapidly adhere to activated or injured endothelium, subendothelial matrix proteins and other activated platelets, thus forming stable aggregates. They combine major roles in the development and progression of cardiovascular diseases and have emerged as one of the most important cellular therapeutic targets since they are now considered key mediators of thrombosis, inflammation, and atherosclerosis. This is supported by a wealth of evidence from large clinical trials, where established anti-platelet drugs have become paramount in the prevention and management of various diseases involving the cardiovascular, cerebrovascular, and peripheral arterial systems. This has triggered interest and efforts to improve both the diagnostic and therapeutic aspects of platelet function in health and disease.



At ISAS (Leibniz-Institut für Analytische Wissenschaften – ISAS – e.V.) we make things measurable that cannot be measured today: Our aim is to promote the development of analytical technologies by combining our expertise on chemistry, biology, physics and informatics. Research at ISAS concentrates on providing methods for a multi-parameter analysis of biological materials; we want to improve the prevention and early diagnosis of diseases and enable faster, more precise therapies.

Excellent interdisciplinary research, the training of up-and-coming scientific talent and the transfer of our findings to science, economy and the general public are our key objectives.

# PAST – FUTURE

## Emeritus professors



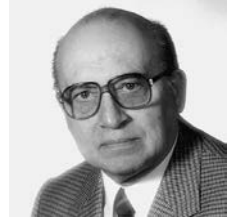
A. Behr



H. Fahlenkamp



C. Friedrich



H. Gieseke



A. Górák



U. Köster



U. Onken



J. Petermann



H.-G. Schecker



H. Schmidt-Traub



S. Schulz



H. Schwind



K. H. Simmrock



K. Strauß



P. Walzel



P. Weinspach



E. Weiß



R. Wichmann



U. Werner



## Habilitation



K. Boettcher



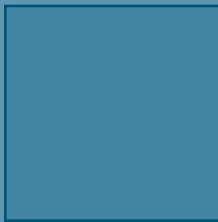
J. Koop



K. Rosenthal



T. Seidensticker



J. Winck





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TU Dortmund  
Fakultät Bio- und Chemieingenieurwesen  
Emil-Figge-Straße 66  
44227 Dortmund