TUHH
Hamburg
University of
Technology

Module Manual

Master of Science (M.Sc.)

Chemical and Bioprocess Engineering

Cohort: Winter Term 2025

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Program description

Content

Chemical process engineering and bioprocess engineering are concerned with the development and execution of processes, in which materials are changed in nature, properties and composition. The variety of such processes is enormous. They range from the production of fuels, fertilisers, inorganic and organic chemicals to materials, pharmaceuticals and food. In addition to scientific, technical and economic aspects, legal issues, environmental protection and sustainability also play an important role in the development and execution of processes.

Chemical process engineering and bioprocess engineering are engineering disciplines that build on physical, chemical and mathematical foundations. Additionally, bioprocess engineering concerns the use of biological systems such as enzymes, cells and entire organisms in technical applications.

The International Master's Program "Chemical and Bioprocess Engineering" at TUHH prepares graduates for challenging engineering jobs in process engineering and biotechnology, as well as for independent work in research. The main course topics of the Master's program are a logical continuation of the core subjects of corresponding Bachelor's programs (e.g. process engineering, bioprocess engineering, energy and environmental engineering). In this regard, it makes no difference whether the student completed his/her Bachelor's at TUHH or at another internationally recognized university in Germany or abroad. The Master's program is characterized by its scientific orientation, clear focus in terms of content and its communication of effective, structured, interdisciplinary working methods. The course content is closely related to the research conducted at the Chemical Engineering School, uniting teaching with research. This guarantees up-to-date lecture content and the possibility of working in research at TUHH (e.g. in relation to a dissertation, seminar contributions and project work).

Career prospects

The aim of the Chemical and Bioprocess Engineering Master's program is to provide graduates of Bachelor's engineering programs with a focus on process engineering or industrial biotechnology with the knowledge and skills that prepare them for further study (PhD) or a career in different areas of the chemical industry and/or biotechnology and plant engineering. The future careers of graduates from the programme can range from research and development to planning, process design and operation in process or bioprocess plants.

Graduates of the Master's program Chemical and Bioprocess Engineering can confidently apply for senior engineering roles. A diverse range of careers are open to graduates of the programme.

In industry:

- Development and improvement of chemical, biotechnical or environmental processes
- Project management, plant engineering and plant operation

Development of principles for and development of new equipment and processes

- Management in production facilities
- Health and safety and safety engineering
- Documentation and patent processing
- Marketing and sales

In the public sector:

- Research and teaching at universities or scientific institutes
- Technical administration and monitoring
- Working for federal and regional authorities, e.g. patent offices, trade supervisory offices, material testing authorities, German Environment Agency

Further prospects:

- Engineering firms
- Intellectual property law firms
- Expert, industry consultant
- Business start-ups

Learning target

The International Master's Program Chemical and Bioprocess Engineering provides graduates with the theoretical knowledge and practical skills to be successful as a process engineer in industry and research. With course content covering traditional process engineering, bioprocess engineering and in-depth theoretical foundations (e.g. numerical methods, applied statistics, applied thermodynamics), graduates receive a rounded education in both chemical and bioprocess engineering, leaving them with excellent career prospects. They are able to work independently and to apply the necessary methods and processes for resolving technical issues; apply new knowledge; scrutinize methods and processes critically and further develop them.

Knowledge:

- Students can demonstrate complex mathematical and scientific knowledge and support this with a broad theoretical and methodical foundation.
- Students can explain principles, methods and areas of application of specialisations in process and bioprocess engineering, as well as chemical engineering in detail.
- Students can state the fundamentals of operations and management, as well as related domains such as the patent system, and relate them to their discipline.
- Students can outline elements of scientific work and research and can give an overview of their application in process and bioprocess engineering, as well as chemical engineering.

Skills:

- Students master the theory-led application of highly demanding theoretical and experimental methods and processes in their specialisation. They can divide more complex problems even if these are unclearly defined, apply solution processes for the partial problems and establish an overall solution.
- Students can propose, evaluate and discuss practical solutions to process engineering issues, and evaluate them responsibly taking into account non-technical conditions (e.g. social, environmental and economic).
- Students can process data and information pragmatically, evaluate it critically and draw conclusions. They can also recognize the interdisciplinary connections of a technical process problem, analyse them and assess their importance or bring their specialist area into an interdisciplinary context.
- Students can investigate and evaluate future technologies and scientific developments and are capable of independent research following the rules of good scientific practice (capacity to complete a PhD).

Social skills:

- Students are able to outline processes and the results of their work in comprehensible written and spoken German and English.
- Students can talk about advanced content and process engineering and bioprocess engineering problems with specialists and lay people in German and English. They can respond appropriately to queries, amendments and comments.
- Students are able to work in groups. They can determine and distribute subsidiary tasks and integrate them. They can meet deadlines and interact socially. They are able and prepared to take leadership roles.

Autonomy:

- Students are able to procure necessary information and set this information in the context of their own knowledge.
- Students can evaluate their existing level of competence realistically, compensate for deficits independently and undertake reasonable extensions.
- Students can develop research areas independently and find or define new problems (life-long learning and research).

Program structure

The Master’s program Chemical and Bioprocess Engineering is divided as follows:

- Core qualification: 12 compulsory courses, 72 LPs, 1st - 3rd semester. This encompasses:

- Specialization: 3 modules amounting to 18 CPs, 2nd and 3rd semester.
- Dissertation: 30 CPs, 4th semester.

This results in a total of 120 CPs.

It is obligatory to choose a specialization. The following specializations are offered:

- General process engineering
- Bioprocess engineering
- Chemical process engineering

Students choose three modules within their specialization amounting to a total of 18 CPs. Students can use the third semester to spend time abroad or on an industry placement as this semester is allocated for the completion of elective courses only.

Core Qualification

Module M0524: Non-technical Courses for Master

Module Responsible	Dagmar Richter
Admission Requirements	None
Recommended Previous Knowledge	None
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	**The Nontechnical Academic Programms (NTA)** imparts skills that, in view of the TUHH’s training profile, professional engineering studies require but are not able to cover fully. Self-reliance, self-management, collaboration and professional and personnel management competences. The department implements these training objectives in its **teaching architecture**, in its **teaching and learning arrangements**, in **teaching areas** and by means of teaching offerings in which students can qualify by opting for **specific competences** and a **competence level** at the Bachelor’s or Master’s level. The teaching offerings are pooled in two different catalogues for nontechnical complementary courses. **The Learning Architecture** consists of a cross-disciplinarily study offering. The centrally designed teaching offering ensures that courses in the nontechnical academic programms follow the specific profiling of TUHH degree courses. The learning architecture demands and trains independent educational planning as regards the individual development of competences. It also provides orientation knowledge in the form of “profiles”. The subjects that can be studied in parallel throughout the student’s entire study program - if need be, it can be studied in one to two semesters. In view of the adaptation problems that individuals commonly face in their first semesters after making the transition from school to university and in order to encourage individually planned semesters abroad, there is no obligation to study these subjects in one or two specific semesters during the course of studies. **Teaching and Learning Arrangements** provide for students, separated into B.Sc. and M.Sc., to learn with and from each other across semesters. The challenge of dealing with interdisciplinarity and a variety of stages of learning in courses are part of the learning architecture and are deliberately encouraged in specific courses. **Fields of Teaching** are based on research findings from the academic disciplines cultural studies, social studies, arts, historical studies, communication studies, migration studies and sustainability research, and from engineering didactics. In addition, from the winter semester 2014/15 students on all Bachelor’s courses will have the opportunity to learn about business management and start-ups in a goal-oriented way. The fields of teaching are augmented by soft skills offers and a foreign language offer. Here, the focus is on encouraging goal-oriented communication skills, e.g. the skills required by outgoing engineers in international and intercultural situations. **The Competence Level** of the courses offered in this area is different as regards the basic training objective in the Bachelor’s and Master’s fields. These differences are reflected in the practical examples used, in content topics that refer to different professional application contexts, and in the higher scientific and theoretical level of abstraction in the B.Sc. This is also reflected in the different quality of soft skills, which relate to the different team positions and different group leadership functions of Bachelor’s and Master’s graduates in their future working life. **Specialized Competence (Knowledge)** Students can • explain specialized areas in context of the relevant non-technical disciplines, • outline basic theories, categories, terminology, models, concepts or artistic techniques in the disciplines represented in the learning area, • different specialist disciplines relate to their own discipline and differentiate it as well as make connections, • sketch the basic outlines of how scientific disciplines, paradigms, models, instruments, methods and forms of representation in the specialized sciences are subject to individual and socio-cultural interpretation and historicity, • Can communicate in a foreign language in a manner appropriate to the subject.
Skills	**Professional Competence (Skills)** In selected sub-areas students can • apply basic and specific methods of the said scientific disciplines, • aquestion a specific technical phenomena, models, theories from the viewpoint of another, aforementioned specialist discipline, • to handle simple and advanced questions in aforementioned scientific disciplines in a sucsessful manner, • justify their decisions on forms of organization and application in practical questions in contexts that go beyond the technical relationship to the subject.

Personal Competence	
Social Competence	**Personal Competences (Social Skills)** Students will be able • to learn to collaborate in different manner, • to present and analyze problems in the abovementioned fields in a partner or group situation in a manner appropriate to the addressees, • to express themselves competently, in a culturally appropriate and gender-sensitive manner in the language of the country (as far as this study-focus would be chosen), • to explain nontechnical items to auditorium with technical background knowledge.
Autonomy	**Personal Competences (Self-reliance)** Students are able in selected areas • to reflect on their own profession and professionalism in the context of real-life fields of application • to organize themselves and their own learning processes • to reflect and decide questions in front of a broad education background • to communicate a nontechnical item in a competent way in writen form or verbaly • to organize themselves as an entrepreneurial subject country (as far as this study-focus would be chosen)
Workload in Hours	Depends on choice of courses
Credit points	6

Courses
Information regarding lectures and courses can be found in the corresponding module handbook published separately.

Module M2070: Responsible Management: Entrepreneurship, Ethics, Sustainability

Courses

Title	Typ	Hrs/wk	CP
Entrepreneurship in Process Engineering (L3403)	Lecture	2	2
Ethics in Process Engineering (L3401)	Lecture	2	2
Sustainability in Process Engineering (L3402)	Lecture	2	2

Module Responsible	Prof. Kerstin Kuchta
Admission Requirements	None
Recommended Previous Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	
Skills	
Personal Competence	
Social Competence	
Autonomy	
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	None
Examination	Subject theoretical and practical work
Examination duration and scale	X
Assignment for the Following Curricula	Chemical and Bioprocess Engineering: Core Qualification: Compulsory Chemical and Bioprocess Engineering: Core Qualification: Compulsory

Course L3403: Entrepreneurship in Process Engineering

Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Christian Lüthje
Language	EN
Cycle	WiSe
Content	How can scientific discoveries become impactful innovations? This course focuses on the early stages of the entrepreneurial journey, helping students in bio-chemical and process engineering to understand the development of problem-driven solutions that have real-world impact—whether by driving innovation within existing companies or creating their own ventures. Students will learn how to identify meaningful problems, validate them through research and industry insights, generate innovative ideas, and test their feasibility (problem-solution fit). The course also introduces market analysis, competition assessment to determine the potential of an idea before deeper business model development. All insights and methods will be applied in a group project, where students tackle a real-world challenge—either suggested by external partners (such as TUHH research institutes, startups, or SMEs) or developed independently based on their own interests. Through hands-on workshops, case studies, and expert-led discussions, students will move from problem discovery to validated solution concepts. The course includes an excursion to a sustainability-focused startup in bio- or chemical process engineering, offering students first-hand insights into real-world entrepreneurial challenges and innovations.
Literature	

Course L3401: Ethics in Process Engineering

Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Maximilian Kiener
Language	EN
Cycle	WiSe
Content	This lecture provides an introduction to ethics with a special focus on the challenges within process engineering. Key topics include the ethics of risk and decision-making, theories of justice and democracy, AI ethics, the future of work, and the concept of responsibility. The course aims to equip students with a critical understanding of ethical frameworks and their application in engineering practice.
Literature	

Course L3402: Sustainability in Process Engineering	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Kerstin Kuchta
Language	EN
Cycle	WiSe
Content	Today, sustainability performance has a relevant impact on a company's economic success and reputation. This course therefore offers a sound introduction to environmental and sustainability management and the fundamental aspects of sustainability strategies, public welfare and the carbon footprint of processes and products. The aim is to develop a global understanding of the most important challenges of sustainable development. Relevant topics such as climate change, population growth, biodiversity, air and water quality and the concept of planetary boundaries are presented. An overview of the framework of environmental law and relevant standards is given. This includes the following aspects: Definition(s) of sustainability, energy and material efficiency and circular economy /Sustainable Development Goals of the UN- Product life cycle, product life cycle management / Basics of carbon footprint (CO2, water, area, etc.)/ Basics of life cycle assessment /Sustainable Manufacturing and Sustainable Services/ Circular Economy/ Remanufacturing / Reconfiguration / Update Factories. The methods of climate accounting are trained using concrete examples and case studies are presented by the students. After completing the course, students will be able to systematically analyse processes for risks and sustainability, carry out climate assessments and develop strategies to manage sustainability in the company in a targeted manner.
Literature	

Module M0537: Applied Thermodynamics: Thermodynamic Properties for Industrial Applications

Courses

Title	Typ	Hrs/wk	CP
Applied Thermodynamics: Thermodynamic Properties for Industrial Applications (L0100)	Lecture	4	3
Applied Thermodynamics: Thermodynamic Properties for Industrial Applications (L0230)	Recitation Section (small)	2	3

Module Responsible	Dr. Simon Müller
Admission Requirements	None
Recommended Previous Knowledge	Thermodynamics III
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students are capable to formulate thermodynamic problems and to specify possible solutions. Furthermore, they can describe the current state of research in thermodynamic property predictions.
Skills	The students are capable to apply modern thermodynamic calculation methods to multi-component mixtures and relevant biological systems. They can calculate phase equilibria and partition coefficients by applying equations of state, gE models, and COSMO-RS methods. They can provide a comparison and a critical assessment of these methods with regard to their industrial relevance. The students are capable to use the software COSMOtherm and relevant property tools of ASPEN and to write short programs for the specific calculation of different thermodynamic properties. They can judge and evaluate the results from thermodynamic calculations/predictions for industrial processes.
Personal Competence	
Social Competence	Students are capable to develop and discuss solutions in small groups; further they can translate these solutions into calculation algorithms.
Autonomy	Students can rank the field of “Applied Thermodynamics” within the scientific and social context. They are capable to define research projects within the field of thermodynamic data calculation.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory** Yes; **Bonus** None; **Form** Written elaboration; **Description**
Examination	Oral exam
Examination duration and scale	20 min
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory

Course L0100: Applied Thermodynamics: Thermodynamic Properties for Industrial Applications

Typ	Lecture
Hrs/wk	4
CP	3
Workload in Hours	Independent Study Time 34, Study Time in Lecture 56
Lecturer	Prof. Ralf Dohrn
Language	EN
Cycle	WiSe
Content	• Phase equilibria in multicomponent systems • Partioning in biorelevant systems • Calculation of phase equilibria in colloidal systems: UNIFAC, COSMO-RS (exercises in computer pool) • Calculation of partitioning coefficients in biological membranes: COSMO-RS (exercises in computer pool) • Application of equations of state (vapour pressure, phase equilibria, etc.) (exercises in computer pool) • Intermolecular forces, interaction Potenitials • Introduction in statistical thermodynamics
Literature	

Course L0230: Applied Thermodynamics: Thermodynamic Properties for Industrial Applications	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Simon Müller
Language	EN
Cycle	WiSe
Content	exercises in computer pool, see lecture description for more details
Literature	-

Module M1038: Particle Technology for International Master Programs

Courses

Title	Typ	Hrs/wk	CP
Excercise Particle Technology for International Master Program (L1928)	Recitation Section (large)	1	1
Particle Technology for IMP (L1289)	Lecture	2	3
Practicle Course Particle Technology for IMP (L1290)	Practical Course	3	2

Module Responsible	Prof. Stefan Heinrich
Admission Requirements	None
Recommended Previous Knowledge	none
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able - to list and to describe processes and unit-operations of solids process engineering, - to describe the characterization of particles and explain particle distributions and their bulk properties.
Skills	students are able to • choose and design apparatuses and processes for solids processing according to the desired solids properties of the product • assess solids with respect to their behavior in solids processing steps
Personal Competence	
Social Competence	students are able to analyze and orally discuss problems in a scientific way.
Autonomy	students are able to analyze and solve problems regarding solid particles independently
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory** Yes; **Bonus** None; **Form** Written elaboration; **Description** sechs Berichte (pro Versuch ein Bericht) à 5-10 Seiten
Examination	Written exam
Examination duration and scale	90 minutes
Assignment for the Following Curricula	Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory

Course L1928: Excercise Particle Technology for International Master Program

Typ	Recitation Section (large)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Stefan Heinrich
Language	EN
Cycle	WiSe
Content	see corresponding lecture
Literature	siehe korrespondierende Vorlesung

Course L1289: Particle Technology for IMP	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Stefan Heinrich
Language	EN
Cycle	WiSe
Content	• Description of particles and particle distributions • Description of a separation process • Description of a particle mixture • Particle size reduction • Agglomeration, particle size enlargement • Storage and flow of bulk solids • Basics of fluid/particle flows • classifying processes • Separation of particles from fluids • Basic fluid mechanics of fluidized beds • Pneumatic and hydraulic transport
Literature	• M. Rhodes: Introduction to Particle Technology, John Wiley & Sons, 1998 • M.E. Fayed & L. Otten: Handbook of Powder Science & Technology, 2nd Ed., Chapman & Hall, 1997 • M. Stieß: Mechanische Verfahrenstechnik 1, 2.Auflage, Springer-Verlag, 1995 (German) • M. Stieß: Mechanische Verfahrenstechnik 2, Springer-Verlag, 1994 (German)

Course L1290: Practicle Course Particle Technology for IMP	
Typ	Practical Course
Hrs/wk	3
CP	2
Workload in Hours	Independent Study Time 18, Study Time in Lecture 42
Lecturer	Prof. Stefan Heinrich
Language	EN
Cycle	WiSe
Content	Following experiments have to be carried out: • Sieving • Bulk properties • Size reduction • Mixing • Gas cyclone • Blaine-test, filtration • Sedimentation
Literature	• M. Rhodes: Introduction to Particle Technology, John Wiley & Sons, 1998 • M.E. Fayed & L. Otten: Handbook of Powder Science & Technology, 2nd Ed., Chapman & Hall, 1997 • M. Stieß: Mechanische Verfahrenstechnik 1, 2.Auflage, Springer-Verlag, 1995 (German) • M. Stieß: Mechanische Verfahrenstechnik 2, Springer-Verlag, 1994 (German)

Module M1970: Process Modelling and Control

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Process modeling and control (L3220)	Lecture	2	3
Process modeling and control (L3221)	Recitation Section (small)	3	3

Module Responsible	Prof. Mirko Skiborowski
Admission Requirements	None
Recommended Previous Knowledge	Engineering fundamentals Unit operations of mechanical and thermal process engineering as well as chemical reaction engineering Conceptual Process Design
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to - classify types of process models and model equations - explain numerical methods for simulation - explain the solution system for flow diagram simulation - classify control structures and present process control concepts for different apparatus and complex process engineering systems
Skills	Students are able to - formulate and implement process control objectives - design and evaluate control strategies and structures - analyze model structure and model parameters from the simulation of processes
Personal Competence	
Social Competence	Students are enabled to develop solutions together in groups
Autonomy	Students are enabled to acquire knowledge on the basis of further literature
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** No; **Bonus** 10 %; **Form** Midterm; **Description**
Examination	Written exam
Examination duration and scale	120 min
Assignment for the Following Curricula	Bioprocess Engineering: Core Qualification: Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory International Management and Engineering: Specialisation II. Process Engineering and Biotechnology: Elective Compulsory Process Engineering: Core Qualification: Compulsory

Course L3220: Process modeling and control

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Mirko Skiborowski
Language	EN
Cycle	WiSe
Content	Process modeling: introduction, mathematical modeling, model building blocks, structured model development, analysis of model equations Process simulation: numeric, validation, flow sheet simulation, solution strategies Process control: process variables, control loops, model-based methods, plant-wide control
Literature	C. Eck, et al., Mathematische Modellierung, Springer, 2017 W. Luyben, Process Modeling, Simulation and Control for Chemical Engineers, 1990 H. Schuler, Prozesssimulation, VCH, 1995 H. Schuler, Prozessführung, Oldenburg, 1999

Course L3221: Process modeling and control	
Typ	Recitation Section (small)
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Mirko Skiborowski
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M2175: Transport Processes

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Multiphase Flows (L0104)	Lecture	2	2
Reactor design under consideration of local transport processes (L0105)	Project-/problem-based Learning	2	2
Heat & Mass Transfer in Process Engineering (L0103)	Lecture	2	2

Module Responsible	Prof. Michael Schlüter
Admission Requirements	None
Recommended Previous Knowledge	All lectures from the undergraduate studies, especially mathematics, chemistry, thermodynamics, fluid mechanics, heat- and mass transfer.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to: • describe transport processes in single- and multiphase flows and they know the analogy between heat- and mass transfer as well as the limits of this analogy. • explain the main transport laws and their application as well as the limits of application. • describe how transport coefficients for heat- and mass transfer can be derived experimentally. • compare different multiphase reactors like trickle bed reactors, pipe reactors, stirring tanks and bubble column reactors. • are known. The Students are able to perform mass and energy balances for different kind of reactors. Further more the industrial application of multiphase reactors for heat- and mass transfer are known.
Skills	The students are able to: • optimize multiphase reactors by using mass- and energy balances, • use transport processes for the design of technical processes, • to choose a multiphase reactor for a specific application.
Personal Competence	
Social Competence	The students are able to discuss in international teams in english and develop an approach under pressure of time.
Autonomy	Students are able to define independently tasks, to solve the problem "design of a multiphase reactor". The knowledge that s necessary is worked out by the students themselves on the basis of the existing knowledge from the lecture. The students are able to decide by themselves what kind of equation and model is applicable to their certain problem. They are able to organize their own team and to define priorities for different tasks.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory** Yes; **Bonus** None; **Form** Group discussion; **Description** Gruppendiskussion
Examination	Written exam
Examination duration and scale	15 min Presentation + 90 min multiple choice written examen
Assignment for the Following Curricula	Bioprocess Engineering: Core Qualification: Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory International Management and Engineering: Specialisation II. Energy and Environmental Engineering: Elective Compulsory International Management and Engineering: Specialisation II. Process Engineering and Biotechnology: Elective Compulsory Renewable Energies: Specialisation Solar Energy Systems: Elective Compulsory Process Engineering: Core Qualification: Compulsory

Course L0104: Multiphase Flows	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Michael Schlüter
Language	EN
Cycle	WiSe
Content	• Interfaces in MPF (boundary layers, surfactants) • Hydrodynamics & pressure drop in Film Flows • Hydrodynamics & pressure drop in Gas-Liquid Pipe Flows • Hydrodynamics & pressure drop in Bubbly Flows • Mass Transfer in Film Flows • Mass Transfer in Gas-Liquid Pipe Flows • Mass Transfer in Bubbly Flows • Reactive mass Transfer in Multiphase Flows • Film Flow: Application Trickle Bed Reactors • Pipe Flow: Application Turbular Reactors • Bubbly Flow: Application Bubble Column Reactors
Literature	Brauer, H.: Grundlagen der Einphasen- und Mehrphasenströmungen. Verlag Sauerländer, Aarau, Frankfurt (M), 1971. Clift, R.; Grace, J.R.; Weber, M.E.: Bubbles, Drops and Particles, Academic Press, New York, 1978. Fan, L.-S.; Tsuchiya, K.: Bubble Wake Dynamics in Liquids and Liquid-Solid Suspensions, Butterworth-Heinemann Series in Chemical Engineering, Boston, USA, 1990. Hewitt, G.F.; Delhaye, J.M.; Zuber, N. (Ed.): Multiphase Science and Technology. Hemisphere Publishing Corp, Vol. 1/1982 bis Vol. 6/1992. Kolev, N.I.: Multiphase flow dynamics. Springer, Vol. 1 and 2, 2002. Levy, S.: Two-Phase Flow in Complex Systems. Verlag John Wiley & Sons, Inc, 1999. Crowe, C.T.: Multiphase Flows with Droplets and Particles. CRC Press, Boca Raton, Fla, 1998.

Course L0105: Reactor design under consideration of local transport processes	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Michael Schlüter
Language	EN
Cycle	WiSe
Content	In this Problem-Based Learning unit the students have to design a multiphase reactor for a fast chemical reaction concerning optimal hydrodynamic conditions of the multiphase flow. The four students in each team have to: • collect and discuss material properties and equations for design from the literature, • calculate the optimal hydrodynamic design, • check the plausibility of the results critically, • write an exposé with the results. This exposé will be used as basis for the discussion within the oral group examen of each team.
Literature	Bird, R.B.; Stewart, W.R.; Lightfoot, E.N.: Transport Phenomena, John Wiley & Sons Inc (2007), ISBN 978-0-470-11539-8. Brauer, H.; Mewes, D.: Stoffaustausch einschließlich chemischer Reaktion; Verlag Sauerländer, Aarau und Frankfurt am Main (1971), ISBN: 3794100085. Brauer, H.: Grundlagen der Einphasen- und Mehrphasenströmungen, Sauerländer, 1971, Clift, R.; Grace, J.R.; Weber, M.E.: Bubbles, Drops, and Particles, Verlag Academic Press, 1978, ISBN 012176950X, 9780121769505 Deckwer, W.-D.: Reaktionstechnik in Blasensäulen, Salle Verlag und Verlag Sauerländer, Aarau, Frankfurt am Main, Berlin, München, Salzburg (1985), DOI 10.1002/CITE.330590530 Deckwer, W.-D.: Bubble Column Reactors. Wiley, New York (1992), DOI 10.1002/AIC.690380821. Fan, L.; Tsuchiya, K.: Bubble wake dynamics in liquids and liquid-solid suspension. Butterworth-Heinemann, (1990), DOI 10.1016/c2009-0-24002-5. Kraume, M., Transportvorgänge in der Verfahrenstechnik, Springer Berlin, 2020, ISBN 978-3-662-60392-5. Lienhard, J. H. (2019). A Heat Transfer Textbook, Dover Publications. ISBN:9780486837352, 0486837351.

Course L0103: Heat & Mass Transfer in Process Engineering	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Michael Schlüter
Language	EN
Cycle	WiSe
Content	• Introduction - Transport Processes in Chemical Engineering • Molecular Heat- and Mass Transfer: Applications of Fourier's and Fick's Law • Convective Heat and Mass Transfer: Applications in Process Engineering • Unsteady State Transport Processes: Cooling & Drying • Transport at fluidic Interfaces: Two Film, Penetration, Surface Renewal • Transport Laws & Balance Equations with turbulence, sinks and sources • Experimental Determination of Transport Coefficients • Design and Scale Up of Reactors for Heat- and Mass Transfer • Reactive Mass Transfer • Processes with Phase Changes – Evaporization and Condensation • Radiative Heat Transfer - Fundamentals • Radiative Heat Transfer - Solar Energy
Literature	1. Baehr, Stephan: Heat and Mass Transfer, Wiley 2002. 2. Bird, Stewart, Lightfood: Transport Phenomena, Springer, 2000. 3. John H. Lienhard: A Heat Transfer Textbook, Phlogiston Press, Cambridge Massachusetts, 2008. 4. Myers: Analytical Methods in Conduction Heat Transfer, McGraw-Hill, 1971. 5. Incropera, De Witt: Fundamentals of Heat and Mass Transfer, Wiley, 2002. 6. Beek, Muttzall: Transport Phenomena, Wiley, 1983. 7. Crank: The Mathematics of Diffusion, Oxford, 1995. 8. Madhusudana: Thermal Contact Conductance, Springer, 1996. 9. Treybal: Mass-Transfer-Operation, McGraw-Hill, 1987.

Module M2142: Biocatalytical and Biotechnological Processes

Courses

Title	Typ	Hrs/wk	CP
Biocatalytical and Biotechnological Processes (L3453)	Lecture	4	6

Module Responsible	Prof. Andreas Liese
Admission Requirements	None
Recommended Previous Knowledge	none
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	´ After successfully finishing this module, students are able: - to give an overview of genetic processes in the cell - to explain the application of industrial relevant biocatalysts - to explain and prove genetic differences between pro- and eukaryotes - to take care of necessary preparation steps for bioprocesses: sterilisation, medium composition and optimization - to design and optimize fermentation processes considering different operational modes (Batch, Fed-Batch, Chemostat) - to explain different steps in upstream processing: process scale - up and scale-down (microfluidic scale to industrial scale) - to give an overview of typical unit operations in downstream processing including important bioprocess examples
Skills	After completing the module, students are able to: - describe the growth of whole cells using kinetic approaches, differentiate between the various basic reactor types in biotechnological processes, and set up and solve differential equations for the mathematical description of fermentation processes. - evaluate the application of scale-up criteria for various bioreactors and process types and apply these criteria to given bioprocess engineering problems (microbial and cell culture processes)
Personal Competence	
Social Competence	Students are able: - to do to a literature survey and give an overview of a topic using scientific literature in an oral presentation - to develop and distribute work assignments for given problems
Autonomy	Students are able to search information for a given problem by themselves prepare summaries of their search results for the teammake themselves familiar with new topics
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory

Course L3453: Biocatalytical and Biotechnological Processes	
Typ	Lecture
Hrs/wk	4
CP	6
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Lecturer	Prof. Andreas Liese, Prof. Anna-Lena Heins, Prof. Johannes Gescher
Language	EN
Cycle	WiSe
Content	The course consists of a four-hour lecture with an integrated seminar. The lecture is divided into three blocks. These blocks cover the basics of genetic modification of biocatalysts and fermentative processes, from process control and scaling to optimization and downstream processing of bioproducts. Institute of Technical Microbiology: The functionality of whole-cell biocatalysts and enzymes, the molecular biological principles of biological systems, and the possibilities for directed or undirected modification of organisms. Institute of Technical Biocatalysis: Fermentation in batch, fed-batch and chemostat Airation of bioprocesses Calculation of main parameters of fermentative processes Institute of Bioprocess and Biosystems Engineering: Preparation for bioprocesses: sterilisation, inoculuum, medium composition and optimization Upstream Processing: bioprocess scale-up and scale-down (microfluidic scale to industrial scale) Downstream Processing: typical unit operations & overview of important bioprocess examples Students are actively involved in the course and receive assignments, the results of which are presented in short presentations. Through these presentations, bonus points of no more than 10% of the total exam score can be achieved.
Literature	L.A. Urry Mills, L. Cain, S.A. Wasserman, P.V. Minorsky, R.B. Orr, Cambell Biology 12th edition; Pearson publishing 2021 A. Liese, K. Seelbach, C. Wandrey: Industrial Biotransformations, Wiley-VCH, 2nd ed. 2006 M. Doran: Bioprocess Engineering Principles, Elsevier, 2nd ed. 2013. K.-E. Jaeger, A. Liese, C. Syldatk: Introduction to Enzyme Technology, Springer, 2024 Bailey, J.E; Ollis, D.F.: Biochemical Engineering Fundamentals. McGraw Hill Chemical Engineering Series, 1986 Krahe, M.: Biochemical Engineering. Ullmann´s Encyclopedia of Industrial Chemistry, 2003. https://onlinelibrary.wiley.com/doi/10.1002/14356007.b04_381

Module M0895: Advanced Chemical Reaction Engineering

Courses

Title	Typ	Hrs/wk	CP
Chemical Reaction Engineering (Advanced Topics) (L0222)	Lecture	2	2
Chemical Reaction Engineering (Advanced Topics) (L0245)	Recitation Section (large)	2	2
Experimental Course Chemical Engineering (Advanced Topics) (L0287)	Practical Course	2	2

Module Responsible	Prof. Raimund Horn
Admission Requirements	None
Recommended Previous Knowledge	Content of the bachelor-lecture "basics of chemical reaction engineering".
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	After completition of the module, students are able to: - identify differences between ideal and non-ideal rectors, - infer fundamental differences in kinetic models for catalyzed reactions, - name modelling algorithms for non-ideal reactors.
Skills	After successfull completition of the module the students are able to -evaluate properties of non-ideal reactors -compare kinetic modells of heterogeneous-catalyzed reactions and develop measuring techniques thereof -choose instruments for temperature, pressure- concentration and mass-flow measurements regarding process conditions -develop a concept for design of experiments
Personal Competence	
Social Competence	The students are able to analyze scientific challenges and elaborate suitable solutions in small groups. Moreover they are able to document these approaches according to scientific guidelines. After successful completition of the lab-course the students have a strong ability to organize themselfes in small groups to solve issues in chemical reaction engineering. The students can discuss their subject related knowledge among each other and with their teachers.
Autonomy	The students are able to obtain further information for experimental planning and assess their relevance autonomously.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** Yes / None / Subject theoretical and practical work /
Examination	Written exam
Examination duration and scale	120 min
Assignment for the Following Curricula	Bioprocess Engineering: Core Qualification: Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory Process Engineering: Core Qualification: Compulsory

Course L0222: Chemical Reaction Engineering (Advanced Topics)	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Raimund Horn
Language	EN
Cycle	SoSe
Content	1. Real reactors (residence time distribution E(t), F(t)-curve, measurement of E(t) or F(t), residence time distribution of ideal reactors, modeling of real reactors, segregated flow model, tanks in series model, dispersion model, compartment models) 2. Heterogeneous catalysis (what is a catalyst, operation principle of a catalyst, volcano plot, homogeneous catalysis, heterogeneous catalysis, biocatalysis, physisorption and chemisorption, turn-over frequency (TOF), Sabatier's principle, Bronstedt-Evans-Polyani-relationship, Adsorption isotherms of single and multi-component systems, kinetic models of heterogeneous catalytic reactions, Langmuir-Hinshelwood kinetics, Eley-Rideal kinetics, power law rate equations, kinetic measurements on heterogeneously catalyzed reactions in the laboratory , microkinetic modeling, catalyst characterization) 3. Diffusion in heterogeneous catalysis (diffusion regimes, Knudsen-diffusion, molecular diffusion, surface diffusion, single-file diffusion, reference systems, Stefan-Maxwell-Equations, Fick's law, pore effectiveness factor, impact of diffusion limitations in heterogeneous catalysis, Damköhler-relation, mass- and energy balance of heterogeneous catalytic reactors) 4. Laboratory measurements in heterogeneous catalysis (temperature, pressure, concentration, mass flow controllers, laboratory reactors, experimental design)
Literature	1. Vorlesungsfolien R. Horn 2. Skript zur Vorlesung F. Keil 3. M. Baerns, A. Behr, A. Brehm, J. Gmehling, H. Hofmann, U. Onken, A. Renken, Technische Chemie, Wiley-VCH 4. G. Emig, E. Klemm, Technische Chemie, Springer 5. A. Behr, D. W. Agar, J. Jörissen, Einführung in die Technische Chemie 6. E. Müller-Erlwein, Chemische Reaktionstechnik 2012, 2. Auflage, Teubner Verlag 7. J. Hagen, Chemiereaktoren: Auslegung und Simulation, 2004, Wiley-VCH 8. H. S. Fogler, Elements of Chemical Reaction Engineering, Prentice Hall B 9. H. S. Fogler, Essentials of Chemical Reaction Engineering, Prentice Hall 10. O. Levenspiel, Chemical Reaction Engineering, John Wiley & Sons, 1998 11. L. D. Schmidt, The Engineering of Chemical Reactions, Oxford Univ. Press, 2009 12. J. B. Butt, Reaction Kinetics and Reactor Design, 2000, Marcel Dekker 13. R. Aris, Elementary Chemical Reactor Analysis, Dover Pubn. Inc., 2000 14. M. E. Davis, R. J. Davis, Fundamentals of Chemical Reaction Engineering, McGraw Hill 15. G. F. Froment, K. B. Bischoff, J. De Wilde, Chemical Reactor Analysis and Design, John Wiley & Sons, 2010 16. A. Jess, P. Wasserscheid, Chemical Technology An Integrated Textbook, WILEY-VCH 17. C. G. Hill, An Introduction to Chemical Engineering Kinetics & Reactor Design, John Wiley & Sons

Course L0245: Chemical Reaction Engineering (Advanced Topics)	
Typ	Recitation Section (large)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Raimund Horn, Dr. Oliver Korup
Language	EN
Cycle	SoSe
Content	1. Real reactors (residence time distribution E(t), F(t)-curve, measurement of E(t) or F(t), residence time distribution of ideal reactors, modeling of real reactors, segregated flow model, tanks in series model, dispersion model, compartment models) 2. Heterogeneous catalysis (what is a catalyst, operation principle of a catalyst, volcano plot, homogeneous catalysis, heterogeneous catalysis, biocatalysis, physisorption and chemisorption, turn-over frequency (TOF), Sabatier's principle, Bronstedt-Evans-Polyani-relationship, Adsorption isotherms of single and multi-component systems, kinetic models of heterogeneous catalytic reactions, Langmuir-Hinshelwood kinetics, Eley-Rideal kinetics, power law rate equations, kinetic measurements on heterogeneously catalyzed reactions in the laboratory , microkinetic modeling, catalyst characterization) 3. Diffusion in heterogeneous catalysis (diffusion regimes, Knudsen-diffusion, molecular diffusion, surface diffusion, single-file diffusion, reference systems, Stefan-Maxwell-Equations, Fick's law, pore effectiveness factor, impact of diffusion limitations in heterogeneous catalysis, Damköhler-relation, mass- and energy balance of heterogeneous catalytic reactors) 4. Laboratory measurements in heterogeneous catalysis (temperature, pressure, concentration, mass flow controllers, laboratory reactors, experimental design)
Literature	1. Vorlesungsfolien R. Horn 2. Skript zur Vorlesung F. Keil 3. M. Baerns, A. Behr, A. Brehm, J. Gmehling, H. Hofmann, U. Onken, A. Renken, Technische Chemie, Wiley-VCH 4. G. Emig, E. Klemm, Technische Chemie, Springer 5. A. Behr, D. W. Agar, J. Jörissen, Einführung in die Technische Chemie 6. E. Müller-Erlwein, Chemische Reaktionstechnik 2012, 2. Auflage, Teubner Verlag 7. J. Hagen, Chemiereaktoren: Auslegung und Simulation, 2004, Wiley-VCH 8. H. S. Fogler, Elements of Chemical Reaction Engineering, Prentice Hall B 9. H. S. Fogler, Essentials of Chemical Reaction Engineering, Prentice Hall 10. O. Levenspiel, Chemical Reaction Engineering, John Wiley & Sons, 1998 11. L. D. Schmidt, The Engineering of Chemical Reactions, Oxford Univ. Press, 2009 12. J. B. Butt, Reaction Kinetics and Reactor Design, 2000, Marcel Dekker 13. R. Aris, Elementary Chemical Reactor Analysis, Dover Pubn. Inc., 2000 14. M. E. Davis, R. J. Davis, Fundamentals of Chemical Reaction Engineering, McGraw Hill 15. G. F. Froment, K. B. Bischoff, J. De Wilde, Chemical Reactor Analysis and Design, John Wiley & Sons, 2010 16. A. Jess, P. Wasserscheid, Chemical Technology An Integrated Textbook, WILEY-VCH 17. C. G. Hill, An Introduction to Chemical Engineering Kinetics & Reactor Design, John Wiley & Sons

Course L0287: Experimental Course Chemical Engineering (Advanced Topics)	
Typ	Practical Course
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Raimund Horn
Language	EN
Cycle	SoSe
Content	Execution and evaluation of several experiments in chemical reaction engineering. * Calculation of error propagation and error analysis * Steady state Wicke-Kallenbach measurements of diffusivities in a catalyst pellet * Interaction of reaction and diffusion in a catalyst particle, dissociation of methanol on zinc oxide * Mass transfer in gas/liquid system * Stability of a CSTR (hydrolysis of acetic anhydride)
Literature	Skript zur Vorlesung, als Buch in der TU-Bibliothek Praktikumsskript Levenspiel, O.: Chemical reaction engineering; John Wiley & Sons, New York, 3. Ed., 1999 VTM 309(LB) Smith, J. M.: Chemical Engineering Kinetics, McGraw Hill, New York, 1981. Hill, C.: Chemical Engineering Kinetics & Reactor Design, John Wiley, New York, 1977. Fogler, H. S. : Elements of Chemical Reaction Engineering , Prentice Hall, 2006 M. Baerns, A. Behr, A. Brehm, J. Gmehling, H. Hofmann, U. Onken, A. Renken: Technische Chemie, VCH , 2006 G. F. Froment, K. B. Bischoff: Chemical Reactor Analysis and Design, Wiley, 1990

Specialization Chemical and Bioprocess Engineering

Module M0523: Business & Management

Module Responsible	Prof. Matthias Meyer
Admission Requirements	Successful completion of the modul "Foundations of Management"
Recommended Previous Knowledge	None
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students are able to find their way around selected special areas of management within the scope of business management. • Students are able to explain basic theories, categories, and models in selected special areas of business management. • Students are able to interrelate technical and management knowledge.
Skills	• Students are able to apply basic methods in selected areas of business management. • Students are able to explain and give reasons for decision proposals on practical issues in areas of business management.
Personal Competence	
Social Competence	• Students are able to communicate in small interdisciplinary groups and to jointly develop solutions for complex problems
Autonomy	• Students are capable of acquiring necessary knowledge independently by means of research and preparation of material.
Workload in Hours	Depends on choice of courses
Credit points	6

Courses
Information regarding lectures and courses can be found in the corresponding module handbook published separately.

Module M0895: Advanced Chemical Reaction Engineering

Courses

Title	Typ	Hrs/wk	CP
Chemical Reaction Engineering (Advanced Topics) (L0222)	Lecture	2	2
Chemical Reaction Engineering (Advanced Topics) (L0245)	Recitation Section (large)	2	2
Experimental Course Chemical Engineering (Advanced Topics) (L0287)	Practical Course	2	2

Module Responsible	Prof. Raimund Horn
Admission Requirements	None
Recommended Previous Knowledge	Content of the bachelor-lecture "basics of chemical reaction engineering".
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	After completition of the module, students are able to: - identify differences between ideal and non-ideal rectors, - infer fundamental differences in kinetic models for catalyzed reactions, - name modelling algorithms for non-ideal reactors.
Skills	After successfull completition of the module the students are able to -evaluate properties of non-ideal reactors -compare kinetic modells of heterogeneous-catalyzed reactions and develop measuring techniques thereof -choose instruments for temperature, pressure- concentration and mass-flow measurements regarding process conditions -develop a concept for design of experiments
Personal Competence	
Social Competence	The students are able to analyze scientific challenges and elaborate suitable solutions in small groups. Moreover they are able to document these approaches according to scientific guidelines. After successful completition of the lab-course the students have a strong ability to organize themselfes in small groups to solve issues in chemical reaction engineering. The students can discuss their subject related knowledge among each other and with their teachers.
Autonomy	The students are able to obtain further information for experimental planning and assess their relevance autonomously.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** Yes / None / Subject theoretical and practical work /
Examination	Written exam
Examination duration and scale	120 min
Assignment for the Following Curricula	Bioprocess Engineering: Core Qualification: Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory Process Engineering: Core Qualification: Compulsory

Course L0222: Chemical Reaction Engineering (Advanced Topics)	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Raimund Horn
Language	EN
Cycle	SoSe
Content	1. Real reactors (residence time distribution E(t), F(t)-curve, measurement of E(t) or F(t), residence time distribution of ideal reactors, modeling of real reactors, segregated flow model, tanks in series model, dispersion model, compartment models) 2. Heterogeneous catalysis (what is a catalyst, operation principle of a catalyst, volcano plot, homogeneous catalysis, heterogeneous catalysis, biocatalysis, physisorption and chemisorption, turn-over frequency (TOF), Sabatier's principle, Bronstedt-Evans-Polyani-relationship, Adsorption isotherms of single and multi-component systems, kinetic models of heterogeneous catalytic reactions, Langmuir-Hinshelwood kinetics, Eley-Rideal kinetics, power law rate equations, kinetic measurements on heterogeneously catalyzed reactions in the laboratory , microkinetic modeling, catalyst characterization) 3. Diffusion in heterogeneous catalysis (diffusion regimes, Knudsen-diffusion, molecular diffusion, surface diffusion, single-file diffusion, reference systems, Stefan-Maxwell-Equations, Fick's law, pore effectiveness factor, impact of diffusion limitations in heterogeneous catalysis, Damköhler-relation, mass- and energy balance of heterogeneous catalytic reactors) 4. Laboratory measurements in heterogeneous catalysis (temperature, pressure, concentration, mass flow controllers, laboratory reactors, experimental design)
Literature	1. Vorlesungsfolien R. Horn 2. Skript zur Vorlesung F. Keil 3. M. Baerns, A. Behr, A. Brehm, J. Gmehling, H. Hofmann, U. Onken, A. Renken, Technische Chemie, Wiley-VCH 4. G. Emig, E. Klemm, Technische Chemie, Springer 5. A. Behr, D. W. Agar, J. Jörissen, Einführung in die Technische Chemie 6. E. Müller-Erlwein, Chemische Reaktionstechnik 2012, 2. Auflage, Teubner Verlag 7. J. Hagen, Chemiereaktoren: Auslegung und Simulation, 2004, Wiley-VCH 8. H. S. Fogler, Elements of Chemical Reaction Engineering, Prentice Hall B 9. H. S. Fogler, Essentials of Chemical Reaction Engineering, Prentice Hall 10. O. Levenspiel, Chemical Reaction Engineering, John Wiley & Sons, 1998 11. L. D. Schmidt, The Engineering of Chemical Reactions, Oxford Univ. Press, 2009 12. J. B. Butt, Reaction Kinetics and Reactor Design, 2000, Marcel Dekker 13. R. Aris, Elementary Chemical Reactor Analysis, Dover Pubn. Inc., 2000 14. M. E. Davis, R. J. Davis, Fundamentals of Chemical Reaction Engineering, McGraw Hill 15. G. F. Froment, K. B. Bischoff, J. De Wilde, Chemical Reactor Analysis and Design, John Wiley & Sons, 2010 16. A. Jess, P. Wasserscheid, Chemical Technology An Integrated Textbook, WILEY-VCH 17. C. G. Hill, An Introduction to Chemical Engineering Kinetics & Reactor Design, John Wiley & Sons

Course L0245: Chemical Reaction Engineering (Advanced Topics)	
Typ	Recitation Section (large)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Raimund Horn, Dr. Oliver Korup
Language	EN
Cycle	SoSe
Content	1. Real reactors (residence time distribution E(t), F(t)-curve, measurement of E(t) or F(t), residence time distribution of ideal reactors, modeling of real reactors, segregated flow model, tanks in series model, dispersion model, compartment models) 2. Heterogeneous catalysis (what is a catalyst, operation principle of a catalyst, volcano plot, homogeneous catalysis, heterogeneous catalysis, biocatalysis, physisorption and chemisorption, turn-over frequency (TOF), Sabatier's principle, Bronstedt-Evans-Polyani-relationship, Adsorption isotherms of single and multi-component systems, kinetic models of heterogeneous catalytic reactions, Langmuir-Hinshelwood kinetics, Eley-Rideal kinetics, power law rate equations, kinetic measurements on heterogeneously catalyzed reactions in the laboratory , microkinetic modeling, catalyst characterization) 3. Diffusion in heterogeneous catalysis (diffusion regimes, Knudsen-diffusion, molecular diffusion, surface diffusion, single-file diffusion, reference systems, Stefan-Maxwell-Equations, Fick's law, pore effectiveness factor, impact of diffusion limitations in heterogeneous catalysis, Damköhler-relation, mass- and energy balance of heterogeneous catalytic reactors) 4. Laboratory measurements in heterogeneous catalysis (temperature, pressure, concentration, mass flow controllers, laboratory reactors, experimental design)
Literature	1. Vorlesungsfolien R. Horn 2. Skript zur Vorlesung F. Keil 3. M. Baerns, A. Behr, A. Brehm, J. Gmehling, H. Hofmann, U. Onken, A. Renken, Technische Chemie, Wiley-VCH 4. G. Emig, E. Klemm, Technische Chemie, Springer 5. A. Behr, D. W. Agar, J. Jörissen, Einführung in die Technische Chemie 6. E. Müller-Erlwein, Chemische Reaktionstechnik 2012, 2. Auflage, Teubner Verlag 7. J. Hagen, Chemiereaktoren: Auslegung und Simulation, 2004, Wiley-VCH 8. H. S. Fogler, Elements of Chemical Reaction Engineering, Prentice Hall B 9. H. S. Fogler, Essentials of Chemical Reaction Engineering, Prentice Hall 10. O. Levenspiel, Chemical Reaction Engineering, John Wiley & Sons, 1998 11. L. D. Schmidt, The Engineering of Chemical Reactions, Oxford Univ. Press, 2009 12. J. B. Butt, Reaction Kinetics and Reactor Design, 2000, Marcel Dekker 13. R. Aris, Elementary Chemical Reactor Analysis, Dover Pubn. Inc., 2000 14. M. E. Davis, R. J. Davis, Fundamentals of Chemical Reaction Engineering, McGraw Hill 15. G. F. Froment, K. B. Bischoff, J. De Wilde, Chemical Reactor Analysis and Design, John Wiley & Sons, 2010 16. A. Jess, P. Wasserscheid, Chemical Technology An Integrated Textbook, WILEY-VCH 17. C. G. Hill, An Introduction to Chemical Engineering Kinetics & Reactor Design, John Wiley & Sons

Course L0287: Experimental Course Chemical Engineering (Advanced Topics)	
Typ	Practical Course
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Raimund Horn
Language	EN
Cycle	SoSe
Content	Execution and evaluation of several experiments in chemical reaction engineering. * Calculation of error propagation and error analysis * Steady state Wicke-Kallenbach measurements of diffusivities in a catalyst pellet * Interaction of reaction and diffusion in a catalyst particle, dissociation of methanol on zinc oxide * Mass transfer in gas/liquid system * Stability of a CSTR (hydrolysis of acetic anhydride)
Literature	Skript zur Vorlesung, als Buch in der TU-Bibliothek Praktikumsskript Levenspiel, O.: Chemical reaction engineering; John Wiley & Sons, New York, 3. Ed., 1999 VTM 309(LB) Smith, J. M.: Chemical Engineering Kinetics, McGraw Hill, New York, 1981. Hill, C.: Chemical Engineering Kinetics & Reactor Design, John Wiley, New York, 1977. Fogler, H. S. : Elements of Chemical Reaction Engineering , Prentice Hall, 2006 M. Baerns, A. Behr, A. Brehm, J. Gmehling, H. Hofmann, U. Onken, A. Renken: Technische Chemie, VCH , 2006 G. F. Froment, K. B. Bischoff: Chemical Reactor Analysis and Design, Wiley, 1990

Module M0898: Heterogeneous Catalysis

Courses

Title	Typ	Hrs/wk	CP
Analysis and Design of Heterogeneous Catalytic Reactors (L0223)	Lecture	2	2
Modern Methods in Heterogeneous Catalysis (L0533)	Lecture	2	2
Modern Methods in Heterogeneous Catalysis (L0534)	Project-/problem-based Learning	2	2

Module Responsible	Prof. Raimund Horn
Admission Requirements	None
Recommended Previous Knowledge	Content of the bachelor-modules "process technology", as well as particle technology, fluidmechanics in process-technology and transport processes.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students are able to apply their knowledge to explain industrial catalytic processes as well as indicate different synthesis routes of established catalyst systems. They are capable to outline dis-/advantages of supported and full-catalysts with respect to their application. Students are able to identify anayltical tools for specific catalytic applications.
Skills	After successfull completion of the module, students are able to use their knowledge to identify suitable analytical tools for specific catalytic applications and to explain their choice. Moreover the students are able to choose and formulate suitable reactor systems for the current synthesis process. Students can apply their knowldege discretely to develop and conduct experiments. They are able to appraise achieved results into a more general context and draw conclusions out of them.
Personal Competence	
Social Competence	The students are able to plan, prepare, conduct and document experiments according to scientific guidelines in small groups. The students can discuss their subject related knowledge among each other and with their teachers.
Autonomy	The students are able to obtain further information for experimental planning and assess their relevance autonomously.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory**: Yes; **Bonus**: None; **Form**: Presentation; **Description**:
Examination	Written exam
Examination duration and scale	120 min
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory

Course L0223: Analysis and Design of Heterogeneous Catalytic Reactors

Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Raimund Horn
Language	EN
Cycle	SoSe
Content	1. Material- and Energybalance of the two-dimensionsal zweidimensionalen pseudo-homogeneous reactor model 2. Numerical solution of ordinary differential equations (Euler, Runge-Kutta, solvers for stiff problems, step controlled solvers) 3. Reactor design with one-dimensional models (ethane cracker, catalyst deactivation, tubular reactor with deactivating catalyst, moving bed reactor with regenerating catalyst, riser reactor, fluidized bed reactor) 4. Partial differential equations (classification, numerical solution Lösung, finite difference method, method of lines) 5. Examples of reactor design (isothermal tubular reactor with axial dispersion, dehydrogenation of ethyl benzene, wrong-way behaviour) 6. Boundary value problems (numerical solution, shooting method, concentration- and temperature profiles in a catalyst pellet, multiphase reactors, trickle bed reactor)
Literature	1. Lecture notes R. Horn 2. Lecture notes F. Keil 3. G. F. Froment, K. B. Bischoff, J. De Wilde, Chemical Reactor Analysis and Design, John Wiley & Sons, 2010 4. R. Aris, Elementary Chemical Reactor Analysis, Dover Pubn. Inc., 2000

Course L0533: Modern Methods in Heterogeneous Catalysis	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Raimund Horn
Language	EN
Cycle	SoSe
Content	Heterogeneous Catalysis and Chemical Reaction Engineering are inextricably linked. About 90% of all chemical intermediates and consumer products (fuels, plastics, fertilizers etc.) are produced with the aid of catalysts. Most of them, in particular large scale products, are produced by heterogeneous catalysis viz. gaseous or liquid reactants react on solid catalysts. In multiphase reactors gases, liquids and a solid catalyst are present. Heterogeneous catalysis plays also a key role in any future energy scenario (fuel cells, electrocatalytic splitting of water) and in environmental engineering (automotive catalysis, photocatalyic abatement of water pollutants). Heterogeneous catalysis is an interdisciplinary science requiring knowledge of different scientific disciplines such as • Materials Science (synthesis and characterization of solid catalysts) • Physics (structure and electronic properties of solids, defects) • Physical Chemistry (thermodynamics, reaction mechanisms, chemical kinetics, adsorption, desorption, spectroscopy, surface chemistry, theory) • Reaction Engineering (catalytic reactors, mass- and heat transport in catalytic reactors, multi-scale modeling, application of heterogeneous catalysis) The class „Modern Methods in Heterogeneous Catalysis“ will deal with the above listed aspects of heterogeneous catalysis beyond the material presented in the normal curriculum of chemical reaction engineering classes. In the corresponding laboratory will have the opportunity to apply their aquired theoretical knowledge by synthesizing a solid catalyst, characterizing it with a variety of modern instrumental methods (e.g. BET, chemisorption, pore analysis, XRD, Raman-Spectroscopy, Electron Microscopy) and measuring its kinetics. Class and laboratory „Modern Methods in Heterogeneous Catalysis“ in combination with the lecture „Analysis and Design of Heterogeneous Catalytic Reactors“ will give interested students the opportunity to specialize in this vibrant, multifaceted and application oriented field of research.
Literature	• J.M. Thomas, W.J. Thomas: Principles and Practice of Heterogeneous Catalysis, VCH • I. Chorkendorff, J. W. Niemantsverdriet, Concepts of Modern Catalysis and Kinetics, WILEY-VCH • B.C. Gates: Catalytic Chemistry, John Wiley • R.A. van Santen, P.W.N.M. van Leeuwen, J.A. Moulijn, B.A. Averill (Eds.): Catalysis: an integrated approach, Elsevier • D.P. Woodruff, T.A. Delchar: Modern Techniques of Surface Science, Cambridge Univ. Press • J.W. Niemantsverdriet: Spectrocopy in Catalysis, VCH • F. Delannay (Ed.): Characterization of heterogeneous catalysts, Marcel Dekker • C.H. Bartholomew, R.J. Farrauto: Fundamentals of Industrial Catalytic Processes (2nd Ed.),Wiley

Course L0534: Modern Methods in Heterogeneous Catalysis	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Raimund Horn
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0617: High Pressure Chemical Engineering

Courses

Title	Typ	Hrs/wk	CP
High pressure plant and vessel design (L1278)	Lecture	2	2
Industrial Processes Under High Pressure (L0116)	Lecture	2	2
Advanced Separation Processes (L0094)	Lecture	2	2

Module Responsible	Dr. Monika Johannsen
Admission Requirements	None
Recommended Previous Knowledge	Fundamentals of Chemistry, Chemical Engineering, Fluid Process Engineering, Thermal Separation Processes, Thermodynamics, Heterogeneous Equilibria
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	After a successful completion of this module, students can: • explain the influence of pressure on the properties of compounds, phase equilibria, and production processes, • describe the thermodynamic fundamentals of separation processes with supercritical fluids, • exemplify models for the description of solid extraction and countercurrent extraction, • discuss parameters for optimization of processes with supercritical fluids.
Skills	After successful completion of this module, students are able to: • compare separation processes with supercritical fluids and conventional solvents, • assess the application potential of high-pressure processes at a given separation task, • include high pressure methods in a given multistep industrial application, • estimate economics of high-pressure processes in terms of investment and operating costs, • perform an experiment with a high pressure apparatus under guidance, • evaluate experimental results, • prepare an experimental protocol.
Personal Competence	
Social Competence	After successful completion of this module, students are able to: • present a scientific topic from an original publication in teams of 2 and defend the contents together.
Autonomy	• Students are able to carry out independent research and independently acquire the necessary subject-specific knowledge. • Students are able to independently develop a topic, present it and discuss it in a scientific manner.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory** Yes; **Bonus** 15 %; **Form** Presentation; **Description**
Examination	Written exam
Examination duration and scale	120 min
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Bioprocess Engineering: Specialisation B - Industrial Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory International Management and Engineering: Specialisation II. Process Engineering and Biotechnology: Elective Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory

Course L1278: High pressure plant and vessel design	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr. Hans Häring
Language	DE/EN
Cycle	SoSe
Content	1. Basic laws and certification standards 2. Basics for calculations of pressurized vessels 3. Stress hypothesis 4. Selection of materials and fabrication processes 5. vessels with thin walls 6. vessels with thick walls 7. Safety installations 8. Safety analysis Applications: - subsea technology (manned and unmanned vessels) - steam vessels - heat exchangers - LPG, LEG transport vessels
Literature	Apparate und Armaturen in der chemischen Hochdrucktechnik, Springer Verlag Spain and Paauwe: High Pressure Technology, Vol. I und II, M. Dekker Verlag AD-Merkblätter, Heumanns Verlag Bertucco; Vetter: High Pressure Process Technology, Elsevier Verlag Sherman; Stadtmuller: Experimental Techniques in High-Pressure Research, Wiley & Sons Verlag Klapp: Apparate- und Anlagentechnik, Springer Verlag

Course L0116: Industrial Processes Under High Pressure	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr. Carsten Zetzl
Language	EN
Cycle	SoSe
Content	Part I : Physical Chemistry and Thermodynamics 1. Introduction: Overview, achieving high pressure, range of parameters. 2. Influence of pressure on properties of fluids: P,v,T-behaviour, enthalpy, internal energy, entropy, heat capacity, viscosity, thermal conductivity, diffusion coefficients, interfacial tension. 3. Influence of pressure on heterogeneous equilibria: Phenomenology of phase equilibria 4. Overview on calculation methods for (high pressure) phase equilibria). Influence of pressure on transport processes, heat and mass transfer. Part II : High Pressure Processes 5. Separation processes at elevated pressures: Absorption, adsorption (pressure swing adsorption), distillation (distillation of air), condensation (liquefaction of gases) 6. Supercritical fluids as solvents: Gas extraction, cleaning, solvents in reacting systems, dyeing, impregnation, particle formation (formulation) 7. Reactions at elevated pressures. Influence of elevated pressure on biochemical systems: Resistance against pressure **Part III : Industrial production** 8. Reaction : Haber-Bosch-process, methanol-synthesis, polymerizations; Hydrations, pyrolysis, hydrocracking; Wet air oxidation, supercritical water oxidation (SCWO) 9. Separation : Linde Process, De-Caffeination, Petrol and Bio-Refinery 10. Industrial High Pressure Applications in Biofuel and Biodiesel Production 11. Sterilization and Enzyme Catalysis 12. Solids handling in high pressure processes, feeding and removal of solids, transport within the reactor. 13. Supercritical fluids for materials processing. 14. Cost Engineering Learning Outcomes: After a successful completion of this module, the student should be able to - understand of the influences of pressure on properties of compounds, phase equilibria, and production processes. - Apply high pressure approches in the complex process design tasks - Estimate Efficiency of high pressure alternatives with respect to investment and operational costs Performance Record: 1. Presence (28 h) 2. Oral presentation of original scientific article (15 min) with written summary 3. Written examination and Case study (2+3 : 32 h Workload) Workload: 60 hours total
Literature	Literatur: Script: High Pressure Chemical Engineering. G. Brunner: Gas Extraction. An Introduction to Fundamentals of Supercritical Fluids and the Application to Separation Processes. Steinkopff, Darmstadt, Springer, New York, 1994.

Course L0094: Advanced Separation Processes	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr. Monika Johannsen
Language	EN
Cycle	SoSe
Content	• Introduction/Overview on Properties of Supercritical Fluids (SCF)and their Application in Gas Extraction Processes • Solubility of Compounds in Supercritical Fluids and Phase Equilibrium with SCF • Extraction from Solid Substrates: Fundamentals, Hydrodynamics and Mass Transfer • Extraction from Solid Substrates: Applications and Processes (including Supercritical Water) • Countercurrent Multistage Extraction: Fundamentals and Methods, Hydrodynamics and Mass Transfer • Countercurrent Multistage Extraction: Applications and Processes • Solvent Cycle, Methods for Precipitation • Supercritical Fluid Chromatography (SFC): Fundamentals and Application • Simulated Moving Bed Chromatography (SMB) • Membrane Separation of Gases at High Pressures • Separation by Reactions in Supercritical Fluids (Enzymes)
Literature	G. Brunner: Gas Extraction. An Introduction to Fundamentals of Supercritical Fluids and the Application to Separation Processes. Steinkopff, Darmstadt, Springer, New York, 1994.

Module M2002: Waste and Resource Management

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Waste management (L3261)	Project-/problem-based Learning	3	3
International waste concepts (L3259)	Lecture	2	2
International waste concepts (L3260)	Recitation Section (small)	1	1

Module Responsible	Prof. Kerstin Kuchta
Admission Requirements	None
Recommended Previous Knowledge	Basics in process engineering
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students are able to describe waste as a resource as well as advanced technologies for recycling and recovery of resources from waste in detail. This covers collection, transport, treatment and disposal in national and international contexts.
Skills	Students are able to select suitable processes for the treatment with respect to the national or cultural and developmental context. They can evaluate the ecological impact and the technical effort of different technologies and management systems.
Personal Competence	
Social Competence	Students can work together as a team of 2-5 persons, participate in subject-specific and interdisciplinary discussions, develop cooperated solutions and defend their own work results in front of others and promote the scientific development of colleagues. Furthermore, they can give and accept professional constructive criticisms.
Autonomy	Students can independently gain additional knowledge of the subject area and apply it in solving the given course tasks and projects.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory** Yes · **Bonus** 20 % · **Form** Written elaboration · **Description**
Examination	Presentation
Examination duration and scale	PowerPoint presentation (10-15 minutes)
Assignment for the Following Curricula	Civil Engineering: Specialisation Water and Traffic: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory Environmental Engineering: Specialisation Energy and Resources: Elective Compulsory International Management and Engineering: Specialisation II. Renewable Energy: Elective Compulsory Process Engineering: Specialisation Environmental Process Engineering: Elective Compulsory Water and Environmental Engineering: Specialisation Cities: Elective Compulsory Water and Environmental Engineering: Specialisation Environment: Elective Compulsory

Course L3261: Waste management

Typ	Project-/problem-based Learning
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Rüdiger Siechau
Language	EN
Cycle	SoSe

Content

- Introduction into the "Waste Management" consisting of:
  - Thermal Process (incinerator, RDF combustion)
  - Biological processes (Wet-/Dryfermentation)
  - technology, energy, emissions, approval , etc.
- Group work
  - design of systems/plants for energy recovery from waste
  - The following points are to be processed:
    - Input: waste (fraction collection and transportation, current quantity, material flows , possible amount of development)
    - Plant (design, process diagram, technology, energy production)
    - Output (energy quantity / type, by-products)
    - Costs and revenues
    - Climate and resource protection (CO2 balance , substitution of primary raw materials / fossil fuels)
    - Location and approval (infrastructure , expiration authorization procedure)
    - Focus at the whole concept (advantages, disadvantages , risks and opportunities , discussion)

Literature

Einführung in die Abfallwirtschaft; Martin Kranert, Klaus Cord-Landwehr (Hrsg.); Vieweg + Teubner Verlag; 2010

Powerpoint-Folien in Stud IP

Course L3259: International waste concepts	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Kerstin Kuchta
Language	EN
Cycle	SoSe
Content	Waste avoidance and recycling are the focus of this lecture. Additionally, waste logistics (Collection, transport, export, fees and taxes) as well as international waste shipment solutions are presented. Other specific wastes, e.g. industrial waste, treatment concepts will be presented and developed by students themselves Waste composition and production on international level, wast eulogistic, collection and treatment in emerging and developing countries. Single national projects and studies will be prepared and presented by students
Literature	Basel convention

Course L3260: International waste concepts	
Typ	Recitation Section (small)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Kerstin Kuchta
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1033: Special Areas of Process Engineering and Bioprocess Engineering

Courses

Title	Typ	Hrs/wk	CP
Solid Matter Process Technology for Biomass (L0052)	Lecture	2	3
Solid Matter Process in Chemical Industry (L2021)	Lecture	2	3
Safety of Chemical Reactions (L1321)	Lecture	2	3

Module Responsible	Prof. Michael Schlüter
Admission Requirements	None
Recommended Previous Knowledge	The students should have passed the Bachelor modules "Process Engineering" successfully.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to find their way around selected special areas of Process Engineering within the scope of Process Engineering. Students are able to explain technical dependencies and models in selected special areas of Process Engineering.
Skills	Students are able to apply basic methods in selected areas of process engineering.
Personal Competence	
Social Competence	Students can discuss in English in international teams and work out a solution under time pressure.
Autonomy	Students can chose independently, in which field the want to deepen their knowledge and skills through the election of courses.
Workload in Hours	Depends on choice of courses
Credit points	6
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Process Engineering: Specialisation Environmental Process Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory

Course L0052: Solid Matter Process Technology for Biomass

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Examination Form	Klausur
Examination duration and scale	60 min
Lecturer	Prof. Werner Sitzmann
Language	DE
Cycle	SoSe
Content	The industrial application of unit operations as part of process engineering is explained by actual examples of solid biomass processes. Size reduction, transportation and dosing, drying and agglomeration of renewable resources are described as important unit operations when producing solid fuels and bioethanol, producing and refining edible oils, when making Btl - and WPC - products. Aspects of explosion protection and plant design complete the lecture.
Literature	Kaltschmitt M., Hartmann H. (Hrsg.): Energie aus Bioamsse, Springer Verlag, 2001, ISBN 3-540-64853-4 Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz, Schriftenreihe Nachwachsende Rohstoffe, Fachagentur Nachwachsende Rohstoffe e.V. www.nachwachsende-rohstoffe.de Bockisch M.: Nahrungsfette und -öle, Ulmer Verlag, 1993, ISBN 380000158175

Course L2021: Solid Matter Process in Chemical Industry

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Examination Form	Schriftliche Ausarbeitung
Examination duration and scale	12 Seiten
Lecturer	Prof. Frank Kleine Jäger
Language	EN
Cycle	SoSe
Content	
Literature	

Course L1321: Safety of Chemical Reactions	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Examination Form	Mündliche Prüfung
Examination duration and scale	30 min
Lecturer	Dr. Marko Hoffmann
Language	DE
Cycle	SoSe
Content	
Literature	

Module M1709: Applied Optimization in Energy and Process Engineering

Courses

Title	Typ	Hrs/wk	CP
Applied optimization in energy and process engineering (L2693)	Integrated Lecture	2	3
Applied optimization in energy and process engineering (L2695)	Recitation Section (small)	3	3

Module Responsible	Prof. Mirko Skiborowski
Admission Requirements	None
Recommended Previous Knowledge	Fundamentals in the field of mathematical modeling and numerical mathematics, as well as a basic understanding of process engineering processes. In particular the contents of the module Process and Plant Engineering II
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The module provides a general introduction to the basics of applied mathematical optimization and deals with application areas on different scales from the identification of kinetic models, to the optimal design of unit operations and the optimization of entire (sub)processes, as well as production planning. In addition to the basic classification and formulation of optimization problems, different solution approaches are discussed and tested during the exercises. Besides deterministic gradient-based methods, metaheuristics such as evolutionary and genetic algorithms and their application are discussed as well. • Introduction to Applied Optimization • Formulation of optimization problems • Linear Optimization • Nonlinear Optimization • Mixed-integer (non)linear optimization • Multi-objective optimization • Global optimization
Skills	After successful participation in the module "Applied Optimization in Energy and Process Engineering", students are able to formulate the different types of optimization problems and to select appropriate solution methods in suitable software such as Matlab and GAMS and to develop improved solution strategies. Furthermore, students will be able to interpret and critically examine the results accordingly.
Personal Competence	
Social Competence	Students are capable of: •develop solutions in heterogeneous small groups
Autonomy	Students are capable of: •taping new knowledge on a special subject by literature research
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** No · **Bonus** 10 % · **Form** Midterm · **Description** Bonuspunkte
Examination	Oral exam
Examination duration and scale	35 min
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Computational Methods and Machine Learning in Engineering: Core Qualification: Elective Compulsory Energy Systems: Specialisation Energy Systems: Elective Compulsory Environmental Engineering: Specialisation Energy and Resources: Elective Compulsory Renewable Energies: Specialisation Bioenergy Systems: Elective Compulsory Renewable Energies: Specialisation Wind Energy Systems: Elective Compulsory Technomathematics: Specialisation III. Engineering Science: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Energy Systems: Elective Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory

Course L2693: Applied optimization in energy and process engineering	
Typ	Integrated Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Mirko Skiborowski
Language	EN
Cycle	SoSe
Content	The lecture offers a general introduction to the basics and possibilities of applied mathematical optimization and deals with application areas on different scales from kinetics identification, optimal design of unit operations to the optimization of entire (sub)processes, and production planning. In addition to the basic classification and formulation of optimization problems, different solution approaches are discussed. Besides deterministic gradient-based methods, metaheuristics such as evolutionary and genetic algorithms and their application are discussed as well. - Introduction to Applied Optimization - Formulation of optimization problems - Linear Optimization - Nonlinear Optimization - Mixed-integer (non)linear optimization - Multi-objective optimization - Global optimization
Literature	Weicker, K., Evolutionäre Algortihmen, Springer, 2015 Edgar, T. F., Himmelblau D. M., Lasdon, L. S., Optimization of Chemical Processes, McGraw Hill, 2001 Biegler, L. Nonlinear Programming - Concepts, Algorithms, and Applications to Chemical Processes, 2010 Kallrath, J. Gemischt-ganzzahlige Optimierung: Modellierung in der Praxis, Vieweg, 2002

Course L2695: Applied optimization in energy and process engineering	
Typ	Recitation Section (small)
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Mirko Skiborowski
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1954: Process Simulation and Process Safety

Courses

Title	Typ	Hrs/wk	CP
CAPE with Computer Exercises (L1039)	Integrated Lecture	3	4
Methods of Process Safety and Dangerous Substances (L1040)	Lecture	2	2

Module Responsible	Prof. Mirko Skiborowski
Admission Requirements	None
Recommended Previous Knowledge	thermal separation processes heat and mass transport processes
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	students can: - outline types of simulation tools - describe principles of flowsheet and equation oriented simulation tools - describe the setting of flowsheet simulation tools - explain the main differences between steady state and dynamic simulations - present the fundamentals of toxicology and hazardous materials - explain the main methods of safety engineering - present the importance of safety analysis with respect to plant design - describe the definitions within the legal accident insurance accident insurance
Skills	students can: - conduct steady state and dynamic simulations - evaluate simulation results and transform them in the practice - choose and combine suitable simulation models into a production plant - evaluate the achieved simulation results regarding practical importance - evaluate the results of many experimental methods regarding safety aspects - review, compare and use results of safety considerations for a plant design
Personal Competence	
Social Competence	students are able to: - work together in teams in order to simulate process elements and develop an integral process - develop in teams a safety concept for a process and present it to the audience
Autonomy	students are able to - act responsible with respect to environment and needs of the society
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Subject theoretical and practical work
Examination duration and scale	Exam 90 minutes and written report
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Bioprocess Engineering: Specialisation B - Industrial Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory Process Engineering: Specialisation Environmental Process Engineering: Elective Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory

Course L1039: CAPE with Computer Exercises	
Typ	Integrated Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Mirko Skiborowski
Language	EN
Cycle	SoSe
Content	I. Introduction 1. Fundamentals of steady state process simulation 1.1. Classes of simulation tools 1.2. Sequential-modularer approach 1.3. Operating mode of ASPEN PLUS 2. Introduction in ASPEN PLUS 2.1. GUI 2.2. Estimation methods of physical properties 2.3. Aspen tools (z.B. Designspecification) 2.4. Convergence methods II. Exercices using ASPEN PLUS and ACM Performance and constraints of ASPEN PLUS ASPEN datenbank using Estimation methods of physical properties Application of model databank, process synthesis Design specifications Sensitivity analysis Optimization tasks Industrial cases
Literature	**-** G. Fieg: Lecture notes **-** Seider, W.D.; Seader, J.D.; Lewin, D.R.: Product and Process Design Principles: Synthesis, Analysis, and Evaluation; Hoboken, J. Wiley & Sons, 2010

Course L1040: Methods of Process Safety and Dangerous Substances	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Mirko Skiborowski, Dr. Thomas Waluga
Language	EN
Cycle	SoSe
Content	Practical implementation of safety analyses (methods) Safety-related parameters and methods for their determination Hazard characteristics according to the Chemicals Act GHS (Globally Harmonized System) for the classification and labelling of chemicals Hazardous substances Toxicology Personal safety Safety considerations in plant design Inherently safe process design Technical measures for plant safety
Literature	Bender, H.: Sicherer Umgang mit Gefahrstoffen; Weinheim (2005) Bender, H.: Das Gefahrstoffbuch. Sicherer Umgang mit Gefahrstoffen in der Praxis; Weinheim (2002) Birett, K.: Umgang mit Gefahrstoffen; Heidelberg (2011) Birgersson, B.; Sterner, O.; Zimerson, E.: Chemie und Gesundheit; Weinheim (1988) O. Antelmann, Diss. an der TU Berlin, 2001 R. Dittmeyer, W. Keim, G. Kreysa, A. Oberholz, Chemische Technik, Prozesse und Produkte, Band 1 Methodische Grundlagen, VCH, 2004-2006, S. 719 H. Pohle, Chemische Industrie, Umweltschutz, Arbeitsschutz, Anlagensicherheit, VCH, Weinheim, 1991 J. Steinbach, Chemische Sicherheitstechnik, VCH, Weinheim, 1995 G. Suter, Identifikation sicherheitskritischer Prozesse, P&A Kompendium, 2004

Module M1308: Modelling and Technical Design of Bio Refinery Processes

Courses

Title	Typ	Hrs/wk	CP
Biorefineries - Technical Design and Optimization (L1832)	Project-/problem-based Learning	3	3
CAPE in Energy Engineering (L0022)	Projection Course	3	3

Module Responsible	Prof. Martin Kaltschmitt
Admission Requirements	None
Recommended Previous Knowledge	Bachelor degree in Process Engineering, Bioprocess Engineering or Energy- and Environmental Engineering
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The tudents can completely design a technical process including mass and energy balances, calculation and layout of different process devices, layout of measurement- and control systems as well as modeling of the overall process. Furthermore, they can describe the basics of the general procedure for the processing of modeling tasks, especially with ASPEN PLUS ® and ASPEN CUSTOM MODELER ®.
Skills	Students are able to simulate and solve scientific task in the context of renewable energy technologies by: • development of modul-comprehensive approaches for the dimensioning and design of production processes • evaluating alternatives input parameter to solve the particular task even with incomplete information, • a systematic documentation of the work results in form of a written version, the presentation itself and the defense of contents. They can use the ASPEN PLUS ® and ASPEN CUSTOM MODELER ® for modeling energy systems and to evaluate the simulation solutions. Through active discussions of various topics within the seminars and exercises of the module, students improve their understanding and the application of the theoretical background and are thus able to transfer what they have learned in practice.
Personal Competence	
Social Competence	Students can • respectfully work together as a team with around 2-3 members, • participate in subject-specific and interdisciplinary discussions in the area of dimensioning and design of production processes, and can develop cooperated solutions, • defend their own work results in front of fellow students and assess the performance of fellow students in comparison to their own performance. Furthermore, they can accept professional constructive criticism.
Autonomy	Students can independently tap knowledge regarding to the given task. They are capable, in consultation with supervisors, to assess their learning level and define further steps on this basis. Furthermore, they can define targets for new application-or research-oriented duties in accordance with the potential social, economic and cultural impact.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	None
Examination	Written elaboration
Examination duration and scale	Written report incl. presentation
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Bioprocess Engineering: Specialisation C - Bioeconomic Process Engineering, Focus Energy and Bioprocess Technology: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Environmental Engineering: Core Qualification: Elective Compulsory Renewable Energies: Core Qualification: Compulsory Process Engineering: Specialisation Environmental Process Engineering: Elective Compulsory

<table>
<tr><th colspan="2">Course L1832: Biorefineries - Technical Design and Optimization</th></tr>
<tr><td>Typ</td><td>Project-/problem-based Learning</td></tr>
<tr><td>Hrs/wk</td><td>3</td></tr>
<tr><td>CP</td><td>3</td></tr>
<tr><td>Workload in Hours</td><td>Independent Study Time 48, Study Time in Lecture 42</td></tr>
<tr><td>Lecturer</td><td>Prof. Oliver Lüdtke</td></tr>
<tr><td>Language</td><td>DE</td></tr>
<tr><td>Cycle</td><td>SoSe</td></tr>
<tr><td>Content</td><td>
I. Repetition of engineering basics

Shell and tube heat exchangers
Steam generators and refrigerating machines
Pumps and turbines
Flow in piping networks
Pumping and mixing of non-newtonian fluids
Requirements to a detailed layout plan

II. Calculation:

Planning and design of a specific bio-refinery plant section, such as Ethanol distillation and fermentation. This is based on empirical valuse of a real, industrial plant.

Mass and energy balances (Aspen)
Equipment design (heat exchangers, pumps, pipes, tanks, etc.) (
Isolation, wall thickness and material selection
Energy demand (electrical, heat or cooling), design of steam boilers and appliances
Selection of fittings, measuring instruments and safety equipment
Definition of main control loops

Hereby, the dependencies of transport phenomena between certain plant sections become evident and methods of calculation are introduced.
In Detail Engineering , it is focused on aspects of plant engineering planning that are relevant for the subsequent construction of the plant.
Depending of time requirement and group size a cost estimation and preparation of a complete R&I flow chart can be implemented as well.

</td></tr>
<tr><td>Literature</td><td>
Perry, R.;Green, R.: Perry's Chemical Engineers' Handbook, 8 th Edition, McGraw Hill Professional, 2007

Sinnot, R. K.: Chemical Engineering Design, Elsevier, 2014
</td></tr>
</table>

<table>
<tr><th colspan="2">Course L0022: CAPE in Energy Engineering</th></tr>
<tr><td>Typ</td><td>Projection Course</td></tr>
<tr><td>Hrs/wk</td><td>3</td></tr>
<tr><td>CP</td><td>3</td></tr>
<tr><td>Workload in Hours</td><td>Independent Study Time 48, Study Time in Lecture 42</td></tr>
<tr><td>Lecturer</td><td>Prof. Martin Kaltschmitt</td></tr>
<tr><td>Language</td><td>DE</td></tr>
<tr><td>Cycle</td><td>SoSe</td></tr>
<tr><td>Content</td><td>

CAPE = Computer-Aided-Project-Engineering
INTRODUCTION TO THE THEORY

Classes of simulation programs
Sequential modular approach
Equation-oriented approach
Simultaneous modular approach
General procedure for the processing of modeling tasks
Special procedure for solving models with repatriations

COMPUTER EXERCISES renewable energy projects WITH ASPEN PLUS ® AND ASPEN CUSTOM MODELER ®

Scope, potential and limitations of Aspen Plus ® and Aspen Custom Modeler ®
Use of integrated databases for material data
Methods for estimating non-existent physical property data
Use of model libraries and Process Synthesis
Application of design specifications and sensitivity analyzes
Solving optimization problems

Within the seminar, the various tasks are actively discussed and applied to various cases of application.
</td></tr>
<tr><td>Literature</td><td>

Aspen Plus® - Aspen Plus User Guide
William L. Luyben; Distillation Design and Control Using Aspen Simulation; ISBN-10: 0-471-77888-5

</td></tr>
</table>

Module M0896: Bioprocess and Biosystems Engineering

Courses

Title	Typ	Hrs/wk	CP
Bioreactor Design and Operation (L1034)	Lecture	2	2
Bioreactors and Biosystems Engineering (L1037)	Project-/problem-based Learning	1	2
Biosystems Engineering (L1036)	Lecture	2	2

Module Responsible	Prof. Anna-Lena Heins
Admission Requirements	None
Recommended Previous Knowledge	Knowledge of bioprocess engineering and process engineering at bachelor level
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	After completion of this module, participants will be able to: • differentiate between different kinds of bioreactors and describe their key features • identify and characterize the peripheral and control systems of bioreactors • depict integrated biosystems (bioprocesses including up- and downstream processing) • name different sterilization methods and evaluate those in terms of different applications • recall and define the advanced methods of modern systems-biological approaches • connect the multiple "omics"-methods and evaluate their application for biological questions • recall the fundamentals of modeling and simulation of biological networks and biotechnological processes and to discuss their methods • assess and apply methods and theories of genomics, transcriptomics, proteomics and metabolomics in order to quantify and optimize biological processes at molecular and process levels.
Skills	After completion of this module, participants will be able to: • describe different process control strategies for bioreactors and chose them after analysis of characteristics of a given bioprocess • plan and construct a bioreactor system including peripherals from lab to pilot plant scale • adapt a present bioreactor system to a new process and optimize it • develop concepts for integration of bioreactors into bioproduction processes • combine the different modeling methods into an overall modeling approach, to apply these methods to specific problems and to evaluate the achieved results critically • connect all process components of biotechnological processes for a holistic system view.
Personal Competence	
Social Competence	After completion of this module, participants will be able to debate technical questions in small teams to enhance the ability to take position to their own opinions and increase their capacity for teamwork. The students can reflect their specific knowledge orally and discuss it with other students and teachers.
Autonomy	After completion of this module, participants will be able to solve a technical problem in teams of approx. 8-12 persons independently including a presentation of the results. •
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	120 min
Assignment for the Following Curricula	Bioprocess Engineering: Core Qualification: Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory International Management and Engineering: Specialisation II. Process Engineering and Biotechnology: Elective Compulsory Renewable Energies: Specialisation Bioenergy Systems: Elective Compulsory Process Engineering: Core Qualification: Compulsory

Course L1034: Bioreactor Design and Operation	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Anna-Lena Heins
Language	EN
Cycle	SoSe
Content	**Design of bioreactors and peripheries:** • reactor types and geometry • materials and surface treatment • agitation system design • insertion of stirrer • sealings • fittings and valves • peripherals • materials • standardization • demonstration in laboratory and pilot plant **Sterile operation:** • theory of sterilisation processes • different sterilisation methods • sterilisation of reactor and probes • industrial sterile test, automated sterilisation • introduction of biological material • autoclaves • continuous sterilisation of fluids • deep bed filters, tangential flow filters • demonstration and practice in pilot plant **Instrumentation and control:** • temperature control and heat exchange • dissolved oxygen control and mass transfer • aeration and mixing • used gassing units and gassing strategies • control of agitation and power input • pH and reactor volume, foaming, membrane gassing **Bioreactor selection and scale-up:** • selection criteria • scale-up and scale-down • reactors for mammalian cell culture **Integrated biosystem:** • interactions and integration of microorganisms, bioreactor and downstream processing • Miniplant technologies **Team work with presentation:** • Operation mode of selected bioprocesses (e.g. fundamentals of batch, fed-batch and continuous cultivation)
Literature	• Storhas, Winfried, Bioreaktoren und periphere Einrichtungen, Braunschweig: Vieweg, 1994 • Chmiel, Horst, Bioprozeßtechnik; Springer 2011 • Krahe, Martin, Biochemical Engineering, Ullmann‘s Encyclopedia of Industrial Chemistry • Pauline M. Doran, Bioprocess Engineering Principles, Second Edition, Academic Press, 2013 • Other lecture materials to be distributed

Course L1037: Bioreactors and Biosystems Engineering	
Typ	Project-/problem-based Learning
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Prof. Anna-Lena Heins
Language	EN
Cycle	SoSe
Content	**Introduction to Biosystems Engineering (Exercise)** **Experimental basis and methods for biosystems analysis** • Introduction to genomics, transcriptomics and proteomics • More detailed treatment of metabolomics • Determination of in-vivo kinetics • Techniques for rapid sampling • Quenching and extraction • Analytical methods for determination of metabolite concentrations **Analysis, modelling and simulation of biological networks** • Metabolic flux analysis • Introduction • Isotope labelling • Elementary flux modes • Mechanistic and structural network models • Regulatory networks • Systems analysis • Structural network analysis • Linear and non-linear dynamic systems • Sensitivity analysis (metabolic control analysis) **Modelling and simulation for bioprocess engineering** • Modelling of bioreactors • Dynamic behaviour of bioprocesses **Selected projects for biosystems engineering** • Miniaturisation of bioreaction systems • Miniplant technology for the integration of biosynthesis and downstream processin • Technical and economic overall assessment of bioproduction processes
Literature	E. Klipp et al. Systems Biology in Practice, Wiley-VCH, 2006 R. Dohrn: Miniplant-Technik, Wiley-VCH, 2006 G.N. Stephanopoulos et. al.: Metabolic Engineering, Academic Press, 1998 I.J. Dunn et. al.: Biological Reaction Engineering, Wiley-VCH, 2003 Lecture materials to be distributed

Course L1036: Biosystems Engineering	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Johannes Gescher, Prof. Anna-Lena Heins
Language	EN
Cycle	SoSe
Content	**Introduction to Biosystems Engineering** **Experimental basis and methods for biosystems analysis** • Introduction to genomics, transcriptomics and proteomics • More detailed treatment of metabolomics • Determination of in-vivo kinetics • Techniques for rapid sampling • Quenching and extraction • Analytical methods for determination of metabolite concentrations **Analysis, modelling and simulation of biological networks** • Metabolic flux analysis • Introduction • Isotope labelling • Elementary flux modes • Mechanistic and structural network models • Regulatory networks • Systems analysis • Structural network analysis • Linear and non-linear dynamic systems • Sensitivity analysis (metabolic control analysis) **Modelling and simulation for bioprocess engineering** • Modelling of bioreactors • Dynamic behaviour of bioprocesses **Selected projects for biosystems engineering** • Miniaturisation of bioreaction systems • Miniplant technology for the integration of biosynthesis and downstream processin • Technical and economic overall assessment of bioproduction processes
Literature	E. Klipp et al. Systems Biology in Practice, Wiley-VCH, 2006 R. Dohrn: Miniplant-Technik, Wiley-VCH, 2006 G.N. Stephanopoulos et. al.: Metabolic Engineering, Academic Press, 1998 I.J. Dunn et. al.: Biological Reaction Engineering, Wiley-VCH, 2003 Lecture materials to be distributed

Module M0952: Industrial Bioprocess Engineering

Courses

Title	Typ	Hrs/wk	CP
Biotechnical Processes (L1065)	Project-/problem-based Learning	2	3
Development of bioprocess engineering processes in industrial practice (L1172)	Seminar	2	3

Module Responsible	Prof. Anna-Lena Heins
Admission Requirements	None
Recommended Previous Knowledge	Knowledge of bioprocess engineering and process engineering at bachelor level
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	After successful completion of the module • the students can outline the current status of research on the specific topics discussed • the students can explain the basic underlying principles of the respective biotechnological production processes
Skills	After successful completion of the module students are able to • analyzing and evaluate current research approaches • Lay-out biotechnological production processes basically
Personal Competence	
Social Competence	Students are able to work together as a team with several students to solve given tasks and discuss their results in the plenary and to defend them.
Autonomy	After completion of this module, participants will be able to solve a technical problem in teams of approx. 8-12 persons independently including a presentation of the results.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Presentation
Examination duration and scale	oral presentation + discussion (45 min) + Written report (10 pages)
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation B - Industrial Bioprocess Engineering: Elective Compulsory Bioprocess Engineering: Specialisation C - Bioeconomic Process Engineering, Focus Energy and Bioprocess Technology: Elective Compulsory Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Process Engineering: Specialisation Environmental Process Engineering: Elective Compulsory

Course L1065: Biotechnical Processes	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Wilfried Blümke
Language	DE/EN
Cycle	SoSe
Content	This course gives an overview of the most important biotechnological production processes. In addition to the individual methods and their specific requirements, general aspects of industrial reality are also addressed, such as: • Asset Lifecycle • Digitization in the bioprocess industry • Basic principles of industrial bioprocess development • Sustainability aspects in the development of bioprocess engineering processes
Literature	Chmiel H (ed). Bioprozesstechnik, Springer 2011, ISBN: 978-3-8274-2476-1 Bailey, James and David F. Ollis: Biochemical Engineering Fundamentals. -2nd ed.; New York: McGraw Hill, 1986. Becker, Th. et al. (2008) Biotechnology. Ullmann's Encyclopedia of Industrial Chemistry. http://www.mrw.interscience.wiley.com/emrw/9783527306732/ueic/article/a04_107/current/abstract Doran, Pauline M.: Bioprocess Engineering Principles, Academic Press, 2003 Hass, V. und R. Pörtner: Praxis der Bioprozesstechnik. Spektrum Akademischer Verlag (2011), 2. Auflage Krahe M (2003) Biochemical Engineering. Ullmann´s Encyclopedia of Industrial Chemistry. http://www.mrw.interscience.wiley.com/ueic/articles/b04_381/frame.html Schuler, M.L. / Kargi, F.: Bioprocess Engineering - Basic concepts

Course L1172: Development of bioprocess engineering processes in industrial practice	
Typ	Seminar
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Stephan Freyer
Language	DE/EN
Cycle	SoSe
Content	This course gives an insight into the methodology used in the development of industrial biotechnology processes. Important aspects of this are, for example, the development of the fermentation and the work-up steps for the respective target molecule, the integration of the partial steps into an overall process, and the cost-effectiveness of the process.
Literature	Chmiel H (ed). Bioprozesstechnik, Springer 2011, ISBN: 978-3-8274-2476-1 [Titel anhand dieser ISBN in Citavi-Projekt übernehmen] Bailey, James and David F. Ollis: Biochemical Engineering Fundamentals. -2nd ed.; New York: McGraw Hill, 1986. Becker, Th. et al. (2008) Biotechnology. Ullmann's Encyclopedia of Industrial Chemistry. http://www.mrw.interscience.wiley.com/emrw/9783527306732/ueic/article/a04_107/current/abstract Doran, Pauline M.: Bioprocess Engineering Principles, Academic Press, 2003 Hass, V. und R. Pörtner: Praxis der Bioprozesstechnik. Spektrum Akademischer Verlag (2011), 2. Auflage Krahe M (2003) Biochemical Engineering. Ullmann´s Encyclopedia of Industrial Chemistry. http://www.mrw.interscience.wiley.com/ueic/articles/b04_381/frame.html Schuler, M.L. / Kargi, F.: Bioprocess Engineering - Basic concepts

Module M2029: Process Imaging

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Process Imaging (L2723)	Lecture	3	3
Applied Process Imaging (L2724)	Project-/problem-based Learning	3	3

Module Responsible	Prof. Alexander Penn
Admission Requirements	None
Recommended Previous Knowledge	No special prerequisites needed. An interest in imaging techniques and image processing is helpful but not mandatory.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The module focuses primarily on discussing established imaging techniques including (a) optical and infrared imaging, (b) magnetic resonance imaging, (c) X-ray imaging and tomography. Moreover, it presents and discusses a range of more recent imaging modalities. The students will learn: 1. what these imaging techniques can measure (such as sample density or concentration, material transport, chemical composition, temperature), 2. how the measurement techniques work (physical measurement principles, hardware requirements, image reconstruction), and 3. how to determine the most suited imaging methods for a given problem.
Skills	After the successful completion of the course, the students shall: 1. understand the physical principles and practical aspects of the most common imaging methods, 2. be able to assess the pros and cons of these methods with regard to cost, complexity, expected contrasts, spatial and temporal resolution, and based on this assessment 3. be able to identify the most suited imaging modality for any specific engineering challenge in the field of chemical and bioprocess engineering.
Personal Competence	
Social Competence	In the problem-based interactive course, students work in small teams and set up two process imaging systems and use these systems to measure relevant process parameters in different chemical and bioprocess engineering applications. The teamwork will foster interpersonal communication skills.
Autonomy	Students are guided to work in self-motivation due to the challenge-based character of this module. A final presentation improves presentation skills.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	None
Examination	Subject theoretical and practical work
Examination duration and scale	70% written examination, 30% active participation and final presentation of the problem-based learning units with a 5-10 page report
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Bioprocess Engineering: Specialisation B - Industrial Bioprocess Engineering: Elective Compulsory Bioprocess Engineering: Specialisation C - Bioeconomic Process Engineering, Focus Energy and Bioprocess Technology: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory Computer Science: Specialisation II: Intelligence Engineering: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory International Management and Engineering: Specialisation II. Process Engineering and Biotechnology: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Process Engineering: Specialisation Environmental Process Engineering: Elective Compulsory

Course L2723: Process Imaging	
Typ	Lecture
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Alexander Penn
Language	EN
Cycle	SoSe
Content	The lecture focuses primarily on presenting and discussing established imaging techniques relevant to the field of engineering including (a) optical and infrared imaging, (b) magnetic resonance imaging, (c) X-ray imaging and tomography. Moreover, it presents and discusses a range of more recent imaging modalities. The students will learn: 1. what these imaging techniques can measure (such as sample density or concentration, material transport, chemical composition, temperature), 2. how the measurement techniques work (physical measurement principles, hardware requirements, image reconstruction), and 3. how to determine the most suited imaging methods for a given problem.
Literature	Wang, M. (2015). Industrial Tomography. Cambridge, UK: Woodhead Publishing. Available as e-book in the library of TUHH: https://katalog.tub.tuhh.de/Record/823579395

Course L2724: Applied Process Imaging	
Typ	Project-/problem-based Learning
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Alexander Penn, Dr. Stefan Benders
Language	EN
Cycle	SoSe
Content	**Content:** The module focuses primarily on discussing established imaging techniques including (a) optical and infrared imaging, (b) magnetic resonance imaging, (c) X-ray imaging and tomography, and (d) ultrasound imaging and also covers a range of more recent imaging modalities. The students will learn: 1. what these imaging techniques can measure (such as sample density or concentration, material transport, chemical composition, temperature), 2. how the measurements work (physical measurement principles, hardware requirements, image reconstruction), and 3. how to determine the most suited imaging methods for a given problem. **Learning goals:** After the successful completion of the course, the students shall: 1. understand the physical principles and practical aspects of the most common imaging methods, 2. be able to assess the pros and cons of these methods with regard to cost, complexity, expected contrasts, spatial and temporal resolution, and based on this assessment 3. be able to identify the most suited imaging modality for any specific engineering challenge in the field of chemical and bioprocess engineering.
Literature	Wang, M. (2015). Industrial Tomography. Cambridge, UK: Woodhead Publishing. Available as e-book in the library of TUHH: https://katalog.tub.tuhh.de/Record/823579395

Module M2028: Computational Fluid Dynamics in Process Engineering

Courses

Title	Typ	Hrs/wk	CP
Lagrangian transport in turbulent flows (L2301)	Lecture	2	3
Computational Fluid Dynamics - Exercises in OpenFoam (L1375)	Recitation Section (small)	1	1
Computational Fluid Dynamics in Process Engineering (L1052)	Lecture	2	2

Module Responsible	Prof. Michael Schlüter
Admission Requirements	None
Recommended Previous Knowledge	• Mathematics I-IV • Basic knowledge in Fluid Mechanics • Basic knowledge in chemical thermodynamics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	After successful completion of the module the students are able to • explain the the basic principles of statistical thermodynamics (ensembles, simple systems) • describe the main approaches in classical Molecular Modeling (Monte Carlo, Molecular Dynamics) in various ensembles • discuss examples of computer programs in detail, • evaluate the application of numerical simulations, • list the possible start and boundary conditions for a numerical simulation.
Skills	The students are able to: • set up computer programs for solving simple problems by Monte Carlo or molecular dynamics, • solve problems by molecular modeling, • set up a numerical grid, • perform a simple numerical simulation with OpenFoam, • evaluate the result of a numerical simulation.
Personal Competence	
Social Competence	The students are able to • develop joint solutions in mixed teams and present them in front of the other students, • to collaborate in a team and to reflect their own contribution toward it.
Autonomy	The students are able to: • evaluate their learning progress and to define the following steps of learning on that basis, • evaluate possible consequences for their profession.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Bioprocess Engineering: Specialisation B - Industrial Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Computational Methods and Machine Learning in Engineering: Core Qualification: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Energy Systems: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Simulation Technology: Elective Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory

Course L2301: Lagrangian transport in turbulent flows

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Yan Jin
Language	EN
Cycle	SoSe
Content	Contents - Common variables and terms for characterizing turbulence (energy spectra, energy cascade, etc.) - An overview of Lagrange analysis methods and experiments in fluid mechanics

	- Critical examination of the concept of turbulence and turbulent structures. -Calculation of the transport of ideal fluid elements and associated analysis methods (absolute and relative diffusion, Lagrangian Coherent Structures, etc.) - Implementation of a Runge-Kutta 4th-order in Matlab - Introduction to particle integration using ODE solver from Matlab - Problems from turbulence research - Application analytical methods with Matlab. Structure: - 14 units a 2x45 min. - 10 units lecture - 4 Units Matlab Exercise- Go through the exercises Matlab, Peer2Peer? Explain solutions to your colleague Learning goals: Students receive very specific, in-depth knowledge from modern turbulence research and transport analysis. → Knowledge The students learn to classify the acquired knowledge, they study approaches to further develop the knowledge themselves and to relate different data sources to each other. → Knowledge, skills The students are trained in the personal competence to independently delve into and research a scientific topic. → Independence Matlab exercises in small groups during the lecture and guided Peer2Peer discussion rounds train communication skills in complex situations. The mixture of precise language and intuitive understanding is learnt. → Knowledge, social competence Required knowledge: Fluid mechanics 1 and 2 advantageous Programming knowledge advantageous
Literature	Bakunin, Oleg G. (2008): Turbulence and Diffusion. Scaling Versus Equations. Berlin [u. a.]: Springer Verlag. Bourgoin, Mickaël; Ouellette, Nicholas T.; Xu, Haitao; Berg, Jacob; Bodenschatz, Eberhard (2006): The role of pair dispersion in turbulent flow. In: Science (New York, N.Y.) 311 (5762), S. 835-838. DOI: 10.1126/science.1121726. Davidson, P. A. (2015): Turbulence. An introduction for scientists and engineers. Second edition. Oxford: Oxford Univ. Press. Graff, L. S.; Guttu, S.; LaCasce, J. H. (2015): Relative Dispersion in the Atmosphere from Reanalysis Winds. In: J. Atmos. Sci. 72 (7), S. 2769-2785. DOI: 10.1175/JAS-D-14-0225.1. Grigoriev, Roman (2011): Transport and Mixing in Laminar Flows. Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA. Haller, George (2015): Lagrangian Coherent Structures. In: Annu. Rev. Fluid Mech. 47 (1), S. 137-162. DOI: 10.1146/annurev-fluid-010313-141322. Kameke, A. von; Huhn, F.; Fernández-García, G.; Muñuzuri, A. P.; Pérez-Muñuzuri, V. (2010): Propagation of a chemical wave front in a quasi-two-dimensional superdiffusive flow. In: Physical review. E, Statistical, nonlinear, and soft matter physics 81 (6 Pt 2), S. 66211. DOI: 10.1103/PhysRevE.81.066211. Kameke, A. von; Huhn, F.; Fernández-García, G.; Muñuzuri, A. P.; Pérez-Muñuzuri, V. (2011): Double cascade turbulence and Richardson dispersion in a horizontal fluid flow induced by Faraday waves. In: Physical review letters 107 (7), S. 74502. DOI: 10.1103/PhysRevLett.107.074502. Kameke, A.v.; Kastens, S.; Rüttinger, S.; Herres-Pawlis, S.; Schlüter, M. (2019): How coherent structures dominate the residence time in a bubble wake: An experimental example. In: Chemical Engineering Science 207, S. 317-326. DOI: 10.1016/j.ces.2019.06.033. Klages, Rainer; Radons, Günter; Sokolov, Igor M. (2008): Anomalous Transport: Wiley. LaCasce, J. H. (2008): Statistics from Lagrangian observations. In: Progress in Oceanography 77 (1), S. 1-29. DOI: 10.1016/j.pocean.2008.02.002. Neufeld, Zoltán; Hernández-García, Emilio (2009): Chemical and Biological Processes in Fluid Flows: PUBLISHED BY IMPERIAL COLLEGE PRESS AND DISTRIBUTED BY WORLD SCIENTIFIC PUBLISHING CO. Onu, K.; Huhn, F.; Haller, G. (2015): LCS Tool: A computational platform for Lagrangian coherent structures. In: Journal of Computational Science 7, S. 26-36. DOI: 10.1016/j.jocs.2014.12.002. Ouellette, Nicholas T.; Xu, Haitao; Bourgoin, Mickaël; Bodenschatz, Eberhard (2006): An experimental study of turbulent relative dispersion models. In: New J. Phys. 8 (6), S. 109. DOI: 10.1088/1367-2630/8/6/109. Pope, Stephen B. (2000): Turbulent Flows. Cambridge: Cambridge University Press.

	Rivera, M. K.; Ecke, R. E. (2005): Pair dispersion and doubling time statistics in two-dimensional turbulence. In: Physical review letters 95 (19), S. 194503. DOI: 10.1103/PhysRevLett.95.194503. Vallis, Geoffrey K. (2010): Atmospheric and oceanic fluid dynamics. Fundamentals and large-scale circulation. 5. printing. Cambridge: Cambridge Univ. Press.

Course L1375: Computational Fluid Dynamics - Exercises in OpenFoam	
Typ	Recitation Section (small)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Michael Schlüter
Language	EN
Cycle	SoSe
Content	• generation of numerical grids with a common grid generator • selection of models and boundary conditions • basic numerical simulation with OpenFoam within the TUHH CIP-Pool
Literature	OpenFoam Tutorials (StudIP)

Course L1052: Computational Fluid Dynamics in Process Engineering	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Michael Schlüter
Language	EN
Cycle	SoSe
Content	• Introduction into partial differential equations • Basic equations • Boundary conditions and grids • Numerical methods • Finite difference method • Finite volume method • Time discretisation and stability • Population balance • Multiphase Systems • Modeling of Turbulent Flows • Exercises: Stability Analysis • Exercises: Example on CFD - analytically/numerically
Literature	Paschedag A.R.: CFD in der Verfahrenstechnik: Allgemeine Grundlagen und mehrphasige Anwendungen, Wiley-VCH, 2004 ISBN 3-527-30994-2. Ferziger, J.H.; Peric, M.: Numerische Strömungsmechanik. Springer-Verlag, Berlin, 2008, ISBN: 3540675868. Ferziger, J.H.; Peric, M.: Computational Methods for Fluid Dynamics. Springer, 2002, ISBN 3-540-42074-6

Module M1777: Introduction to model-based industrial process development for biopharmaceuticals

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Design and Scale up of aerated bioreactors for biopharmaceutical products (L2922)	Seminar	2	3
Insights into biopharmaceutical production (L2921)	Seminar	2	3

Module Responsible	Prof. Michael Schlüter
Admission Requirements	None
Recommended Previous Knowledge	All lectures from the undergraduate studies, especially mathematics, chemistry, thermodynamics, fluid mechanics, heat- and mass transfer, transport processes
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students will be able to: • describe and evaluate pharmaceutical processes from a process engineering perspective. • name and use the essential models for process development • describe and evaluate bioreactors for pharmaceutical processes, especially gassed stirred tank reactors. • describe various pharmaceutical processes and contrast their modes of operation and essential characteristics.
Skills	Students will be able to: • Describe, optimize and design biopharmaceutical processes using models, • Describe, optimize and design gassed stirred reactors as a typical type of apparatus.
Personal Competence	
Social Competence	The students are able to discuss in international teams in english and develop an approach under pressure of time.
Autonomy	Students are able to independently define tasks for working on the overall problem of "Modeling a process for biopharmaceutical production". The knowledge required for this is acquired by the students themselves, building on the knowledge imparted in the lecture, and they decide which equations and models from the lecture are to be used for implementation. They can organize themselves in a team and assign priorities for subtasks.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	20 min
Assignment for the Following Curricula	Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory

Course L2922: Design and Scale up of aerated bioreactors for biopharmaceutical products

Typ	Seminar
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Jürgen Fitschen, Dr. Thomas Wucherpfennig
Language	EN
Cycle	SoSe
Content	• Introduction to aerated stirred tank reactors and alternative reactor concepts • Mixing and mass transfer performance (example with M-STAR) • Energy dissipation rates and shear stress • Gas holdup and bubble size distribution • Experimental methods for the characterization of aerated stirred tank reactors • Common design and scale up concepts • Concept of compartments • Design and scale up assisted by Computational Fluid Dynamics
Literature	

Course L2921: Insights into biopharmaceutical production	
Typ	Seminar
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Jürgen Fitschen, Dr. Thomas Wucherpfennig
Language	EN
Cycle	SoSe
Content	• Introduction to biopharma including biopharmaceutical products (e.g. vaccine) • Biopharma market • Clinical studies • Quality of products • Drug substance process development (cell therapy) • Drug product development • Insilico process development (equipment, process, digital twin) • Scale-up, transfer and production of biopharmaceutical products • Regulatory topics and market authorization • Biopharma lab & production planning • Data, handling, statistics, Experiment Planning (DOE) • Capacity modeling, Software “Bio-G”
Literature	

Module M2094: Solid Process Engineering and Air Pollution Abatement in Chemical Industry

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Solid Matter Process in Chemical Industry (L2021)	Lecture	2	3
Air Pollution Abatement (L0203)	Lecture	2	3

Module Responsible	Dr. Swantje Pietsch-Braune
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge of process engineering and chemistry Basic knowledge of solids process engineering and separation technology
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	After successful completion of the module students are able to • discuss legal regulations in the area of emissions and air quality • explain the effects of air pollutants on the environment, • name and explan off gas tretament processes and to define their area of application • describe and design processes of solid process engineering that are applied on an industrial scale in the chemical industry • comprehensively capture process steps and create process chains
Skills	Students are able to • combine processes for cleaning of off-gases depending on the pollutants contained in the gases • design processes of mechanical process engineering on industrial scale
Personal Competence	
Social Competence	
Autonomy	
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory

Course L2021: Solid Matter Process in Chemical Industry

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Frank Kleine Jäger
Language	EN
Cycle	SoSe
Content	
Literature	

Course L0203: Air Pollution Abatement

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Swantje Pietsch-Braune
Language	EN
Cycle	SoSe
Content	In the lecture methods for the reduction of emissions from industrial plants are treated. At the beginning a short survey of the different forms of air pollutants is given. In the second part physical principals for the removal of particulate and gaseous pollutants form flue gases are treated. Industrial applications of these principles are demonstrated with examples showing the removal of specific compounds, e.g. sulfur or mercury from flue gases of incinerators.
Literature	Handbook of air pollution prevention and control, Nicholas P. Cheremisinoff. - Amsterdam [u.a.] : Butterworth-Heinemann, 2002 Atmospheric pollution : history, science, and regulation, Mark Zachary Jacobson. - Cambridge [u.a.] : Cambridge Univ. Press, 2002 Air pollution control technology handbook, Karl B. Schnelle. - Boca Raton [u.a.] : CRC Press, c 2002 Air pollution, Jeremy Colls. - 2. ed. - London [u.a.] : Spon, 2002

Module M2006: Waste Treatment and Recycling

Courses

Title	Typ	Hrs/wk	CP
Planning of waste treatment plants (L3267)	Project-/problem-based Learning	3	3
Recycling technologies and thermal waste treatment (L3265)	Lecture	2	2
Recycling technologies and thermal waste treatment (L3266)	Recitation Section (small)	1	1

Module Responsible	Prof. Kerstin Kuchta
Admission Requirements	None
Recommended Previous Knowledge	• Basics of thermo dynamics • Basics of fluid dynamics • fluid dynamics chemistry
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students can name, describe current issue and problems in the field of waste treatment (mechanical, chemical and thermal) and contemplate them in the context of their field. The industrial application of unit operations as part of process engineering is explained by actual examples of waste technologies . Compostion, particle sizes, transportation and dosing of wastes are described as important unit operations . Students will be able to design and design waste treatment technology equipment.
Skills	The students are able to select suitable processes for the treatment of wastes or raw material with respect to their characteristics and the process aims. They can evaluate the efforts and costs for processes and select economically feasible treatment concepts.
Personal Competence	
Social Competence	Students can • respectfully work together as a team and discuss technical tasks • participate in subject-specific and interdisciplinary discussions, • develop cooperated solutions • promote the scientific development and accept professional constructive criticism.
Autonomy	Students can independently tap knowledge of the subject area and transform it to new questions. They are capable, in consultation with supervisors, to assess their learning level and define further steps on this basis. Furthermore, they can define targets for new application-or research-oriented duties in accordance with the potential social, economic and cultural impact.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	120 min
Assignment for the Following Curricula	Civil Engineering: Specialisation Water and Traffic: Elective Compulsory Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation General Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Environmental Engineering: Specialisation Energy and Resources: Elective Compulsory International Management and Engineering: Specialisation II. Renewable Energy: Elective Compulsory Renewable Energies: Specialisation Bioenergy Systems: Elective Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory Process Engineering: Specialisation Environmental Process Engineering: Elective Compulsory Water and Environmental Engineering: Specialisation Environment: Compulsory Water and Environmental Engineering: Specialisation Cities: Elective Compulsory

Course L3267: Planning of waste treatment plants	
Typ	Project-/problem-based Learning
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Rüdiger Siechau
Language	EN
Cycle	WiSe
Content	The focus is on getting to know the organization and practice of waste management companies. Topics such as planning, financing and logistics will be discussed and there will be an excursion (waste incineration plant, vehicle fleet and collection systems / containers). Project based learning: You will be given a task to work on independently in groups of 4 to 6 students. All tools and data needed for the project work will be discussed in the lecture "Recycling Technologies and Thermal Waste Treatment". Course documents can be downloaded from StudIP. Communication during the project work also takes place via StudIP.
Literature	• Einführung in die Abfallwirtschaft; Martin Kranert, Klaus Cord-Landwehr (Hrsg.); Vieweg + Teubner Verlag; 2010 • PowerPoint Präsentationen in Stud IP

Course L3265: Recycling technologies and thermal waste treatment	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Kerstin Kuchta
Language	EN
Cycle	WiSe
Content	• Introduction, actual state-of-the-art of waste incineration, aims. legal background, reaction principals • basics of incineration processes: waste composition, calorific value, calculation of air demand and flue gas composition • Incineration techniques: grate firing, ash transfer, boiler • Flue gas cleaning: Volume, composition, legal frame work and emission limits, dry treatment, scrubber, de-nox techniques, dioxin elimination, Mercury elimination • Ash treatment: Mass, quality, treatment concepts, recycling, disposal
Literature	Thomé-Kozmiensky, K. J. (Hrsg.): Thermische Abfallbehandlung Bande 1-7. EF-Verlag für Energie- und Umwelttechnik, Berlin, 196 - 2013.

Course L3266: Recycling technologies and thermal waste treatment	
Typ	Recitation Section (small)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Kerstin Kuchta
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M1354: Advanced Fuels

Courses

Title	Typ	Hrs/wk	CP
Second generation biofuels and electricity based fuels (L2414)	Lecture	2	2
Carbon dioxide as an economic determinant in the mobility sector (L1926)	Lecture	1	1
Mobility and climate protection (L2416)	Recitation Section (small)	2	2
Sustainability aspects and regulatory framework (L2415)	Lecture	1	1

Module Responsible	Prof. Martin Kaltschmitt
Admission Requirements	None
Recommended Previous Knowledge	Bachelor degree in Process Engineering, Bioprocess Engineering or Energy- and Environmental Engineering
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Within the module, students learn about different provision pathways for the production of advanced fuels (biofuels like e.g. alcohol-to-jet; electricity-based fuels like e.g. power-to-liquid). The different processes chains are explained and the regulatory framework for sustainable fuel production is examined. This includes, for example, the requirements of the Renewable Energies Directive II and the conditions and aspects for a market ramp-up of these fuels. For the holistic assessment of the various fuel options, they are also examined under environmental and economic factors.
Skills	After successfully participating, the students are able to solve simulation and application tasks of renewable energy technology: • Module-spanning solutions for the design and presentation of fuel production processes resp. the fuel provision chains • Comprehensive analysis of various fuel production options in technical, ecological and economic terms Through active discussions of the various topics within the lectures and exercises of the module, the students improve their understanding and application of the theoretical foundations and are thus able to transfer the learned to the practice.
Personal Competence	
Social Competence	The students can discuss scientific tasks in a subject-specific and interdisciplinary way and develop joint solutions.
Autonomy	The students are able to access independent sources about the questions to be addressed and to acquire the necessary knowledge. They are able to assess their respective learning situation concretely in consultation with their supervisor and to define further questions and solutions.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory**: Yes; **Bonus**: 20 %; **Form**: Written elaboration; **Description**: Details werden in der ersten Veranstaltung bekannt gegeben.
Examination	Written exam
Examination duration and scale	120 min
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Bioprocess Engineering: Specialisation B - Industrial Bioprocess Engineering: Elective Compulsory Bioprocess Engineering: Specialisation C - Bioeconomic Process Engineering, Focus Energy and Bioprocess Technology: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Energy Systems: Specialisation Energy Systems: Elective Compulsory Environmental Engineering: Specialisation Energy and Resources: Elective Compulsory Aircraft Systems Engineering: Core Qualification: Elective Compulsory Logistics, Infrastructure and Mobility: Specialisation Production and Logistics: Elective Compulsory Logistics, Infrastructure and Mobility: Specialisation Infrastructure and Mobility: Elective Compulsory Renewable Energies: Specialisation Wind Energy Systems: Elective Compulsory Renewable Energies: Specialisation Solar Energy Systems: Elective Compulsory Renewable Energies: Specialisation Bioenergy Systems: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Process Engineering: Specialisation Environmental Process Engineering: Elective Compulsory

Course L2414: Second generation biofuels and electricity based fuels	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Martin Kaltschmitt
Language	DE/EN
Cycle	WiSe
Content	• General overview of various power-based fuels and their process paths, including power-to-liquid process (Fischer-Tropsch synthesis, methanol synthesis), power-to-gas (Sabatier process) • Origin, production and use of these fuels
Literature	• Vorlesungsskript

Course L1926: Carbon dioxide as an economic determinant in the mobility sector	
Typ	Lecture
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Dr. Karsten Wilbrand
Language	DE/EN
Cycle	WiSe
Content	• General overview of various advanced biofuels and their process pathways (including gas-to-liquid, HEFA and Alcohol-to-Jet processes) • Origin, production and use of these fuels
Literature	• Babu, V.: Biofuels Production. Beverly, Mass: Scrivener [u.a.], 2013 • Olsson, L.: Biofuels. Berlin, Heidelberg: Springer-Verlag Berlin Heidelberg, 2007 • William, L. L.: Distillation Design and Control Using Aspen Simulation; ISBN-10: 0-471-77888-5 • Perry, R.; Green, R.: Perry's Chemical Engineers' Handbook, 8th Edition, McGraw Hill Professional, 20 • Sinnot, R. K.: Chemical Engineering Design, Elsevier, 2014 • Kaltschmitt, M.; Neuling, U. (Ed.): Biokerosene - Status and Prospects; Springer, Berlin, Heidelberg, 2018

Course L2416: Mobility and climate protection	
Typ	Recitation Section (small)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr. Benedikt Buchspies, Dr. Karsten Wilbrand
Language	DE/EN
Cycle	WiSe
Content	Application of the acquired theoretical knowledge from the respective lectures on the basis of concrete tasks from practice • Design and simulation of sub-processes of production processes in Aspen Plus ® • Ecological and economic analysis of fuel supply paths • Classification of case studies into applicable regulations
Literature	• Skriptum zur Vorlesung • Aspen Plus® - Aspen Plus User Guide

Course L2415: Sustainability aspects and regulatory framework	
Typ	Lecture
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Dr. Benedikt Buchspies
Language	DE/EN
Cycle	WiSe
Content	Holistic examination of the different fuel paths with the following main topics, among others: • Consideration of the environmental impact of the various alternative fuels • Economic consideration of the different alternative fuels • Regulatory framework for alternative fuels • Certification of alternative fuels • Market introduction models of alternative fuels
Literature	• European Commission - Joint Research Center (2010): International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance. Joint Research Center (JRC) Institut for Environment and Sustainability, Luxembourg • Richtlinie (EU) 2018/2001 des Europäischen Parlaments und des Rates vom 11. Dezember 2018 zur Förderung der Nutzung von Energie aus erneuerbaren Quellen

Module M0537: Applied Thermodynamics: Thermodynamic Properties for Industrial Applications

Courses

Title	Typ	Hrs/wk	CP
Applied Thermodynamics: Thermodynamic Properties for Industrial Applications (L0100)	Lecture	4	3
Applied Thermodynamics: Thermodynamic Properties for Industrial Applications (L0230)	Recitation Section (small)	2	3

Module Responsible	Dr. Simon Müller
Admission Requirements	None
Recommended Previous Knowledge	Thermodynamics III
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students are capable to formulate thermodynamic problems and to specify possible solutions. Furthermore, they can describe the current state of research in thermodynamic property predictions.
Skills	The students are capable to apply modern thermodynamic calculation methods to multi-component mixtures and relevant biological systems. They can calculate phase equilibria and partition coefficients by applying equations of state, gE models, and COSMO-RS methods. They can provide a comparison and a critical assessment of these methods with regard to their industrial relevance. The students are capable to use the software COSMOtherm and relevant property tools of ASPEN and to write short programs for the specific calculation of different thermodynamic properties. They can judge and evaluate the results from thermodynamic calculations/predictions for industrial processes.
Personal Competence	
Social Competence	Students are capable to develop and discuss solutions in small groups; further they can translate these solutions into calculation algorithms.
Autonomy	Students can rank the field of “Applied Thermodynamics” within the scientific and social context. They are capable to define research projects within the field of thermodynamic data calculation.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory** Yes, **Bonus** None, **Form** Written elaboration, **Description**
Examination	Oral exam
Examination duration and scale	20 min
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory

Course L0100: Applied Thermodynamics: Thermodynamic Properties for Industrial Applications

Typ	Lecture
Hrs/wk	4
CP	3
Workload in Hours	Independent Study Time 34, Study Time in Lecture 56
Lecturer	Prof. Ralf Dohrn
Language	EN
Cycle	WiSe
Content	• Phase equilibria in multicomponent systems • Partioning in biorelevant systems • Calculation of phase equilibria in colloidal systems: UNIFAC, COSMO-RS (exercises in computer pool) • Calculation of partitioning coefficients in biological membranes: COSMO-RS (exercises in computer pool) • Application of equations of state (vapour pressure, phase equilibria, etc.) (exercises in computer pool) • Intermolecular forces, interaction Potenitials • Introduction in statistical thermodynamics
Literature	

Course L0230: Applied Thermodynamics: Thermodynamic Properties for Industrial Applications	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Simon Müller
Language	EN
Cycle	WiSe
Content	exercises in computer pool, see lecture description for more details
Literature	-

Module M0900: Examples in Solid Process Engineering

Courses

Title	Typ	Hrs/wk	CP
Fluidization Technology (L0431)	Lecture	2	2
Practical Course Fluidization Technology and Drying Technology (L1369)	Practical Course	1	1
Drying Technology (L3366)	Lecture	2	2
Exercises in Fluidization Technology and Drying Technology (L1372)	Recitation Section (small)	1	1

Module Responsible	Prof. Stefan Heinrich
Admission Requirements	None
Recommended Previous Knowledge	Knowledge from the module particle technology
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	After completion of the module the students will be able to describe based on examples the assembly of solids engineering processes consisting of multiple apparatuses and subprocesses. They are able to describe the coaction and interrelation of subprocesses.
Skills	Students are able to analyze tasks in the field of solids process engineering and to combine suitable subprocesses in a process chain.
Personal Competence	
Social Competence	Students are able to discuss technical problems in a scientific manner.
Autonomy	Students are able to acquire scientific knowledge independently and discuss technical problems in a scientific manner.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** Yes / None / Written elaboration / drei Berichte (pro Versuch ein Bericht) à 5-10 Seiten
Examination	Written exam
Examination duration and scale	120 minutes
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Renewable Energies: Specialisation Bioenergy Systems: Elective Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory

Course L0431: Fluidization Technology

Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Stefan Heinrich
Language	EN
Cycle	WiSe
Content	Introduction: definition, fluidization regimes, comparison with other types of gas/solids reactors Typical fluidized bed applications Fluidmechanical principle Local fluid mechanics of gas/solid fluidization Fast fluidization (circulating fluidized bed) Entrainment Solids mixing in fluidized beds Application of fluidized beds to granulation and drying processes
Literature	Kunii, D.; Levenspiel, O.: Fluidization Engineering. Butterworth Heinemann, Boston, 1991.

Course L1369: Practical Course Fluidization Technology and Drying Technology	
Typ	Practical Course
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Stefan Heinrich
Language	EN
Cycle	WiSe
Content	Experiments: • Determination of the minimum fluidization velocity • Heat transfer in fluidized beds • Granulation • Spray drying • Freeze drying
Literature	Kunii, D.; Levenspiel, O.: Fluidization Engineering. Butterworth Heinemann, Boston, 1991.

Course L3366: Drying Technology	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr. Swantje Pietsch-Braune
Language	EN
Cycle	WiSe
Content	• Fundamental knowledge different drying technologies • Understand and calculate heat and mass transfer processes involved in the different drying technologies • Learn about most important types of dryers for industrial applications
Literature	• Mujumdar, A. S., & Tsotsas, E. (2007). Modern drying technology. Weinheim: Wiley-VCH. • Krischer, O., Kast, W., & Kröll, K. (1978). Die wissenschaftlichen Grundlagen der Trocknungstechnik (3., neubearb. Aufl.). Berlin [u.a.]: Springer.

Course L1372: Exercises in Fluidization Technology and Drying Technology	
Typ	Recitation Section (small)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Stefan Heinrich
Language	EN
Cycle	WiSe
Content	Exercises and calculation examples for the lectures Fluidization Technology and Drying Technology
Literature	Kunii, D.; Levenspiel, O.: Fluidization Engineering. Butterworth Heinemann, Boston, 1991.

Module M2142: Biocatalytical and Biotechnological Processes

Courses

Title	Typ	Hrs/wk	CP
Biocatalytical and Biotechnological Processes (L3453)	Lecture	4	6

Module Responsible	Prof. Andreas Liese
Admission Requirements	None
Recommended Previous Knowledge	none
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	´ After successfully finishing this module, students are able: - to give an overview of genetic processes in the cell - to explain the application of industrial relevant biocatalysts - to explain and prove genetic differences between pro- and eukaryotes - to take care of necessary preparation steps for bioprocesses: sterilisation, medium composition and optimization - to design and optimize fermentation processes considering different operational modes (Batch, Fed-Batch, Chemostat) - to explain different steps in upstream processing: process scale - up and scale-down (microfluidic scale to industrial scale) - to give an overview of typical unit operations in downstream processing including important bioprocess examples
Skills	After completing the module, students are able to: - describe the growth of whole cells using kinetic approaches, differentiate between the various basic reactor types in biotechnological processes, and set up and solve differential equations for the mathematical description of fermentation processes. - evaluate the application of scale-up criteria for various bioreactors and process types and apply these criteria to given bioprocess engineering problems (microbial and cell culture processes)
Personal Competence	
Social Competence	Students are able: - to do to a literature survey and give an overview of a topic using scientific literature in an oral presentation - to develop and distribute work assignments for given problems
Autonomy	Students are able to search information for a given problem by themselves prepare summaries of their search results for the teammake themselves familiar with new topics
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory

Course L3453: Biocatalytical and Biotechnological Processes	
Typ	Lecture
Hrs/wk	4
CP	6
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Lecturer	Prof. Andreas Liese, Prof. Anna-Lena Heins, Prof. Johannes Gescher
Language	EN
Cycle	WiSe
Content	The course consists of a four-hour lecture with an integrated seminar. The lecture is divided into three blocks. These blocks cover the basics of genetic modification of biocatalysts and fermentative processes, from process control and scaling to optimization and downstream processing of bioproducts. Institute of Technical Microbiology: The functionality of whole-cell biocatalysts and enzymes, the molecular biological principles of biological systems, and the possibilities for directed or undirected modification of organisms. Institute of Technical Biocatalysis: Fermentation in batch, fed-batch and chemostat Airation of bioprocesses Calculation of main parameters of fermentative processes Institute of Bioprocess and Biosystems Engineering: Preparation for bioprocesses: sterilisation, inoculuum, medium composition and optimization Upstream Processing: bioprocess scale-up and scale-down (microfluidic scale to industrial scale) Downstream Processing: typical unit operations & overview of important bioprocess examples Students are actively involved in the course and receive assignments, the results of which are presented in short presentations. Through these presentations, bonus points of no more than 10% of the total exam score can be achieved.
Literature	L.A. Urry Mills, L. Cain, S.A. Wasserman, P.V. Minorsky, R.B. Orr, Cambell Biology 12th edition; Pearson publishing 2021 A. Liese, K. Seelbach, C. Wandrey: Industrial Biotransformations, Wiley-VCH, 2nd ed. 2006 M. Doran: Bioprocess Engineering Principles, Elsevier, 2nd ed. 2013. K.-E. Jaeger, A. Liese, C. Syldatk: Introduction to Enzyme Technology, Springer, 2024 Bailey, J.E; Ollis, D.F.: Biochemical Engineering Fundamentals. McGraw Hill Chemical Engineering Series, 1986 Krahe, M.: Biochemical Engineering. Ullmann´s Encyclopedia of Industrial Chemistry, 2003. https://onlinelibrary.wiley.com/doi/10.1002/14356007.b04_381

Module M2003: Biological Waste Treatment

Courses

Title	Typ	Hrs/wk	CP
Waste and Environmental Chemistry (L0328)	Practical Course	2	2
Biological Waste Treatment (L0318)	Project-/problem-based Learning	3	4

Module Responsible	Prof. Kerstin Kuchta
Admission Requirements	None
Recommended Previous Knowledge	chemical and biological basics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The module aims possess knowledge concerning the planning of biological waste treatment plants. Students are able to explain the design and layout of anaerobic and aerobic waste treatment plants in detail, describe different techniques for waste gas treatment plants for biological waste treatment plants and explain different methods for waste analytics.
Skills	The students are able to discuss the compilation of design and layout of plants. They can critically evaluate techniques and quality control measurements. The students can recherché and evaluate literature and date connected to the tasks given in der module and plan additional tests. They are capable of reflecting and evaluating findings in the group.
Personal Competence	
Social Competence	Students can participate in subject-specific and interdisciplinary discussions, develop cooperated solutions and defend their own work results in front of others and promote the scientific development in front of colleagues. Furthermore, they can give and accept professional constructive criticism.
Autonomy	Students can independently tap knowledge from literature, business or test reports and transform it to the course projects. They are capable, in consultation with supervisors as well as in the interim presentation, to assess their learning level and define further steps on this basis. Furthermore, they can define targets for new application-or research-oriented duties in accordance with the potential social, economic and cultural impact.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** Yes / None / Subject theoretical and practical work /
Examination	Presentation
Examination duration and scale	Elaboration and Presentation (15-25 minutes in groups)
Assignment for the Following Curricula	Civil Engineering: Specialisation Coastal Engineering: Elective Compulsory Civil Engineering: Specialisation Geotechnical Engineering: Elective Compulsory Civil Engineering: Specialisation Structural Engineering: Elective Compulsory Civil Engineering: Specialisation Water and Traffic: Elective Compulsory Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation General Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Environmental Engineering: Core Qualification: Compulsory International Management and Engineering: Specialisation II. Renewable Energy: Elective Compulsory Process Engineering: Specialisation Environmental Process Engineering: Elective Compulsory Water and Environmental Engineering: Specialisation Cities: Elective Compulsory Water and Environmental Engineering: Specialisation Environment: Elective Compulsory

Course L0328: Waste and Environmental Chemistry	
Typ	Practical Course
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Kerstin Kuchta
Language	EN
Cycle	WiSe
Content	The participants are divided into groups. Each group prepares a transcript on the experiment performed, which is then used as basis for discussing the results and to evaluate the performance of the group and the individual student. In some experiments the test procedure and the results are presented in seminar form, accompanied by discussion and results evaluation. Experiments ar e.g. Screening and particle size determination Fos/Tac AAS Chalorific value
Literature	Scripte

Course L0318: Biological Waste Treatment	
Typ	Project-/problem-based Learning
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Kerstin Kuchta
Language	EN
Cycle	WiSe
Content	1. Introduction 2. biological basics 3. determination process specific material characterization 4. aerobic degradation (Composting, stabilization) 5. anaerobic degradation (Biogas production, fermentation) 6. Technical layout and process design 7. Flue gas treatment 8. Plant design practical phase
Literature	

Module M1796: Magnetic resonance in engineering

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Fundamentals of Magnetic Resonance (L2968)	Lecture	3	3
Magnetic Resonance in Engineering (L2969)	Project-/problem-based Learning	3	3

Module Responsible	Dr. Stefan Benders
Admission Requirements	None
Recommended Previous Knowledge	No special previous knowledge is necessary.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	This module covers the fundamentals of nuclear magnetic resonance spectroscopy (NMR) and magnetic resonance imaging (MRI) and their applications in engineering disciplines. The module consists of a classical lecture complemented by a problem-based learning course that includes practical hands-on experience on magnetic resonance devices. The module will be held in English.
Skills	After the successful completion of the course the students shall: 1. Understand the physical principles and practical aspects of magnetic resonance in engineering. 2. Know how to safely operate NMR and MRI systems. 3. Know how to run standard experimental sequences and how to implement more advanced sequence protocols. 4. Have an overview of the current capabilities and limits of the MR technique
Personal Competence	
Social Competence	In the problem-based course Magnetic Resonance in Engineering, the students will obtain hands-on experience on how to operate NMR spectrometers and high-field and low-field MRI systems. The course will cover safety aspects, pulse sequence design, spectral image analysis, and image reconstruction. The students will work in small groups on practical tasks on different NMR and MRI systems located at the campus of TUHH.
Autonomy	Through the practical character of the PBL course, the student shall improve their communication skills.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	None
Examination	Subject theoretical and practical work
Examination duration and scale	120 Minutes
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Bioprocess Engineering: Specialisation B - Industrial Bioprocess Engineering: Elective Compulsory Bioprocess Engineering: Specialisation C - Bioeconomic Process Engineering, Focus Energy and Bioprocess Technology: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation General Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Materials Science and Engineering: Specialisation Engineering Materials: Elective Compulsory Materials Science and Engineering: Specialisation Nano and Hybrid Materials: Elective Compulsory Materials Science: Specialisation Engineering Materials: Elective Compulsory Materials Science: Specialisation Nano and Hybrid Materials: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Process Engineering: Specialisation Environmental Process Engineering: Elective Compulsory

Course L2968: Fundamentals of Magnetic Resonance	
Typ	Lecture
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Dr. Stefan Benders
Language	EN
Cycle	WiSe
Content	This lecture covers the fundamentals magnetic resonance imaging (MRI) and magnetic resonance spectroscopy (NMR). It focuses on the following topics: 1. The fundamentals of magnetic resonance: magnetism, magnetic fields, radiofrequency, spin, relaxation 2. Hardware for magnetic resonance: magnets (high-field and low-field), radiofrequency coil design, magnetic field gradients 3. NMR-Spectroscopy: chemical shift, J-Coupling, 2D NMR, solid-state, MAS 4. Relaxometry: single-sided NMR, contrasts, 5. Magnetic resonance imaging (MRI): gradients, coils, k-space, imaging sequences, ultrafast Imaging, parallel imaging, velocimetry, CEST 6. Hyperpolarization techniques: DNP, p-H2, optical pumping with Xe 7. Applications of magnetic resonance in chemical engineering 8. Applications of magnetic resonance in material science and engineering 9. Applications of magnetic resonance in biomedical engineering
Literature	Stapf, S., & Han, S. (2006). NMR imaging in chemical engineering. Weinheim: Wiley-VCH. ISBN: 978-3-527-60719-8 Blümich B., (2003) NMR imaging of materials. Oxford University Press, Online- ISBN: 9780191709524 , doi: https://doi.org/10.1093/acprof:oso/9780198526766.001.0001 Brown R. W., Cheng Y. N., Haacke E. M., Thompson M. R., Venkatesan R., (2014) Magnetic Resonance Imaging: Physical Principles and Sequence Design, Second Edition, John Wiley & Sons, Inc., doi: 10.1002/9781118633953 Haber-Pohlmeier, Sabina, Bernhard Blumich, and Luisa Ciobanu, (2022) Magnetic Resonance Microscopy: Instrumentation and Applications in Engineering, Life Science, and Energy Research. John Wiley & Sons

Course L2969: Magnetic Resonance in Engineering	
Typ	Project-/problem-based Learning
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Dr. Stefan Benders
Language	EN
Cycle	WiSe
Content	In this course, the theoretical basics of magnetic resonance spectroscopy and magnetic resonance tomography are supplemented with practical experiments on the respective devices. The practical handling and operation of the equipment will be learned.
Literature	Stapf, S., & Han, S. (2006). NMR imaging in chemical engineering. Weinheim: Wiley-VCH. ISBN: 978-3-527-60719-8 Blümich B., (2003) NMR imaging of materials. Oxford University Press, Online- ISBN: 9780191709524, doi: https://doi.org/10.1093/acprof:oso/9780198526766.001.0001 Brown R. W., Cheng Y. N., Haacke E. M., Thompson M. R., Venkatesan R., (2014) Magnetic Resonance Imaging: Physical Principles and Sequence Design, Second Edition, John Wiley & Sons, Inc., doi: 10.1002/9781118633953

Module M1970: Process Modelling and Control

Courses

Title	Typ	Hrs/wk	CP
Process modeling and control (L3220)	Lecture	2	3
Process modeling and control (L3221)	Recitation Section (small)	3	3

Module Responsible	Prof. Mirko Skiborowski
Admission Requirements	None
Recommended Previous Knowledge	Engineering fundamentals Unit operations of mechanical and thermal process engineering as well as chemical reaction engineering Conceptual Process Design
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to - classify types of process models and model equations - explain numerical methods for simulation - explain the solution system for flow diagram simulation - classify control structures and present process control concepts for different apparatus and complex process engineering systems
Skills	Students are able to - formulate and implement process control objectives - design and evaluate control strategies and structures - analyze model structure and model parameters from the simulation of processes
Personal Competence	
Social Competence	Students are enabled to develop solutions together in groups
Autonomy	Students are enabled to acquire knowledge on the basis of further literature
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** No · **Bonus** 10 % · **Form** Midterm · **Description**
Examination	Written exam
Examination duration and scale	120 min
Assignment for the Following Curricula	Bioprocess Engineering: Core Qualification: Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory International Management and Engineering: Specialisation II. Process Engineering and Biotechnology: Elective Compulsory Process Engineering: Core Qualification: Compulsory

Course L3220: Process modeling and control

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Mirko Skiborowski
Language	EN
Cycle	WiSe
Content	Process modeling: introduction, mathematical modeling, model building blocks, structured model development, analysis of model equations Process simulation: numeric, validation, flow sheet simulation, solution strategies Process control: process variables, control loops, model-based methods, plant-wide control
Literature	C. Eck, et al., Mathematische Modellierung, Springer, 2017 W. Luyben, Process Modeling, Simulation and Control for Chemical Engineers, 1990 H. Schuler, Prozesssimulation, VCH, 1995 H. Schuler, Prozessführung, Oldenburg, 1999

Course L3221: Process modeling and control	
Typ	Recitation Section (small)
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Mirko Skiborowski
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M1778: Special Topics on Fluid Mechanics

Courses

Title	Typ	Hrs/wk	CP
Application of numerical methods in process engineering (L2923)	Lecture	2	2
Non invasive measurement techniques for Multiphase Flows (L2924)	Lecture	2	2
Non invasive measurement techniques for Multiphase Flows (L2925)	Practical Course	2	2

Module Responsible	Prof. Michael Schlüter
Admission Requirements	None
Recommended Previous Knowledge	All lectures from the undergraduate studies, especially mathematics, chemistry, thermodynamics, fluid mechanics, heat- and mass transfer.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students will be able to: • apply numerical simulations to concrete flow problems in process engineering. • experimentally analysis of basic parameters in industrial multiphase flows • critically assess how reliably numerical methods work and decide which quantities need to be validated with experimental data.
Skills	Students are able to: • perform numerical simulations in single and multiphase flows especially in technical applications • choose and apply experimental methods in multiphase flows especially in industrial aparatuses
Personal Competence	
Social Competence	The students are able to discuss in international teams in english and develop an approach under pressure of time.
Autonomy	Students are able to independently define tasks for working on the overall problem "Experimental and numerical analysis of multiphase reactors". The knowledge required for this is acquired by the students themselves, building on the knowledge imparted in the lecture, and they decide which experimental and numerical methods from the lecture and the practical course are to be used for implementation. They can organize themselves in a team and assign priorities for subtasks.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	20 min
Assignment for the Following Curricula	Chemical and Bioprocess Engineering: Specialisation General Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Computational Methods and Machine Learning in Engineering: Core Qualification: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory

Course L2923: Application of numerical methods in process engineering	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr. Yan Jin, Prof. Michael Schlüter
Language	EN
Cycle	WiSe
Content	This lecture introduces a number of significant research topics in fluid mechanics and their up-to-date progresses. Through the lecture, students will learn how to solve real scientific and engineering flow problems using numerical and experimental methods. The lecture helps the students to prepare for their master thesis. The detailed contents include: • Wall bounded flows (channel flows; pipe flows; wall roughness) • Convection in porous media (multiscale physics; flow instabilities) • Flows in turbomachinery (compressor/turbine cascades; wind turbines) • Flows in biological and physiological processes (digestion in stomach; respiratory system • Interfacial mass transfer of bubbly flows • Comparison between experiments and simulation, experimental validation • Combustion in engines (optional)
Literature	Numerische Strömungsmechanik, Joel H. Ferziger, Milovan Perić & Robert L. Street, Springer Vieweg, 2020 Strömungsmechanik, Heinz Herwig & Bastian Schmandt, Springer Vieweg, 2015. Fundamentals of Multiphase Flow, Christopher E. Brennen, Cambridge University Press, 2005. OpenFOAM User Guide, version 11, 11th July 2023. OpenFOAM Programmer’s Guide, Version 3.0.1, 2015

Course L2924: Non invasive measurement techniques for Multiphase Flows	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr. Felix Kexel
Language	EN
Cycle	WiSe
Content	• Flow measurement techniques (Particle Image Velocimetry, Particle Tracking Velocimetry,...) • Concentration measurement techniques (Laser Induced Fluorescence, UV/VIS Imaging, ...) • Measurement of Particle Size Distribution (Bubbles, Droplets, Particles) • Measurement techniques for Microflows • Measurement techniques for Multiphase flows in industrial application
Literature	Raffel, M.; Willert, C.E.; Wereley, S.T.; Kompenhans, J.: Particle Image Velocimetry, Springer Berlin, Heidelberg (2007), ISBN 978-3-642-43166-1, DOI: https://doi.org/10.1007/978-3-540-72308-0. Schlüter, M. (2011). Lokale Messverfahren für Mehrphasenströmungen. Chemie Ingenieur Technik. 83. (7), 1084-1095. https://doi.org/10.1002/cite.201100039

Course L2925: Non invasive measurement techniques for Multiphase Flows	
Typ	Practical Course
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr. Felix Kexel
Language	EN
Cycle	WiSe
Content	Exemplary measurements in the laboratory of the Institute of Multiphase Flows: • Flow measurements(Particle Image Velocimetry, Particle Tracking Velocimetry,...) • Concentration measurements (Laser Induced Fluorescence, UV/VIS Imaging, ...) • Particle Size Distribution measurements (Bubbles, Droplets, Particles) • Measurements in microflows
Literature	Raffel, M.; Willert, C.E.; Wereley, S.T.; Kompenhans, J.: Particle Image Velocimetry, Springer Berlin, Heidelberg (2007), ISBN 978-3-642-43166-1, DOI: https://doi.org/10.1007/978-3-540-72308-0. Schlüter, M. (2011). Lokale Messverfahren für Mehrphasenströmungen. Chemie Ingenieur Technik. 83. (7), 1084-1095. https://doi.org/10.1002/cite.201100039

Module M0545: Separation Technologies for Life Sciences

Courses

Title	Typ	Hrs/wk	CP
Chromatographic Separation Processes (L0093)	Lecture	2	2
Unit Operations for Bio-Related Systems (L0112)	Lecture	2	2
Unit Operations for Bio-Related Systems (L0113)	Project-/problem-based Learning	2	2

Module Responsible	Dr. Pavel Gurikov
Admission Requirements	None
Recommended Previous Knowledge	Fundamentals of Chemistry, Fluid Process Engineering, Thermal Separation Processes, Chemical Engineering, Chemical Engineering, Bioprocess Engineering Basic knowledge in thermodynamics and in unit operations related to thermal separation processes
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	On completion of the module, students are able to present an overview of the basic thermal process technology operations that are used, in particular, in the separation and purification of biochemically manufactured products. Students can describe chromatographic separation techniques and classic and new basic operations in thermal process technology and their areas of use. In their choice of separation operation students are able to take the specific properties and limitations of biomolecules into consideration. Using different phase diagrams they can explain the principle behind the basic operation and its suitability for bioseparation problems.
Skills	On completion of the module, students are able to assess the separation processes for bio- and pharmaceutical products that have been dealt with for their suitability for a specific separation problem. They can use simulation software to establish the productivity and economic efficiency of bioseparation processes. In small groups they are able to jointly design a downstream process and to present their findings in plenary and summarize them in a joint report.
Personal Competence	
Social Competence	Students are able in small heterogeneous groups to jointly devise a solution to a technical problem by using project management methods such as keeping minutes and sharing tasks and information.
Autonomy	Students are able to prepare for a group assignment by working their way into a given problem on their own. They can procure the necessary information from suitable literature sources and assess its quality themselves. They are also capable of independently preparing the information gained in a way that all participants can understand (by means of reports, minutes, and presentations).
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** Yes / None / Presentation
Examination	Written exam
Examination duration and scale	120 minutes; theoretical questions and calculations
Assignment for the Following Curricula	Bioprocess Engineering: Core Qualification: Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory

Course L0093: Chromatographic Separation Processes	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr. Daniel Ohde, Dr. Paul Bubenheim
Language	EN
Cycle	WiSe
Content	• Introduction: overview, history of chromatography, LC (HPLC), GC, SFC • Fundamentals of linear (analytical) chromatography, retention time/factor, separation factor, peak resolution, band broadening, Van-Deemter equation • Fundamentals of nonlinear chromatography, discontinuous and continuous preparative chromatography (annular, true moving bed - TMB, simulated moving bed - SMB) • Adsorption equilibrium: experimental determination of adsorption isotherms and modeling • Equipment for chromatography, production and characterization of chromatographic adsorbents • Method development, scale up methods, process design, modeling of chromatographic processes, economic aspects • Applications: e.g. normal phase chromatography, reversed phase chromatography, hydrophobic interaction chromatography, chiral chromatography, bioaffinity chromatography, ion exchange chromatography
Literature	• Schmidt-Traub, H.: Preparative Chromatography of Fine Chemicals and Pharmaceutical Agents. Weinheim: Wiley-VCH (2005) - eBook • Carta, G.: Protein chromatography: process development and scale-up. Weinheim: Wiley-VCH (2010) • Guiochon, G.; Lin, B.: Modeling for Preparative Chromatography. Amsterdam: Elsevier (2003) • Hagel, L.: Handbook of process chromatography: development, manufacturing, validation and economics. London ;Burlington, MA Academic (2008) - eBook

Course L0112: Unit Operations for Bio-Related Systems	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr. Pavel Gurikov
Language	EN
Cycle	WiSe
Content	Contents: • Introduction: overview about the separation process in biotechnology and pharmacy • Handling of multicomponent systems • Adsorption of biologic molecules • Crystallization of biologic molecules • Reactive extraction • Aqueous two-phase systems • Micellar systems: micellar extraction and micellar chromatographie • Electrophoresis • Choice of the separation process for the specific systems Learning Outcomes: • Basic knowledge of separation processes for biotechnological and pharmaceutical processes • Identification of specific features and limitations in bio-related systems • Proof of economical value of the process
Literature	"Handbook of Bioseparations", Ed. S. Ahuja http://www.elsevier.com/books/handbook-of-bioseparations-2/ahuja/978-0-12-045540-9 "Bioseparations Engineering" M. R. Ladish http://eu.wiley.com/WileyCDA/WileyTitle/productCd-0471244767.html

Course L0113: Unit Operations for Bio-Related Systems	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr. Pavel Gurikov
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M0636: Cell and Tissue Engineering

Courses

Title	Typ	Hrs/wk	CP
Fundamentals of Cell and Tissue Engineering (L0355)	Lecture	2	3
Bioprocess Engineering for Medical Applications (L0356)	Lecture	2	3

Module Responsible	Prof. Anna-Lena Heins
Admission Requirements	None
Recommended Previous Knowledge	Knowledge of bioprocess engineering and process engineering at bachelor level
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	After successful completion of the module the students - know the basic principles of cell and tissue culture - know the relevant metabolic and physiological properties of animal and human cells - are able to explain and describe the basic underlying principles of bioreactors for cell and tissue cultures, in contrast to microbial fermentations - are able to explain the essential steps (unit operations) in downstream - are able to explain, analyze and describe the kinetic relationships and significant litigation strategies for cell culture reactors
Skills	The students are able - to analyze and perform mathematical modeling to cellular metabolism at a higher level - are able to to develop process control strategies for cell culture systems
Personal Competence	
Social Competence	After completion of this module, participants will be able to debate technical questions in small teams to enhance the ability to take position to their own opinions and increase their capacity for teamwork. The students can reflect their specific knowledge orally and discuss it with other students and teachers.
Autonomy	After completion of this module, participants will be able to solve a technical problem in teams of approx. 8-12 persons independently including a presentation of the results.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	120 min
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Bioprocess Engineering: Specialisation B - Industrial Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation General Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory

Course L0355: Fundamentals of Cell and Tissue Engineering	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Johannes Möller, Prof. Anna-Lena Heins
Language	EN
Cycle	WiSe
Content	Overview of cell culture technology and tissue engineering (cell culture product manufacturing, complexity of protein therapeutics, examples of tissue engineering) (Pörtner, Zeng) Fundamentals of cell biology for process engineering (cells: source, composition and structure. interactions with environment, growth and death - cell cycle, protein glycolysation) (Pörtner) Cell physiology for process engineering (Overview of central metabolism, genomics etc.) (Zeng) Medium design (impact of media on the overall cell culture process, basic components of culture medium, serum and protein-free media) (Pörtner) Stochiometry and kinetics of cell growth and product formation (growth of mammalian cells, quantitative description of cell growth & product formation, kinetics of growth)
Literature	Butler, M (2004) Animal Cell Culture Technology - The basics, 2nd ed. Oxford University Press Ozturk SS, Hu WS (eds) (2006) Cell Culture Technology For Pharmaceutical and Cell-Based Therapies. Taylor & Francis Group, New York Eibl, R.; D. Eibl; R. Pörtner; G. Catapano and P. Czermak: Cell and Tissue Reaction Engineering, Springer (2008). ISBN 978-3-540-68175-5 Pörtner R (ed) (2013) Animal Cell Biotechnology - Methods and Protocols. Humana Press

Course L0356: Bioprocess Engineering for Medical Applications	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Johannes Möller, Prof. Anna-Lena Heins
Language	EN
Cycle	WiSe
Content	Requirements for cell culture processess, shear effects, microcarrier technology Reactor systems for mammalian cell culture (production systems) (design, layout, scale-up: suspension reactors (stirrer, aeration, cell retention), fixed bed, fluidized bed (carrier), hollow fiber reactors (membranes), dialysis reactors, Reactor systems for Tissue Engineering, Prozess strategies (batch, fed-batch, continuous, perfusion, mathematical modelling), control (oxygen, substrate etc.) • Downstream
Literature	Butler, M (2004) Animal Cell Culture Technology - The basics, 2nd ed. Oxford University Press Ozturk SS, Hu WS (eds) (2006) Cell Culture Technology For Pharmaceutical and Cell-Based Therapies. Taylor & Francis Group, New York Eibl, R.; D. Eibl; R. Pörtner; G. Catapano and P. Czermak: Cell and Tissue Reaction Engineering, Springer (2008). ISBN 978-3-540-68175-5 Pörtner R (ed) (2013) Animal Cell Biotechnology - Methods and Protocols. Humana Press

Module M2004: Sustainable Circular Economy

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Circular Economy (L3264)	Seminar	2	3
Environment and Sustainability (L0319)	Lecture	2	3

Module Responsible	Prof. Kerstin Kuchta
Admission Requirements	None
Recommended Previous Knowledge	none
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to describe single techniques and to give an overview for the field of safety and risk assessment, Circular Economy as well as environmental and sustainable engineering, in detail: • basics in safety and reliability of technical facilities • risk assessment and reliability analysis methods • Circularity of material • Identification and evaluation of material flows • energy production and supply • sustainable product design
Skills	Students are able apply interdisciplinary system-oriented methods for Circularity and risk assessment as well as sustainability reporting. They can evaluate the effort and costs for processes and select economically feasible treatment concepts.
Personal Competence	
Social Competence	
Autonomy	Students can gain knowledge of the subject area from given sources and transform it to new questions. Furthermore, they can define targets for new application or research-oriented duties in for risk management and sustainability concepts accordance with the potential social, economic and cultural impact.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written elaboration
Examination duration and scale	Elaboration and presentation (45 minutes in groups)
Assignment for the Following Curricula	Civil Engineering: Core Qualification: Compulsory Bioprocess Engineering: Specialisation C - Bioeconomic Process Engineering, Focus Management and Controlling: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation General Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Environmental Engineering: Specialisation Energy and Resources: Elective Compulsory Mechanical Engineering - Product Development and Production: Specialisation Product Development: Elective Compulsory Mechanical Engineering - Product Development and Production: Specialisation Production: Elective Compulsory Mechanical Engineering - Product Development and Production: Specialisation Materials: Elective Compulsory Product Development, Materials and Production: Specialisation Product Development: Elective Compulsory Product Development, Materials and Production: Specialisation Production: Elective Compulsory Product Development, Materials and Production: Specialisation Materials: Elective Compulsory Water and Environmental Engineering: Core Qualification: Compulsory

Course L3264: Circular Economy

Typ	Seminar
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Marco Ritzkowski
Language	EN
Cycle	WiSe
Content	The seminar deals with the basic idea as well as with core elements, advantages and challenges of the circular economy using concrete examples. The transition from linear to circular material flows is illustrated using the aspects of product design, reuse, recycling, avoidance (resource conservation) and the sharing economy. The concepts and examples presented are discussed with the students, deepened in group work and then presented.
Literature	Suitable literature will be announced in the course.

Course L0319: Environment and Sustainability	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Kerstin Kuchta
Language	EN
Cycle	WiSe
Content	This course presents actual methodologies and examples of environmental relevant, sustainable technologies, concepts and strategies in the field of energy supply, product design, water supply, waste water treatment or mobility. The following list shows examples: • Production and use of biochar • Energy production with algae • Environmentally friendly product design • Clean development mechanisms • Democracy and energy • Alternative mobility
Literature	Wird in der Veranstaltung bekannt gegeben.

Module M2048: Technical Complementary Course for Chemical and Bioprocess Engineering (acc. to Subject Specific Regulations)

Courses

Title	Typ	Hrs/wk	CP

Module Responsible	Prof. Alexander Penn
Admission Requirements	None
Recommended Previous Knowledge	See selected module according to Subject Specific Regulations
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	See selected module according to Subject Specific Regulations
Skills	See selected module according to Subject Specific Regulations
Personal Competence	
Social Competence	See selected module according to Subject Specific Regulations
Autonomy	See selected module according to Subject Specific Regulations
Workload in Hours	Depends on choice of courses
Credit points	6
Assignment for the Following Curricula	Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory

Module M1017: Food Technology

Courses

Title	Typ	Hrs/wk	CP
Food Technology (L1216)	Lecture	2	3
Experimental Course: Brewing Technology (L1242)	Practical Course	2	3

Module Responsible	Prof. Stefan Heinrich
Admission Requirements	None
Recommended Previous Knowledge	• Basic knowledge of partice technology • Separation Technique; Heat and Mass Transfer I
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	After successful completion of the module students are able to • discuss the material properties of food • explain basic of production processes in food engineering • describe some selected processes
Skills	Students are able to • choose and design process chains for the processing of food • asses the effect of the single process steps on the material properties of food
Personal Competence	
Social Competence	Students are enabled to discuss knowledge in a scientific environment.
Autonomy	Students are able to acquire scientific knowledge independently and knowledge in a scientific manner.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory**: Yes; **Bonus**: None; **Form**: Written elaboration; **Description**: 10 - 15 Seiten
Examination	Written exam
Examination duration and scale	120 minutes
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory

Course L1216: Food Technology

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Stefan Heinrich, Prof. Stefan Palzer
Language	DE
Cycle	WiSe
Content	1. Material properties: Rheology, Transport coefficients, Measuring devices, Quality aspects 2. Processes at ambient condition, at elevated temperature and pressure 3. energy analysis 4. Selected processes: Seed oil production; Roasted Coffee
Literature	M. Bockisch: Handbuch der Lebensmitteltechnologie , Stuttgart, 1993 R. Eggers: Vorlesungsmanuskript

Course L1242: Experimental Course: Brewing Technology	
Typ	Practical Course
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Stefan Heinrich, Prof. Andreas Liese
Language	DE/EN
Cycle	WiSe
Content	In the frame of the course the basics of fermentation, fluid processing and process engineering will be repeated. Following all aspects of manufacturing of beer will be explained: selection and processing of raw materials, different liquid and solid unit operations, packaging technology and final quality assurance/sensory evaluation. The students will perform all unit operations in pilot scale. The objective is that student experience and adopt a holistic view of food manufacturing.
Literature	Ludwig Narziss: Abriss der Bierbrauerei, 7. Auflage, Wiley VCH

Module M1955: Process Intensification in Process Engineering

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Process Intensification in Process Engineering (L1978)	Lecture	2	2
Process Intensification in Process Engineering (L1715)	Project-/problem-based Learning	3	4

Module Responsible	Prof. Mirko Skiborowski
Admission Requirements	None
Recommended Previous Knowledge	Process and Plant Engineering 1 Process and Plant Engineering 2 Basics in Process Engineering
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to evaluate hybrid processes
Skills	Students are able to evaluate processes with regard to their suitability as hybrid processes and to interpret them accordingly.
Personal Competence	
Social Competence	Students are able to apply the principles of project management for small groups.
Autonomy	Students are able to acquire and discuss specialized knowledge about hybrid processes.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Subject theoretical and practical work
Examination duration and scale	Project report incl. PM-documents and written Exam (45 minutes)
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Bioprocess Engineering: Specialisation B - Industrial Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation General Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory

Course L1978: Process Intensification in Process Engineering

Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr. Thomas Waluga, Prof. Mirko Skiborowski
Language	EN
Cycle	WiSe
Content	Introduction to integrated and hybrid processes in chemical and biotechnological process engineering; advantages and disadvantages, process windows, differentiation criteria; Process synthesis and process modeling Process examples from industry and research: reactive distillation, dividing wall columns, reactive dividing wall columns, SHOP and MerOX, centrifuges, membrane-supported processes
Literature	- H. Schmidt-Traub; Integrated Reaction and Separation Operations: Modelling and Experimental Validation; Springer 2006 - K. Sundmacher, A. Kienle, A. Seidel-Morgenstern; Integrated Chemical Processes: Synthesis, Operation, Analysis, and Control; Wiley-VCH 2005 - Mexandre C. Dimian (Ed); Integrated Design and Simulation of Chemical Processes; in Computer Aided Chemical Engineering, Volume 13, Pages 1-698 (2003)

Course L1715: Process Intensification in Process Engineering	
Typ	Project-/problem-based Learning
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Dr. Thomas Waluga, Prof. Mirko Skiborowski
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M2084: Scaling of bioprocesses

Courses

Title	Typ	Hrs/wk	CP
Practical Scaling of Bioprocesses (L3357)	Practical Course	2	2
Scaling of Bioprocesses (L3355)	Lecture	2	2
Scaling of Bioprocesses (Exercise) (L3356)	Recitation Section (small)	2	2

Module Responsible	Prof. Anna-Lena Heins
Admission Requirements	None
Recommended Previous Knowledge	• Content of the module "Biological and biochemical basics" • Content of the module "Bioprocess Engineering I" • Content of the module "Bioprocess Engineering II" • Content of the module "Bioprocess and Biosystems Engineering"
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	After completing the module, participants will be able to • Describe and evaluate microfluidic cultivations and the phenomena to be investigated therein • Define ideally mixed bioprocesses on a laboratory scale as a reference stat • Describe and design different multi-compartment bioreactors (advantages and disadvantages of each setup, process examples and characterization of the setups • Name phenomena at pilot scale and industrial scale (examples of unsuccessful and successful scaling, Gradients of process parameters and mixing insufficiencies that are relevant in industrial scale bioreactors, how to scale today and in the future) in comparison to laboratory scal • Define and objectively quantify phenotypic population heterogeneity • Describe modeling techniques to describe mixing insufficiencies and cell responses
Skills	After completing the module, participants will be able to • describe scaling concepts for bioreactors from laboratory scale to industrial scale and select a suitable strategy for a given proces • plan and calculate a bioreactor system including peripherals from laboratory to pilot plant scale • transfer an existing industrial bioprocess to a multi-compartment bioreactor, taking into account the characteristics for detailed investigation of cell physiology • combine the analytical methods covered to investigate heterogeneities and mixed insufficiencies, apply them to specific problems and critically evaluate the results obtained • break down a complex overall problem into sub-problems, paying particular attention to the interface proble • subject the process chain of scaling from bioprocess development to industrial production to a critical overall assessment
Personal Competence	
Social Competence	After completion of this module, participants will be able to debate technical questions in small interdisciplinary teams to enhance the ability to take position to their own opinions and increase their capacity for teamwork. The students can reflect their specific knowledge orally and discuss it with other students and teachers.
Autonomy	After completion of this module, participants will be able to solve a technical problem in teams of approx. up to 5 persons independently including a presentation of the results.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory** Yes · **Bonus** None · **Form** Written elaboration · **Description** Protokoll
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Bioprocess Engineering: Specialisation B - Industrial Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory

Course L3357: Practical Scaling of Bioprocesses	
Typ	Practical Course
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Anna-Lena Heins
Language	EN
Cycle	SoSe
Content	The multi-compartment bioreactor concept designed in the exercise is to be implemented in practice in the laboratory in small groups. Subsequently, an experiment on the physiological characterization of cells in the bioreactor system will be carried out. The results of the various experiments will be presented to the other groups in a final “student conference” and discussed in the plenum
Literature	Aktuelle publizierte Literatur zu den Vorlesungsinhalten

Course L3355: Scaling of Bioprocesses	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Anna-Lena Heins
Language	EN
Cycle	WiSe
Content	• Microfluidic cultivations and the phenomena investigated therein • Ideally mixed bioprocesses on a laboratory scale • Different multi-compartment bioreactors (advantages and disadvantages of each setup, bioprocess examples and characterization of the setups) • Pilot scale and industrial scale phenomena (examples of unsuccessful and successful scaling, gradients and mixing insufficiencies relevant in industrial bioreactors, how to scale today and in the future) compared to laboratory scal • Phenotypic population heterogeneity and objective quantificatio • Modeling techniques to describe mixing insufficiencies and cell responses in bioreactors at different scales
Literature	Aktuelle Publikationen zu den Vorlesungsinhalten Current published studies on the lecture contents

Course L3356: Scaling of Bioprocesses (Exercise)	
Typ	Recitation Section (small)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Anna-Lena Heins
Language	EN
Cycle	WiSe
Content	In-depth exercises (using relevant software tools) on the contents of the reated lecture and application to bioprocess examples Design of a multi-compartment bioreactor for specific bioprocess examples in small groups
Literature	Aktuelle publizierte Literature zu den Übungsthemen

Module M2050: Cellular and Molecular Biotechnology

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Applications of whole cell biocatalysts in biotechnology (L3301)	Seminar	1	1
Advanced microbial genetics (L3302)	Lecture	1	1
Challenges for genetic engineering in biotechnology (L3303)	Seminar	1	1
Microbial Diversity in Applications (L3300)	Lecture	1	1
Parctical course: Cellular and molecular biotechnology (L3304)	Practical Course	2	2

Module Responsible	Prof. Johannes Gescher
Admission Requirements	None
Recommended Previous Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	
Skills	
Personal Competence	
Social Competence	
Autonomy	
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory** Yes; **Bonus** None; **Form** Presentation; **Description** Vortrag
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory International Management and Engineering: Specialisation II. Process Engineering and Biotechnology: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory

Course L3301: Applications of whole cell biocatalysts in biotechnology

Typ	Seminar
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Johannes Gescher
Language	EN
Cycle	WiSe
Content	
Literature	

Course L3302: Advanced microbial genetics

Typ	Lecture
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Johannes Gescher
Language	EN
Cycle	WiSe
Content	
Literature	

Course L3303: Challenges for genetic engineering in biotechnology

Typ	Seminar
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Johannes Gescher
Language	EN
Cycle	WiSe
Content	
Literature	

Course L3300: Microbial Diversity in Applications	
Typ	Lecture
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Johannes Gescher
Language	EN
Cycle	WiSe
Content	
Literature	

Course L3304: Parctical course: Cellular and molecular biotechnology	
Typ	Practical Course
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Johannes Gescher
Language	EN
Cycle	WiSe
Content	
Literature	

Module M0973: Biocatalysis

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Biocatalysis and Enzyme Technology (L1158)	Lecture	2	3
Technical Biocatalysis (L1157)	Lecture	2	3

Module Responsible	Prof. Andreas Liese
Admission Requirements	None
Recommended Previous Knowledge	Knowledge of bioprocess engineering and process engineering at bachelor level
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	After successful completion of this course, students will be able to • reflect a broad knowledge about enzymes and their applications in academia and industry • have an overview of relevant biotransformations und name the general definitions
Skills	After successful completion of this course, students will be able to • understand the fundamentals of biocatalysis and enzyme processes and transfer this to new tasks • know the several enzyme reactors and the important parameters of enzyme processes • use their gained knowledge about the realisation of processes. Transfer this to new tasks • analyse and discuss special tasks of processes in plenum and give solutions • communicate and discuss in English
Personal Competence	
Social Competence	After completion of this module, participants will be able to debate technical and biocatalytical questions in small teams to enhance the ability to take position to their own opinions and increase their capacity for teamwork.
Autonomy	After completion of this module, participants will be able to solve a technical problem independently including a presentation of the results.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Bioprocess Engineering: Core Qualification: Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory

Course L1158: Biocatalysis and Enzyme Technology	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Andreas Liese
Language	EN
Cycle	WiSe
Content	1. Introduction: Impact and potential of enzyme-catalysed processes in biotechnology. 2. History of microbial and enzymatic biotransformations. 3. Chirality - definition & measurement 4. Basic biochemical reactions, structure and function of enzymes. 5. Biocatalytic retrosynthesis of asymmetric molecules 6. Enzyme kinetics: mechanisms, calculations, multisubstrate reactions. 7. Reactors for biotransformations.
Literature	• K. Faber: Biotransformations in Organic Chemistry, Springer, 5th Ed., 2004 • A. Liese, K. Seelbach, C. Wandrey: Industrial Biotransformations, Wiley-VCH, 2006 • R. B. Silverman: The Organic Chemistry of Enzyme-Catalysed Reactions, Academic Press, 2000 • K. Buchholz, V. Kasche, U. Bornscheuer: Biocatalysts and Enzyme Technology. VCH, 2005. • R. D. Schmidt: Pocket Guide to Biotechnology and Genetic Engineering, Woley-VCH, 2003

Course L1157: Technical Biocatalysis	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Andreas Liese
Language	EN
Cycle	WiSe
Content	1. Introduction 2. Production and Down Stream Processing of Biocatalysts 3. Analytics (offline/online) 4. Reaction Engineering & Process Control • Definitions • Reactors • Membrane Processes • Immobilization 5. Process Optimization • Simplex / DOE / GA 6. Examples of Industrial Processes • food / feed • fine chemicals 7. Non-Aqueous Solvents as Reaction Media • ionic liquids • scCO2 • solvent free
Literature	• A. Liese, K. Seelbach, C. Wandrey: Industrial Biotransformations, Wiley-VCH, 2006 • H. Chmiel: Bioprozeßtechnik, Elsevier, 2005 • K. Buchholz, V. Kasche, U. Bornscheuer: Biocatalysts and Enzyme Technology, VCH, 2005 • R. D. Schmidt: Pocket Guide to Biotechnology and Genetic Engineering, Woley-VCH, 2003

Module M1038: Particle Technology for International Master Programs

Courses

Title	Typ	Hrs/wk	CP
Excercise Particle Technology for International Master Program (L1928)	Recitation Section (large)	1	1
Particle Technology for IMP (L1289)	Lecture	2	3
Practicle Course Particle Technology for IMP (L1290)	Practical Course	3	2

Module Responsible	Prof. Stefan Heinrich
Admission Requirements	None
Recommended Previous Knowledge	none
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able - to list and to describe processes and unit-operations of solids process engineering, - to describe the characterization of particles and explain particle distributions and their bulk properties.
Skills	students are able to • choose and design apparatuses and processes for solids processing according to the desired solids properties of the product • assess solids with respect to their behavior in solids processing steps
Personal Competence	
Social Competence	students are able to analyze and orally discuss problems in a scientific way.
Autonomy	students are able to analyze and solve problems regarding solid particles independently
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory** Yes; **Bonus** None; **Form** Written elaboration; **Description** sechs Berichte (pro Versuch ein Bericht) à 5-10 Seiten
Examination	Written exam
Examination duration and scale	90 minutes
Assignment for the Following Curricula	Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory

Course L1928: Excercise Particle Technology for International Master Program

Typ	Recitation Section (large)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Stefan Heinrich
Language	EN
Cycle	WiSe
Content	see corresponding lecture
Literature	siehe korrespondierende Vorlesung

Course L1289: Particle Technology for IMP	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Stefan Heinrich
Language	EN
Cycle	WiSe
Content	• Description of particles and particle distributions • Description of a separation process • Description of a particle mixture • Particle size reduction • Agglomeration, particle size enlargement • Storage and flow of bulk solids • Basics of fluid/particle flows • classifying processes • Separation of particles from fluids • Basic fluid mechanics of fluidized beds • Pneumatic and hydraulic transport
Literature	• M. Rhodes: Introduction to Particle Technology, John Wiley & Sons, 1998 • M.E. Fayed & L. Otten: Handbook of Powder Science & Technology, 2nd Ed., Chapman & Hall, 1997 • M. Stieß: Mechanische Verfahrenstechnik 1, 2.Auflage, Springer-Verlag, 1995 (German) • M. Stieß: Mechanische Verfahrenstechnik 2, Springer-Verlag, 1994 (German)

Course L1290: Practicle Course Particle Technology for IMP	
Typ	Practical Course
Hrs/wk	3
CP	2
Workload in Hours	Independent Study Time 18, Study Time in Lecture 42
Lecturer	Prof. Stefan Heinrich
Language	EN
Cycle	WiSe
Content	Following experiments have to be carried out: • Sieving • Bulk properties • Size reduction • Mixing • Gas cyclone • Blaine-test, filtration • Sedimentation
Literature	• M. Rhodes: Introduction to Particle Technology, John Wiley & Sons, 1998 • M.E. Fayed & L. Otten: Handbook of Powder Science & Technology, 2nd Ed., Chapman & Hall, 1997 • M. Stieß: Mechanische Verfahrenstechnik 1, 2.Auflage, Springer-Verlag, 1995 (German) • M. Stieß: Mechanische Verfahrenstechnik 2, Springer-Verlag, 1994 (German)

Module M0951: Bioprocess Engineering Advanced Practical Course

Courses

Title	Typ	Hrs/wk	CP
Bioprocess Engineering Advanced Practical Course (L1112)	Practical Course	3	3
Advanced Practical Course in Microbiology (L0878)	Practical Course	3	3

Module Responsible	Prof. Anna-Lena Heins
Admission Requirements	None
Recommended Previous Knowledge	Bioprocess Engineering - Fundamental Practical Course
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	After completing this module, students are able to perform and explain the essential steps of a process for the production of the semi-synthetic beta-lactam antibiotic amoxicillin using microorganisms as well as cell-free enzymes.
Skills	The students can perform practical tasks in a chemical / biotechnological laboratory. This especially includes the fermentation of filamentous fungi in submersed culture, the recovery of intermediates from the fermentation broth and the processing of those intermediates using cell-free enzymes. They can record and interpret the results of guided experiments and create an error analysis and present the results.
Personal Competence	
Social Competence	Sudents can reflect their specific knowledge orally and discuss this with other students and teachers.
Autonomy	After completing the module the students are able to independently protocol experiments and to discuss, analyze and record the results. They can present those results as a team.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	None
Examination	Written elaboration
Examination duration and scale	Written report
Assignment for the Following Curricula	Bioprocess Engineering: Core Qualification: Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory

Course L1112: Bioprocess Engineering Advanced Practical Course

Typ	Practical Course
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Anna-Lena Heins, Prof. Andreas Liese
Language	EN
Cycle	WiSe
Content	This experimental course focuses on a complete process from starting material like glucose over several production steps to a valuable final product. Production of the semi-synthetic beta-lactam antibiotic amoxicillin is investigated and conducted as an example for industrial processes on a laboratory scale involving microorganisms as well as cell free enzymes. The first step - fermentation of Penicillium chrysogenum to produce penicillin G - is carried out in the Institute of Bioprocess and Biosystems Engineering of Prof. Zeng. After recovery of penicillin G it is hydrolysed by penicillin acylase (Escherichia coli) to produce 6-aminopenicillanic acid which is further acylated by the same enzyme to produce amoxicillin. The enzymatic steps are done in the Institute of Technical Biocatalysis of Prof. Liese. A colloquium is part of the course.
Literature	Liese A, Seelbach K, Wandrey C, Industrial Biotransformations, Wiley-VCH, 2006 Chmiel H, Einführung in die Bioverfahrenstechnik, Elsevier Spektrum Akademischer Verlag, 2006 Schügerl K, Bioreaktionstechnik: Bioprozesse mit Mikroorganismen und Zellen. Prozeßüberwachung, Birkhäuser, 1997

Course L0878: Advanced Practical Course in Microbiology	
Typ	Practical Course
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Johannes Gescher
Language	EN
Cycle	WiSe
Content	Participation in actual projects: - From gene to product in heterologous hosts - Molecular biology - Enzyme assays - Taxonomy
Literature	-Molekulare Biotechnologie: Grundlagen und Anwendungen David Clark. -Watson Molekularbiologie 6., aktualisierte Auflage. James D. Watson, Tania A. Baker, Stephen P. Bell, Alexander Gann, Michael Levine, Richard Losick -Allgemeine Mikrobiologie. Georg Fuchs, Marc Bramkamp, Petra Dersch, Thomas Eitinger, Johann Heider -Course Script of the respective lecture and practical course script

Module M2171: Sustainable Process Design Project

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Sustainable Process Design Project (L1048)	Integrated Lecture	2	2
Sustainable Process Design Project (L1977)	Project-/problem-based Learning	3	4

Module Responsible	Prof. Mirko Skiborowski
Admission Requirements	None
Recommended Previous Knowledge	Process Design and Process Modelling thermal separation processes heat and mass transport processes CAPE (absolut necessarily!)
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	students can: - reproduce the main elements of design of industrial processes - give an overview and explain the phases of design - describe and explain energy, mass balances, cost estimation methods and economic evaluation of invest projects - justify and discuss process control concepts and fundamentals of process optimization
Skills	students are capable of: -conduction and evaluation of design of unit operations - combination of unit operation to a complex process plant - use of cost estimation methods for the prediction of production costs - carry out the pfd-diagram
Personal Competence	
Social Competence	students are able to discuss and develop in groups the design of an industrial process
Autonomy	students are able to reflect the consequences of their professional activity
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Subject theoretical and practical work
Examination duration and scale	Written report and oral exam (30 min)
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation B - Industrial Bioprocess Engineering: Elective Compulsory Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation General Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory

Course L1048: Sustainable Process Design Project	
Typ	Integrated Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Mirko Skiborowski, Dr. Thomas Waluga
Language	EN
Cycle	WiSe
Content	Presentation of the task Introduction to design and analysis of a chemical processing plant (example chemical processing plants) Discussion of the process, preparation of process flow diagram Calculation of material balance Calculation of energy balance Designing/Sizing of the equipment Capital cost estimation Production cost estimation Process control & HAZOP Study Lecture 11 = Process optimization Lecture 12 = Final Project Presentation
Literature	Richard Turton; Analysis, Synthesis and Design of Chemical Processes:International Edition Harry Silla; Chemical Process Engineering: Design And Economics Coulson and Richardson's Chemical Engineering, Volume 6, Second Edition: Chemical Engineering Design Lorenz T. Biegler;Systematic Methods of Chemical Process Design Max S. Peters, Klaus Timmerhaus; Plant Design and Economics for Chemical Engineers James Douglas; Conceptual Design of Chemical Processes Robin Smith; Chemical Process: Design and Integration Warren D. Seider; Process design principles, synthesis analysis and evaluation

Course L1977: Sustainable Process Design Project	
Typ	Project-/problem-based Learning
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Mirko Skiborowski, Dr. Thomas Waluga
Language	EN
Cycle	WiSe
Content	Creation of a flowsheet for an industrial process Calculation of the mass and energy balance Calculation of investment and manufacturing costs Possibilities of process intensification Comparison of conventional and intensified processes
Literature	Richard Turton; Analysis, Synthesis and Design of Chemical Processes:International Edition Harry Silla; Chemical Process Engineering: Design And Economics Coulson and Richardson's Chemical Engineering, Volume 6, Second Edition: Chemical Engineering Design Lorenz T. Biegler;Systematic Methods of Chemical Process Design Max S. Peters, Klaus Timmerhaus; Plant Design and Economics for Chemical Engineers James Douglas; Conceptual Design of Chemical Processes Robin Smith; Chemical Process: Design and Integration Warren D. Seider; Process design principles, synthesis analysis and evaluation

Module M2170: SMART Reactors

Courses

Title	Typ	Hrs/wk	CP
Special Features of SMART Reactors (L3475)	Seminar	2	2
Introduction to SMART Reactors (L3473)	Seminar	2	2
Lattice Boltzmann Simulations for SMART Reactors (L3474)	Seminar	2	2

Module Responsible	Prof. Michael Schlüter
Admission Requirements	None
Recommended Previous Knowledge	lectures from the undergraduate studies, especially mathematics, chemistry, thermodynamics, fluid mechanics, heat- and mass transfer
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to experimentally analyse, model and simulate transport processes in SMART Reactors as well as identify and further develop components for SMART Reactors.
Skills	The students are able to to describe and optimize SMART Reactors.
Personal Competence	
Social Competence	The students are able to discuss in international teams in english and develop an approach under pressure of time.
Autonomy	Students are able to independently define tasks for working on the overall problem of “Components for SMART reactors”. Based on the knowledge provided in the lecture, students acquire the necessary knowledge themselves and decide which methods from the lecture are to be used for implementation. They can organise themselves in a team and assign priorities for subtasks.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	None
Examination	Subject theoretical and practical work
Examination duration and scale	Poster presentation, 1 hour
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Bioprocess Engineering: Specialisation B - Industrial Bioprocess Engineering: Elective Compulsory Bioprocess Engineering: Specialisation C - Bioeconomic Process Engineering, Focus Energy and Bioprocess Technology: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Process Engineering: Specialisation Environmental Process Engineering: Elective Compulsory

Course L3475: Special Features of SMART Reactors

Typ	Seminar
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Michael Schlüter, Weitere Mitarbeiter
Language	EN
Cycle	WiSe
Content	
Literature	

Course L3473: Introduction to SMART Reactors

Typ	Seminar
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Michael Schlüter
Language	EN
Cycle	WiSe
Content	
Literature	

Course L3474: Lattice Boltzmann Simulations for SMART Reactors	
Typ	Seminar
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Christian Weiland
Language	EN
Cycle	WiSe
Content	
Literature	

Module M2175: Transport Processes

Courses

Title	Typ	Hrs/wk	CP
Multiphase Flows (L0104)	Lecture	2	2
Reactor design under consideration of local transport processes (L0105)	Project-/problem-based Learning	2	2
Heat & Mass Transfer in Process Engineering (L0103)	Lecture	2	2

Module Responsible	Prof. Michael Schlüter
Admission Requirements	None
Recommended Previous Knowledge	All lectures from the undergraduate studies, especially mathematics, chemistry, thermodynamics, fluid mechanics, heat- and mass transfer.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to: • describe transport processes in single- and multiphase flows and they know the analogy between heat- and mass transfer as well as the limits of this analogy. • explain the main transport laws and their application as well as the limits of application. • describe how transport coefficients for heat- and mass transfer can be derived experimentally. • compare different multiphase reactors like trickle bed reactors, pipe reactors, stirring tanks and bubble column reactors. • are known. The Students are able to perform mass and energy balances for different kind of reactors. Further more the industrial application of multiphase reactors for heat- and mass transfer are known.
Skills	The students are able to: • optimize multiphase reactors by using mass- and energy balances, • use transport processes for the design of technical processes, • to choose a multiphase reactor for a specific application.
Personal Competence	
Social Competence	The students are able to discuss in international teams in english and develop an approach under pressure of time.
Autonomy	Students are able to define independently tasks, to solve the problem "design of a multiphase reactor". The knowledge that s necessary is worked out by the students themselves on the basis of the existing knowledge from the lecture. The students are able to decide by themselves what kind of equation and model is applicable to their certain problem. They are able to organize their own team and to define priorities for different tasks.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** Yes / None / Group discussion / Gruppendiskussion
Examination	Written exam
Examination duration and scale	15 min Presentation + 90 min multiple choice written examen
Assignment for the Following Curricula	Bioprocess Engineering: Core Qualification: Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory International Management and Engineering: Specialisation II. Energy and Environmental Engineering: Elective Compulsory International Management and Engineering: Specialisation II. Process Engineering and Biotechnology: Elective Compulsory Renewable Energies: Specialisation Solar Energy Systems: Elective Compulsory Process Engineering: Core Qualification: Compulsory

Course L0104: Multiphase Flows	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Michael Schlüter
Language	EN
Cycle	WiSe
Content	• Interfaces in MPF (boundary layers, surfactants) • Hydrodynamics & pressure drop in Film Flows • Hydrodynamics & pressure drop in Gas-Liquid Pipe Flows • Hydrodynamics & pressure drop in Bubbly Flows • Mass Transfer in Film Flows • Mass Transfer in Gas-Liquid Pipe Flows • Mass Transfer in Bubbly Flows • Reactive mass Transfer in Multiphase Flows • Film Flow: Application Trickle Bed Reactors • Pipe Flow: Application Turbular Reactors • Bubbly Flow: Application Bubble Column Reactors
Literature	Brauer, H.: Grundlagen der Einphasen- und Mehrphasenströmungen. Verlag Sauerländer, Aarau, Frankfurt (M), 1971. Clift, R.; Grace, J.R.; Weber, M.E.: Bubbles, Drops and Particles, Academic Press, New York, 1978. Fan, L.-S.; Tsuchiya, K.: Bubble Wake Dynamics in Liquids and Liquid-Solid Suspensions, Butterworth-Heinemann Series in Chemical Engineering, Boston, USA, 1990. Hewitt, G.F.; Delhaye, J.M.; Zuber, N. (Ed.): Multiphase Science and Technology. Hemisphere Publishing Corp, Vol. 1/1982 bis Vol. 6/1992. Kolev, N.I.: Multiphase flow dynamics. Springer, Vol. 1 and 2, 2002. Levy, S.: Two-Phase Flow in Complex Systems. Verlag John Wiley & Sons, Inc, 1999. Crowe, C.T.: Multiphase Flows with Droplets and Particles. CRC Press, Boca Raton, Fla, 1998.

Course L0105: Reactor design under consideration of local transport processes	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Michael Schlüter
Language	EN
Cycle	WiSe
Content	In this Problem-Based Learning unit the students have to design a multiphase reactor for a fast chemical reaction concerning optimal hydrodynamic conditions of the multiphase flow. The four students in each team have to: • collect and discuss material properties and equations for design from the literature, • calculate the optimal hydrodynamic design, • check the plausibility of the results critically, • write an exposé with the results. This exposé will be used as basis for the discussion within the oral group examen of each team.
Literature	Bird, R.B.; Stewart, W.R.; Lightfoot, E.N.: Transport Phenomena, John Wiley & Sons Inc (2007), ISBN 978-0-470-11539-8. Brauer, H.; Mewes, D.: Stoffaustausch einschließlich chemischer Reaktion; Verlag Sauerländer, Aarau und Frankfurt am Main (1971), ISBN: 3794100085. Brauer, H.: Grundlagen der Einphasen- und Mehrphasenströmungen, Sauerländer, 1971, Clift, R.; Grace, J.R.; Weber, M.E.: Bubbles, Drops, and Particles, Verlag Academic Press, 1978, ISBN 012176950X, 9780121769505 Deckwer, W.-D.: Reaktionstechnik in Blasensäulen, Salle Verlag und Verlag Sauerländer, Aarau, Frankfurt am Main, Berlin, München, Salzburg (1985), DOI 10.1002/CITE.330590530 Deckwer, W.-D.: Bubble Column Reactors. Wiley, New York (1992), DOI 10.1002/AIC.690380821. Fan, L.; Tsuchiya, K.: Bubble wake dynamics in liquids and liquid-solid suspension. Butterworth-Heinemann, (1990), DOI 10.1016/c2009-0-24002-5. Kraume, M., Transportvorgänge in der Verfahrenstechnik, Springer Berlin, 2020, ISBN 978-3-662-60392-5. Lienhard, J. H. (2019). A Heat Transfer Textbook, Dover Publications. ISBN:9780486837352, 0486837351.

Course L0103: Heat & Mass Transfer in Process Engineering	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Michael Schlüter
Language	EN
Cycle	WiSe
Content	• Introduction - Transport Processes in Chemical Engineering • Molecular Heat- and Mass Transfer: Applications of Fourier's and Fick's Law • Convective Heat and Mass Transfer: Applications in Process Engineering • Unsteady State Transport Processes: Cooling & Drying • Transport at fluidic Interfaces: Two Film, Penetration, Surface Renewal • Transport Laws & Balance Equations with turbulence, sinks and sources • Experimental Determination of Transport Coefficients • Design and Scale Up of Reactors for Heat- and Mass Transfer • Reactive Mass Transfer • Processes with Phase Changes – Evaporization and Condensation • Radiative Heat Transfer - Fundamentals • Radiative Heat Transfer - Solar Energy
Literature	1. Baehr, Stephan: Heat and Mass Transfer, Wiley 2002. 2. Bird, Stewart, Lightfood: Transport Phenomena, Springer, 2000. 3. John H. Lienhard: A Heat Transfer Textbook, Phlogiston Press, Cambridge Massachusetts, 2008. 4. Myers: Analytical Methods in Conduction Heat Transfer, McGraw-Hill, 1971. 5. Incropera, De Witt: Fundamentals of Heat and Mass Transfer, Wiley, 2002. 6. Beek, Muttzall: Transport Phenomena, Wiley, 1983. 7. Crank: The Mathematics of Diffusion, Oxford, 1995. 8. Madhusudana: Thermal Contact Conductance, Springer, 1996. 9. Treybal: Mass-Transfer-Operation, McGraw-Hill, 1987.

Module M2049: Research project Chemical and Bioprocess Engineering

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Research project Chemical and Bioprocess Engineering (L3299)	Project-/problem-based Learning	12	12

Module Responsible	Dozenten des SD V
Admission Requirements	None
Recommended Previous Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	
Skills	
Personal Competence	
Social Competence	
Autonomy	
Workload in Hours	Independent Study Time 192, Study Time in Lecture 168
Credit points	12
Course achievement	None
Examination	Study work
Examination duration and scale	approx. 6-15 pages
Assignment for the Following Curricula	Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory

Course L3299: Research project Chemical and Bioprocess Engineering

Typ	Project-/problem-based Learning
Hrs/wk	12
CP	12
Workload in Hours	Independent Study Time 192, Study Time in Lecture 168
Lecturer	Dozenten des SD V
Language	DE/EN
Cycle	WiSe/SoSe
Content	In this research project, students are to be introduced to independent scientific work. Current research projects offered by the institutes of the Faculty of Process Engineering are provided and published on their websites.
Literature	Die Betreuungspersonen eines jeden Forschungsprojektes stellen die dazu gehörigen Fachliteratur zur Verfügung. Dies ist vor allem Primärliteratur (peer-reviewed journal publications) sowie Fachbücher im jeweiligen Forschungsgebiet.

Supplement Modules

Module M0714: Numerical Methods for Ordinary Differential Equations

Courses

Title	Typ	Hrs/wk	CP
Numerical Treatment of Ordinary Differential Equations (L0576)	Lecture	2	3
Numerical Treatment of Ordinary Differential Equations (L0582)	Recitation Section (small)	2	3

Module Responsible	Prof. Daniel Ruprecht
Admission Requirements	None
Recommended Previous Knowledge	• Mathematik I, II, III for Engineers (German or English) or Analysis & Linear Algebra I + II plus Analysis III for Technomathematiker. • Basic knowledge of MATLAB, Python or a similar programming language.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to • name numerical methods for the solution of ordinary differential equations and explain their core ideas, • formulate convergence statements for the taught numerical methods (including the necessary assumptions about the solved problem), • explain aspects regarding the practical realisation of a method, • select the appropriate numerical method for specific problems, implement the numerical algorithms efficiently and interpret the numerical results.
Skills	Students are able to • implement, apply and compare numerical methods for the solution of ordinary differential equations, • explain the convergence behaviour of numerical methods, taking into consideration the solved problem and selected algorithm, • develop a suitable solution approach for a given problem, if necessary by combining multiple algorithms, realise this approach and critically evaluate results.
Personal Competence	
Social Competence	Students are able to • work together in heterogeneous teams (i.e., teams from different study programs and with different background knowledge), explain theoretical foundations and support each other with practical aspects regarding the implementation of algorithms.
Autonomy	Students are capable • to assess whether the provided theoretical and practical excercises are better solved individually or in a team and • to assess their individual progress and, if necessary, to ask questions and seek help.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Technical Complementary Course: Elective Compulsory Chemical and Bioprocess Engineering: Technical Complementary Course: Elective Compulsory Computational Methods and Machine Learning in Engineering: Core Qualification: Elective Compulsory Computer Science: Specialisation III. Mathematics: Elective Compulsory Data Science: Specialisation I. Data Science & Mathematics: Elective Compulsory Electrical Engineering and Information Technology: Specialisation Control and Power Systems Engineering: Elective Compulsory Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Energy Systems: Core Qualification: Elective Compulsory Aircraft Systems Engineering: Core Qualification: Elective Compulsory Interdisciplinary Mathematics: Specialisation II. Numerical - Modelling Training: Compulsory Mechatronics: Core Qualification: Elective Compulsory Technomathematics: Specialisation I. Mathematics: Elective Compulsory Theoretical Mechanical Engineering: Core Qualification: Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory

Course L0576: Numerical Treatment of Ordinary Differential Equations	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Daniel Ruprecht
Language	DE/EN
Cycle	SoSe
Content	Numerical methods for Initial Value Problems • single step methods • multistep methods • stiff problems • differential algebraic equations (DAE) of index 1 Numerical methods for Boundary Value Problems • multiple shooting method • difference methods
Literature	• E. Hairer, S. Noersett, G. Wanner: Solving Ordinary Differential Equations I: Nonstiff Problems. • E. Hairer, G. Wanner: Solving Ordinary Differential Equations II: Stiff and Differential-Algebraic Problems. • D. Griffiths, D. Higham: Numerical Methods for Ordinary Differential Equations.

Course L0582: Numerical Treatment of Ordinary Differential Equations	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Daniel Ruprecht
Language	DE/EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1737: Power-to-X Process

Courses

Title	Typ	Hrs/wk	CP
Power-to-X process (L2805)	Lecture	2	2
Power-to-X process (L2806)	Recitation Section (large)	1	2
Practical aspects of energy conversion (L2807)	Practical Course	1	2

Module Responsible	Prof. Jakob Albert
Admission Requirements	None
Recommended Previous Knowledge	• Basic knowledge from the Bachelor's degree course in process engineering • Chemical reaction engineering • Process and plant engineering
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can: • explain the energy transition in Germany, • give an overview of the versatile application possibilities of power-to-X processes, • evaluate different power-to-X concepts with regard to their technical challenges and social benefits.
Skills	The students are able to: • develop concepts for the technical implementation of power-to-X processes, • evaluate practical aspects of energy conversion to platform chemicals using laboratory experiments, • apply the acquired knowledge to various engineering-relevant power-to-X processes.
Personal Competence	
Social Competence	The students: • are able to independently discuss approaches to solutions and problems in the field of the energy transition in Germany in an interdisciplinary small group, • are able to work together in small groups on subject-specific tasks, • are able to work out the practical aspects of energy conversion to platform chemicals on the basis of laboratory experiments, carry out and evaluate the analytics of the products and precisely summarise the results of the experiments in a protocol.
Autonomy	The students • are able to independently obtain extensive literature on the topic and to gain knowledge from it, • are able to independently solve tasks on the topic and assess their learning status based on the feedback given, • are able to independently conduct experimental studies on the topic.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Chemical and Bioprocess Engineering: Technical Complementary Course: Elective Compulsory Chemical and Bioprocess Engineering: Technical Complementary Course: Elective Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory Process Engineering: Specialisation Environmental Process Engineering: Elective Compulsory

Course L2805: Power-to-X process	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Jakob Albert
Language	DE
Cycle	SoSe
Content	• Regenerative surplus energy • Electrolysis • CO2 sources for Power-to-X • Power-to-heat • Power-to-Power • Power-to-gas (SNG) • Power-to-Syngas • Power-to-Methanol • Power-to-Fuels • Power-to-ammonia • LOHC (Liquid organic hydrogen carrier) • Economic and ecological comparison of different concepts
Literature	1. A. Jess, P. Wasserscheid, „Chemical Technology“, Wiley VCH, 2013 2. H. Watter, „Regenerative Energiesysteme“, Springer, 2015

Course L2806: Power-to-X process	
Typ	Recitation Section (large)
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Stefanie Wesinger
Language	DE
Cycle	SoSe
Content	In exercise, the contents of the lecture are further deepened and transferred into practical application. This is done using example tasks from practice, which are made available to the students. The students are to solve these tasks independently or in groups with the help of the lecture material. The solution is then discussed with students under scientific guidance, with parts of the task being presented on the blackboard.
Literature	1. A. Jess, P. Wasserscheid, „Chemical Technology“, Wiley VCH, 2013 2. H. Watter, „Regenerative Energiesysteme“, Springer, 2015

Course L2807: Practical aspects of energy conversion	
Typ	Practical Course
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Dr. Maximilian Poller
Language	DE
Cycle	SoSe
Content	In the laboratory practical course, practical experiments on power-to-X processes are carried out. The challenges for the technical implementation of power-to-x processes are made clear to the students. The associated analysis of the test samples is also part of the laboratory practical course and is carried out and evaluated by the students themselves. The results are precisely summarised and scientifically presented in an experimental protocol.
Literature	1. A. Jess, P. Wasserscheid, „Chemical Technology“, Wiley VCH, 2013 2. H. Watter, „Regenerative Energiesysteme“, Springer, 2015

Module M0802: Membrane Technology

Courses

Title	Typ	Hrs/wk	CP
Membrane Technology (L0399)	Lecture	2	3
Membrane Technology (L0400)	Recitation Section (small)	1	2
Membrane Technology (L0401)	Practical Course	1	1

Module Responsible	Prof. Mathias Ernst
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge of water chemistry. Knowledge of the core processes involved in water, gas and steam treatment
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students will be able to rank the technical applications of industrially important membrane processes. They will be able to explain the different driving forces behind existing membrane separation processes. Students will be able to name materials used in membrane filtration and their advantages and disadvantages. Students will be able to explain the key differences in the use of membranes in water, other liquid media, gases and in liquid/gas mixtures.
Skills	Students will be able to prepare mathematical equations for material transport in porous and solution-diffusion membranes and calculate key parameters in the membrane separation process. They will be able to handle technical membrane processes using available boundary data and provide recommendations for the sequence of different treatment processes. Through their own experiments, students will be able to classify the separation efficiency, filtration characteristics and application of different membrane materials. Students will be able to characterise the formation of the fouling layer in different waters and apply technical measures to control this.
Personal Competence	
Social Competence	Students will be able to work in diverse teams on tasks in the field of membrane technology. They will be able to make decisions within their group on laboratory experiments to be undertaken jointly and present these to others.
Autonomy	Students will be in a position to solve homework on the topic of membrane technology independently. They will be capable of finding creative solutions to technical questions.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Civil Engineering: Specialisation Water and Traffic: Elective Compulsory Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Bioprocess Engineering: Specialisation B - Industrial Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation General Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Technical Complementary Course: Elective Compulsory Chemical and Bioprocess Engineering: Technical Complementary Course: Elective Compulsory Environmental Engineering: Specialisation Water Quality and Water Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory Process Engineering: Specialisation Environmental Process Engineering: Elective Compulsory Water and Environmental Engineering: Specialisation Water: Elective Compulsory Water and Environmental Engineering: Specialisation Environment: Elective Compulsory Water and Environmental Engineering: Specialisation Cities: Elective Compulsory

Course L0399: Membrane Technology	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Mathias Ernst
Language	EN
Cycle	WiSe
Content	The lecture on membrane technology supply provides students with a broad understanding of existing membrane treatment processes, encompassing pressure driven membrane processes, membrane application in electrodialyis, pervaporation as well as membrane distillation. The lectures main focus is the industrial production of drinking water like particle separation or desalination; however gas separation processes as well as specific wastewater oriented applications such as membrane bioreactor systems will be discussed as well. Initially, basics in low pressure and high pressure membrane applications are presented (microfiltration, ultrafiltration, nanofiltration, reverse osmosis). Students learn about essential water quality parameter, transport equations and key parameter for pore membrane as well as solution diffusion membrane systems. The lecture sets a specific focus on fouling and scaling issues and provides knowledge on methods how to tackle with these phenomena in real water treatment application. A further part of the lecture deals with the character and manufacturing of different membrane materials and the characterization of membrane material by simple methods and advanced analysis. The functions, advantages and drawbacks of different membrane housings and modules are explained. Students learn how an industrial membrane application is designed in the succession of treatment steps like pre-treatment, water conditioning, membrane integration and post-treatment of water. Besides theory, the students will be provided with knowledge on membrane demo-site examples and insights in industrial practice.
Literature	• T. Melin, R. Rautenbach: Membranverfahren: Grundlagen der Modul- und Anlagenauslegung (2., erweiterte Auflage), Springer-Verlag, Berlin 2004. • Marcel Mulder, Basic Principles of Membrane Technology, Kluwer Academic Publishers, Dordrecht, The Netherlands • Richard W. Baker, Membrane Technology and Applications, Second Edition, John Wiley & Sons, Ltd., 2004

Course L0400: Membrane Technology	
Typ	Recitation Section (small)
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Prof. Mathias Ernst
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Course L0401: Membrane Technology	
Typ	Practical Course
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Mathias Ernst
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M0801: Water Resources and -Supply

Courses

Title	Typ	Hrs/wk	CP
Chemistry of Drinking Water Treatment (L0311)	Lecture	2	1
Chemistry of Drinking Water Treatment (L0312)	Recitation Section (large)	1	2
Water Resource Management (L0402)	Lecture	2	2
Water Resource Management (L0403)	Recitation Section (small)	1	1

Module Responsible	Prof. Mathias Ernst
Admission Requirements	None
Recommended Previous Knowledge	Knowledge of water management and the key processes involved in water treatment.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students will be able to outline key areas of conflict in water management, as well as their mutual dependence for sustainable water supply. They will understand relevant economic, environmental and social factors. Students will be able to explain and outline the organisational structures of water companies. They will be able to explain the available water treatment processes and the scope of their application.
Skills	Students will be able to assess complex problems in drinking water production and establish solutions involving water management and technical measures. They will be able to assess the evaluation methods that can be used for this. Students will be able to carry out chemical calculations for selected treatment processes and apply generally accepted technical rules and standards to these processes.
Personal Competence	
Social Competence	Working in a diverse group of specialists, students will be able to develop and document complex solutions for the management and treatment of drinking water. They will be able to take an appropriate professional position, for example representing user interests. They will be able to develop joint solutions in teams of diverse experts and present these solutions to others.
Autonomy	Students will be in a position to work on a subject independently and present on this subject.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	60 min (chemistry) + presentation
Assignment for the Following Curricula	Civil Engineering: Specialisation Structural Engineering: Elective Compulsory Civil Engineering: Specialisation Geotechnical Engineering: Elective Compulsory Civil Engineering: Specialisation Water and Traffic: Compulsory Civil Engineering: Specialisation Coastal Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Technical Complementary Course: Elective Compulsory Chemical and Bioprocess Engineering: Technical Complementary Course: Elective Compulsory International Management and Engineering: Specialisation II. Energy and Environmental Engineering: Elective Compulsory Process Engineering: Specialisation Environmental Process Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory Water and Environmental Engineering: Specialisation Water: Compulsory Water and Environmental Engineering: Specialisation Environment: Elective Compulsory Water and Environmental Engineering: Specialisation Cities: Elective Compulsory

Course L0311: Chemistry of Drinking Water Treatment	
Typ	Lecture
Hrs/wk	2
CP	1
Workload in Hours	Independent Study Time 2, Study Time in Lecture 28
Lecturer	Dr. Klaus Johannsen
Language	DE
Cycle	WiSe
Content	The topic of this course is water chemistry with respect to drinking water treatment and water distribution Major topics are solubility of gases, carbonic acid system and calcium carbonate, blending, softening, redox processes, materials and legal requirements on drinking water treatment. Focus is put on generally accepted rules of technology (DVGW- and DIN-standards). Special emphasis is put on calculations using realistic analysis data (e.g. calculation of pH or calcium carbonate dissolution potential) in exercises. Students can get a feedback and gain extra points for exam by solving problems for homework. Knowledge of drinking water treatment processes is vital for this lecture. Therefore the most important processes are explained coordinated with the course “ Water resources management“ in the beginning of the semester.
Literature	**MHW (rev. by Crittenden, J. et al.):** Water treatment principles and design. John Wiley & Sons, Hoboken, 2005. **Stumm, W., Morgan, J.J.**: Aquatic chemistry. John Wiley & Sons, New York, 1996. **DVGW (Hrsg.):** Wasseraufbereitung - Grundlagen und Verfahren. Oldenbourg Industrie Verlag, München, 2004. **Jensen, J. N.**: A Problem Solving Approach to Aquatic Chemistry. John Wiley & Sons, Inc., New York, 2003.

Course L0312: Chemistry of Drinking Water Treatment	
Typ	Recitation Section (large)
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Dr. Klaus Johannsen
Language	DE
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Course L0402: Water Resource Management	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Mathias Ernst
Language	DE
Cycle	WiSe
Content	The lecture provides comprehensive knowledge on interaction of water ressource management and drinking water supply. Content overview: • Current situation of global water resources - User and Stakeholder conflicts - Wasserressourcenmanagement in urbane Gebieten - Rechtliche Aspekte, Organisationsformen Trinkwasserversorgungsunternehmen. - Ökobilanzierung, Benchmarking in der Wasserversorgung
Literature	• Aktuelle UN World Water Development Reports • Branchenbild der deutschen Wasserwirtschaft, VKU (2011) • Aktuelle Artikel wissenschaftlicher Zeitschriften • Ppt der Vorlesung

Course L0403: Water Resource Management	
Typ	Recitation Section (small)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Mathias Ernst
Language	DE
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M0822: Process Modeling in Water Technology

Courses

Title	Typ	Hrs/wk	CP
Process Modelling of Wastewater Treatment (L0522)	Project-/problem-based Learning	2	3
Process Modeling in Drinking Water Treatment (L0314)	Project-/problem-based Learning	2	3

Module Responsible	Dr. Klaus Johannsen
Admission Requirements	None
Recommended Previous Knowledge	Knowledge of the most important processes in drinking water and waste water treatment.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to explain selected processes of drinking water and waste water treatment in detail. They are able to explain basics as well as possibilities and limitations of dynamic modeling.
Skills	Students are able to use the most important features Modelica offers. They are able to transpose selected processes in drinking water and waste water treatment into a mathematical model in Modelica with respect to equilibrium, kinetics and mass balances. They are able to set up and apply models and assess their possibilities and limitations.
Personal Competence	
Social Competence	Students are able to solve problems and document solutions in a group with members of different technical background. They are able to give appropriate feedback and can work constructively with feedback concerning their work.
Autonomy	Students are able to define a problem, gain the required knowledge and set up a model.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Civil Engineering: Specialisation Water and Traffic: Elective Compulsory Chemical and Bioprocess Engineering: Technical Complementary Course: Elective Compulsory Chemical and Bioprocess Engineering: Technical Complementary Course: Elective Compulsory Environmental Engineering: Specialisation Water Quality and Water Engineering: Elective Compulsory Process Engineering: Specialisation Environmental Process Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory Water and Environmental Engineering: Specialisation Water: Elective Compulsory Water and Environmental Engineering: Specialisation Environment: Elective Compulsory Water and Environmental Engineering: Specialisation Cities: Elective Compulsory

Course L0522: Process Modelling of Wastewater Treatment	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Joachim Behrendt
Language	DE/EN
Cycle	WiSe
Content	Mass and energy balances Tracer modelling Activated Sludge Model Wastewater Treatment Plant Modelling (continously and SBR) Sludge Treatment (ADM, aerobic autothermal) Biofilm Modelling
Literature	**Henze, Mogens** (Seminar on Activated Sludge Modelling, ; Kollekolle Seminar on Activated Sludge Modelling, ;) Activated sludge modelling : processes in theory and practice ; selected proceedings of the 5th Kollekolle Seminar on Activated Sludge Modelling, held in Kollekolle, Denmark, 10 - 12 September 2001 ISBN: 1843394146 [London] : IWA Publ., 2002 TUB_HH_Katalog **Henze, Mogens** Activated sludge models ASM1, ASM2, ASM2d and ASM3 ISBN: 1900222248 London : IWA Publ., 2002 TUB_HH_Katalog **Henze, Mogens** Wastewater treatment : biological and chemical processes ISBN: 3540422285 (Pp.) Berlin [u.a.] : Springer, 2002 TUB_HH_Katalog **Wiesmann, Udo** (Choi, In Su; Dombrowski, Eva-Maria;) Fundamentals of biological wastewater treatment ISBN: 3527312196 (Gb.) URL: http://deposit.ddb.de/cgi-bin/dokserv?id=2774611&prov=M&dok_var=1&dok_ext=htm Weinheim : WILEY-VCH, 2007 TUB_HH_Katalog

Course L0314: Process Modeling in Drinking Water Treatment	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Klaus Johannsen
Language	EN
Cycle	WiSe
Content	In this course selected drinking water treatment processes (e.g. aeration or activated carbon adsorption) are modeled dynamically using the programming language Modelica, that is increasingly used in industry. In this course OpenModelica is used, an free access frontend of the programming language Modelica. In the beginning of the course the use of OpenModelica is explainded by means of simple examples. Together required elements and structure of the model are developed. The implementation in OpenModelica and the application of the model is done individually or in groups respectively. Students get feedback and can gain extra points for the exam.
Literature	**OpenModelica:** https://openmodelica.org/index.php/download/download-windows **OpenModelica - Modelica Tutorial:** https://openmodelica.org/index.php/useresresources/userdocumentation **OpenModelica - Users Guide:** https://openmodelica.org/index.php/useresresources/userdocumentation **Peter Fritzson:** Principles of Object-Oriented Modeling and Simulation with Modelica 2.1,Wiley-IEEE Press, ISBN 0-471-471631. **MHW (rev. by Crittenden, J. et al.):** Water treatment principles and design. John Wiley & Sons, Hoboken, 2005. **Stumm, W., Morgan, J.J.**: Aquatic chemistry. John Wiley & Sons, New York, 1996. **DVGW (Hrsg.):** Wasseraufbereitung - Grundlagen und Verfahren. Oldenbourg Industrie Verlag, München, 2004.

Module M1736: Industrial Homogeneous Catalysis

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Homogeneous catalysis in application (L2804)	Practical Course	1	2
Industrial homogeneous catalysis (L2802)	Lecture	2	2
Industrial homogeneous catalysis (L2803)	Recitation Section (large)	1	2

Module Responsible	Prof. Jakob Albert
Admission Requirements	None
Recommended Previous Knowledge	• Basic knowledge from the Bachelor's degree course in process engineering • Chemical reaction engineering • Process and plant engineering
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can: • explain the principle of homogeneous catalysis, • give an overview of the versatile applications of homogeneous catalysis in industry • evaluate different homogeneously catalysed reactions with regard to their technical challenges and economic significance.
Skills	The students are able to • develop concepts for the technical implementation of homogeneously catalysed reactions, • evaluate practical aspects of homogeneous catalysis using laboratory experiments, • apply the acquired knowledge to different homogeneously catalysed reactions.
Personal Competence	
Social Competence	The students: • are able to work out the practical aspects of homogeneous catalysis on the basis of laboratory experiments, to carry out and evaluate the analytics of the products and to precisely summarise the results of the experiments in a protocol. • are able to independently discuss approaches to solutions and problems in the field of homogeneous catalysis in an interdisciplinary small group, • are able to work together in small groups on subject-specific tasks, Translated with www.DeepL.com/Translator (free version)
Autonomy	The students • are able to independently obtain extensive literature on the topic and to gain knowledge from it, • are able to independently solve tasks on the topic and assess their learning status based on the feedback given, • are able to independently conduct experimental studies on the topic.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation General Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Technical Complementary Course: Elective Compulsory Chemical and Bioprocess Engineering: Technical Complementary Course: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory

Course L2804: Homogeneous catalysis in application

Typ	Practical Course
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Prof. Jakob Albert
Language	EN
Cycle	WiSe
Content	In the laboratory practical course, practical experiments are carried out with reference to industrial application of homogeneous catalysis. The hurdles to the technical implementation of homogeneously catalysed reactions are made clear to the students. The associated analysis of the experimental samples is also part of the laboratory practical course and is carried out and evaluated by the students themselves. The results are precisely summarised and scientifically presented in an experimental protocol.
Literature	1. A. Jess, P. Wasserscheid, „Chemical Technology“, Wiley VCH, 2013 2. A. Behr, „Angewandte homogene Katalyse“, Wiley-VCH, 2008

Course L2802: Industrial homogeneous catalysis	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr. Maximilian Poller
Language	EN
Cycle	WiSe
Content	• Introduction to homogeneous catalysis • Elementary steps of catalysis • Homogeneous transition metal catalysis • Hydroformylation • Wacker process • Monsanto process • Shell higher olefin process (SHOP) • Extractive-oxidative desulphurisation (ECODS) • Phase transfer catalysis • Liquid-liquid two-phase catalysis • Catalyst recycling • Reactor concepts
Literature	1. A. Jess, P. Wasserscheid, „Chemical Technology“, Wiley VCH, 2013 2. A. Behr, „Angewandte homogene Katalyse“, Wiley-VCH, 2008

Course L2803: Industrial homogeneous catalysis	
Typ	Recitation Section (large)
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Nick Hermann, Dr. Maximilian Poller
Language	EN
Cycle	WiSe
Content	In this exercise the contents of the lecture are further deepened and transferred into practical application. This is done using example tasks from practice, which are made available to the students. The students are to solve these tasks independently or in groups with the help of the lecture material. The solution is then discussed with students under scientific guidance, with parts of the task being presented on the blackboard.
Literature	1. A. Jess, P. Wasserscheid, „Chemical Technology“, Wiley VCH, 2013 2. A. Behr, „Angewandte homogene Katalyse“, Wiley-VCH, 2008

Module M2033: Subsurface Processes

Courses

Title	Typ	Hrs/wk	CP
Modeling of Subsurface Processes (L2731)	Recitation Section (small)	3	3
Subsurface Solute Transport (L2728)	Lecture	2	2
Subsurface Solute Transport (L2729)	Recitation Section (large)	1	1

Module Responsible	Dr. Milad Aminzadeh
Admission Requirements	None
Recommended Previous Knowledge	Basic Mathematics, Hydrology
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Upon completion of this module, the students will understand the mechanisms controlling solute transport in soil and natural porous media and will be able to work with the equations that govern the fate and transport of solutes in porous media. Analytical, numerical and experimental tools and techniques will be used in this module.
Skills	In addition to the physical insights, the students will be exposed to analytical, experimental and numerical tools and techniques in this module. This provides them with an excellent opportunity to improve their skills on multiple fronts which will be useful in their future career.
Personal Competence	
Social Competence	Teamwork & problem solving
Autonomy	The students will be involved in writing individual reports and presentation. This will contribute to the students' ability and willingness to work independently and responsibly.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	None
Examination	Subject theoretical and practical work
Examination duration and scale	Report
Assignment for the Following Curricula	Civil Engineering: Specialisation Structural Engineering: Elective Compulsory Civil Engineering: Specialisation Geotechnical Engineering: Elective Compulsory Civil Engineering: Specialisation Coastal Engineering: Elective Compulsory Civil Engineering: Specialisation Water and Traffic: Elective Compulsory Civil Engineering: Specialisation Computational Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Technical Complementary Course: Elective Compulsory Chemical and Bioprocess Engineering: Technical Complementary Course: Elective Compulsory Environmental Engineering: Core Qualification: Compulsory Process Engineering: Specialisation Environmental Process Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory Water and Environmental Engineering: Specialisation Water: Compulsory Water and Environmental Engineering: Specialisation Environment: Elective Compulsory

Course L2731: Modeling of Subsurface Processes

Typ	Recitation Section (small)
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Mohammad Aziz Zarif
Language	EN
Cycle	WiSe
Content	Basic usage and background of chosen computer software to calculate flow and transport in the saturated and unsaturated zone and to analyze field data like pumping test data
Literature	siehe korrespondierende Vorlesung

Course L2728: Subsurface Solute Transport	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr. Milad Aminzadeh
Language	EN
Cycle	WiSe
Content	Basic physical properties of soil: Definition and quantification; Liquid flow in soils (Darcy’s law); Solute transport in soils; Practical analysis to measure dispersion coefficient in soil under different boundary conditions; Advanced topics (e.g. Application of Artificial Intelligence to predict soil salinization)
Literature	- Environmental Soil Physics, by Daniel Hillel - Soil Physics, Sixth Edition, by William A. Jury and Robert Horton

Course L2729: Subsurface Solute Transport	
Typ	Recitation Section (large)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Dr. Milad Aminzadeh
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M1614: Optics for Engineers

Courses

Title	Typ	Hrs/wk	CP
Optics for Engineers (L2437)	Lecture	3	3
Optics for Engineers (L2438)	Project-/problem-based Learning	3	3

Module Responsible	Prof. Thorsten Kern
Admission Requirements	None
Recommended Previous Knowledge	- Basics of physics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Teaching subject ist the design of simple optical systems for illumination and imaging optics • Basic values for optical systems and lighting technology • Spectrum, black-bodies, color-perception • Light-Sources und their characterization • Photometrics • Ray-Optics • Matrix-Optics • Stops, Pupils and Windows • Light-field Technology • Introduction to Wave-Optics • Introduction to Holography
Skills	Understandings of optics as part of light and electromagnetic spectrum. Design rules, approach to designing optics
Personal Competence	
Social Competence	
Autonomy	
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory** Yes; **Bonus** None; **Form** Subject theoretical and practical work; **Description** Teilnahme an Laborübungen und Simulation
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Chemical and Bioprocess Engineering: Technical Complementary Course: Elective Compulsory Chemical and Bioprocess Engineering: Technical Complementary Course: Elective Compulsory Theoretical Mechanical Engineering: Core Qualification: Elective Compulsory

Course L2437: Optics for Engineers

Typ	Lecture
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Thorsten Kern
Language	EN
Cycle	WiSe
Content	• Basic values for optical systems and lighting technology • Spectrum, black-bodies, color-perception • Light-Sources und their characterization • Photometrics • Ray-Optics • Matrix-Optics • Stops, Pupils and Windows • Light-field Technology • Introduction to Wave-Optics • Introduction to Holography
Literature	

Course L2438: Optics for Engineers	
Typ	Project-/problem-based Learning
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Thorsten Kern
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Thesis

Module M-002: Master Thesis

Courses			
Title	**Typ**	**Hrs/wk**	**CP**

Module Responsible	Professoren der TUHH
Admission Requirements	• According to General Regulations §21 (1): At least 60 credit points have to be achieved in study programme. The examinations board decides on exceptions.
Recommended Previous Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• The students can use specialized knowledge (facts, theories, and methods) of their subject competently on specialized issues. • The students can explain in depth the relevant approaches and terminologies in one or more areas of their subject, describing current developments and taking up a critical position on them. • The students can place a research task in their subject area in its context and describe and critically assess the state of research.
Skills	The students are able: • To select, apply and, if necessary, develop further methods that are suitable for solving the specialized problem in question. • To apply knowledge they have acquired and methods they have learnt in the course of their studies to complex and/or incompletely defined problems in a solution-oriented way. • To develop new scientific findings in their subject area and subject them to a critical assessment.
Personal Competence	
Social Competence	Students can • Both in writing and orally outline a scientific issue for an expert audience accurately, understandably and in a structured way. • Deal with issues competently in an expert discussion and answer them in a manner that is appropriate to the addressees while upholding their own assessments and viewpoints convincingly.
Autonomy	Students are able: • To structure a project of their own in work packages and to work them off accordingly. • To work their way in depth into a largely unknown subject and to access the information required for them to do so. • To apply the techniques of scientific work comprehensively in research of their own.
Workload in Hours	Independent Study Time 900, Study Time in Lecture 0
Credit points	30
Course achievement	None
Examination	Thesis
Examination duration and scale	According to General Regulations
Assignment for the Following Curricula	Civil Engineering: Thesis: Compulsory Bioprocess Engineering: Thesis: Compulsory Chemical and Bioprocess Engineering: Thesis: Compulsory Chemical and Bioprocess Engineering: Thesis: Compulsory Computational Methods and Machine Learning in Engineering: Thesis: Compulsory Computer Science: Thesis: Compulsory Data Science: Thesis: Compulsory Electrical Engineering and Information Technology: Thesis: Compulsory Electrical Engineering: Thesis: Compulsory Energy Systems: Thesis: Compulsory Environmental Engineering: Thesis: Compulsory Aircraft Systems Engineering: Thesis: Compulsory Global Innovation Management: Thesis: Compulsory Computer Science in Engineering: Thesis: Compulsory Information and Communication Systems: Thesis: Compulsory Interdisciplinary Mathematics: Thesis: Compulsory International Production Management: Thesis: Compulsory International Management and Engineering: Thesis: Compulsory Joint European Master in Environmental Studies - Cities and Sustainability: Thesis: Compulsory Logistics, Infrastructure and Mobility: Thesis: Compulsory Aeronautics: Thesis: Compulsory Mechanical Engineering - Product Development and Production: Thesis: Compulsory Materials Science and Engineering: Thesis: Compulsory

	Materials Science: Thesis: Compulsory Mechanical Engineering and Management: Thesis: Compulsory Mechatronics: Thesis: Compulsory Biomedical Engineering: Thesis: Compulsory Microelectronics and Microsystems: Thesis: Compulsory Product Development, Materials and Production: Thesis: Compulsory Renewable Energies: Thesis: Compulsory Naval Architecture and Ocean Engineering: Thesis: Compulsory Naval Architecture and Ocean Engineering: Thesis: Compulsory Ship and Offshore Technology: Thesis: Compulsory Theoretical Mechanical Engineering: Thesis: Compulsory Process Engineering: Thesis: Compulsory Water and Environmental Engineering: Thesis: Compulsory Certification in Engineering & Advisory in Aviation: Thesis: Compulsory