Technische Universität Braunschweig

Module Guide

Description of the degree program

Battery and Hydrogen Technology (Master)
PO 1

Date: 24.07.2026

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Compulsory Modules

Title	Future Battery Production Systems		
Number	2521000070	**Module version**	
Shorttext		**Language**	english
Frequency of offer	only in the summer term	**Teaching unit**	Fakultät für Maschinen-bau
Module duration	1	**Institution**	Institut für Partikeltech-nik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Sabrina Zell-mer
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Expected performance/ Type of examina-tion	1 examination element: written exam (90 min) or oral exam (30 min)		
Course achievement	presentation (10 min)		

Contents

The module is divided into two blocks and aims to convey knowledge based on research-based learning. In addition to reviewing the fundamentals of battery chemistry, including materials, manufacturing processes, and recycling technologies, the focus in the first block is on a deeper understanding of innovative battery technologies, current recycling methods, and relevant research topics. Furthermore, students will gain initial practical experience in the research infrastructures of TU Braunschweig.

In the second block, Research-based learning is emphasized. Research questions with various challenges are presented, which are then addressed in groups. Students must allocate responsibilities and work on the research questions theoretically and, if necessary, practically. The presentation of intermediate and final results is done through a written elaboration (e.g., a strategy paper) as well as through a presentation

Objective qualification

Upon completion of the module, students will be able to:

- Demonstrate foundational knowledge of the battery lifecycle and next-generation batteries, as well as analyze complex questions related to these topics.
- Critically analyze and address current research questions regarding the battery lifecycle.
- Work effectively in a team and, if necessary, provide guidance.
- Identify complex problems and develop structured approaches to solutions.
- Independently acquire and apply new complex knowledge.
- Process, present, and communicate results in various goal-oriented ways.

Literature

- Itani, Khaled, and Alexandre De Bernardinis. "Review on new-generation batteries technologies: trends and future directions." Energies 16.22 (2023): 7530.

- Fan, Ersha, et al. "Sustainable recycling technology for Li-ion batteries and beyond: challenges and future prospects." Chemical reviews 120.14 (2020): 7020-7063.
- Yang, Chuanbo, et al. "Addressing the safety of next-generation batteries." Nature 645.8081 (2025): 603-613.

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
Future Battery Production Systems	3,0	Lecture/Exercise	english

Title	Hydrogen as Future Energy Carrier		
Number	2536000010	**Module version**	
Shorttext		**Language**	english
Frequency of offer	only in the winter term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	1	**Institution**	Institut für Verbrennungskraftmaschinen und Brennstoffzellen
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Michael Heere
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Expected performance/ Type of examination	1 examination element: written exam (90 min) or oral exam (30 min)		
Course achievement			

Contents

The topic of the lecture “Hydrogen as Future Energy Carrier” deals with element number 1 from the perspective of its physicochemical properties. Hydrogen itself is not a primary energy carrier – wherever it is used, it must first be produced. Depending on the production method, hydrogen is assigned a color code. Accordingly, after a detailed presentation of hydrogen production and H# utilization, especially in the transport sector, the lecture places them within a color#coding scheme. Geogenic hydrogen is examined and evaluated in terms of its potential. The energy#related aspects of storing hydrogen in gaseous, liquid and solid forms are then discussed, followed by storage in mixed form. The chemico#physical storage in metal hydrides, complex metal hydrides and metal–organic frameworks (MOFs) is taught. As a possible storage solution for intermittently generated renewable energies, the “power-to-gas” concept is presented, which serves as an exemplary case for the entire hydrogen#based energy cycle. Hydrogen safety concepts as well as relevant standards and guidelines teach safe handling of hydrogen in small#scale applications and larger systems. Examples from the transport sector round off the lecture and bridge to mobile applications.

Objective qualification

The lecture covers the mobility topic of hydrogen and hydrogen as an energy carrier of the future. Through participation, students are enabled to explain the fundamental aspects of the hydrogen cycle economy and to apply objective criteria to its ecological implementation in the transport sector. They are able to specify the basic physical as well as chemical properties of hydrogen. Moreover, students can independently apply thermodynamic properties along with the associated kinetic and efficiency calculations. They can analyze and explain both established and emerging storage forms for hydrogen. They are also capable of evaluating the advantages and disadvantages of hydrogen use compared to battery-electric propulsion in automobiles and of drawing a comparison with alternative hydrogen combustion. Based on this knowledge, they can determine which option is energetically more favorable. Through in-depth discussions, students become sensitized to safety-relevant issues related to hydrogen as an energy carrier and can develop and assess appropriate safety concepts.

Literature

1. Töpler, J. and J. Lehmann, Wasserstoff und Brennstoffzelle. 2014: Springer
2. Hirose, K., Handbook of hydrogen storage: new materials for future energy storage. 2010: John Wiley & Sons

Remark

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
Hydrogen as Future Energy Carrier	2,0	Lecture	english
Hydrogen as Future Energy Carrier	1,0	Exercise	english

Title	Modern Modelling and Artificial Intelligence		
Number	2521000090	**Module version**	
Shorttext		**Language**	english
Frequency of offer	only in the winter term	**Teaching unit**	Fakultät für Maschinen-bau
Module duration	1	**Institution**	Institut für Partikeltech-nik
Hours per Week / ECTS	4 / 5,0	**Module owner**	Prof. Dr. Carsten Schilde
Workload (h)	150		
Class attendance (h)	56	**Self studying (h)**	94
Compulsory requirements			
Expected performance/ Type of examina-tion	1 examination element: Written exam (90 min) or oral exam (30 min)		
Course achievement	1 course achievement: Development and documentation of AI models		

Contents

The lecture covers the fundamental concepts, methods, and tools of modern machine learning (ML) and artificial intelligence (AI). These include learning paradigms, model classes, training and evaluation methods, as well as the historical development and current categorization of AI. In addition, topics such as optimization methods, model robustness, uncertainty quantification, and ethical aspects are systematically addressed.

Students learn about essential methods of supervised and unsupervised learning, probabilistic models, neural networks, and methods of model interpretability. A particular focus is placed on hybrid modeling approaches that combine physical knowledge with ML, such as for process prediction, adaptive modeling, or control of process engineering systems. In addition, current architectures such as graph attention networks, transformer models, diffusion models, and mixture-of-experts are introduced. The industrial perspective, with its focus on handling real data sets, uncertainties, fault detection, soft sensing, and process optimization, complements the methodological foundations. The theoretical content is put into practice in exercises. Students implement methods in Python, train and evaluate models, and analyze their behaviour. An accompanying practical training course deepens their knowledge with realistic tasks, such as the development of a data-driven or hybrid model for a process engineering system.

Objective qualification

Upon completion of the module, students will have a solid understanding of key methods of modern machine learning and artificial intelligence. They will be able to categorize and describe fundamental learning paradigms, model classes, and current AI architectures such as hybrid modeling approaches, graph attention networks, transformer models, diffusion models, and mixture of experts, and evaluate their suitability for process engineering applications. Based on the theoretical and practical knowledge they have gained, they will be able to select suitable data-driven and hybrid methods, assess their robustness and uncertainties, and implement them using Python. Students will be able to analyze real data sets, develop and validate models, and combine and further develop different approaches in a meaningful way in order to independently solve complex process and system modeling tasks.

Literature

Beispielhafte Literatur:

- Neural Networks and Deep Learning (Charu C. Aggarwal);

- Hybrid Modeling in Process Industries (Jarka Glassey);
- Physics-Informed Machine Learning (Karniadakis et al.);
- Pattern Recognition and Machine Learning (ChristopherBishop);
- Attention Is All You Need (Ashish Vaswani et al.)

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
Modern Modelling and Artificial Intelligence	4,0	Lecture/Exercise	english ger-man

Elective Modules

Title	Additive Layer Manufacturing		
Number	2510300	**Module version**	
Shorttext		**Language**	english
Frequency of offer	only in the summer term	**Teaching unit**	Fakultät für Maschinen-bau
Module duration	1	**Institution**	Institut für Mechanik und Adaptronik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Markus Böl
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Expected performance/ Type of examina-tion	1 examination element: written exam, 120 minutes or oral exam, 30 minutes		
Course achievement			

Contents

Materials for ALM: - Polymers, metals, ceramics, paper, powders, thermoplastics, ALM manufacturing processes in direct layer build-up - Polymerisation, polymer jetting - Sintering and melting - Extrusion - Powder binder processes - Layer Manufacturing Modelling - Basics - FEM - Basics of optimisation algorithms - Basics of structural optimisation - especially topology optimisation Modelling - Application of different optimisation algorithms in topology optimisation - Approaches for the consideration of direction-dependent material parameters within form finding Design of components to be manufactured using ALM methods with 3D CAD data generation Design of simple components - Tensile specimens for determining characteristic values - Production and testing of a simple component in competition with other students

Objective qualification

After completing the module, students can select the most appropriate 3D printing technology and respective materials to manufacture parts by 3D printing. Furthermore, they are able to plan and execute the whole process chain, starting with CAD model and finishing with real, ready-to-use parts. They can select appropriate post-processing steps, surface preparation and surface treatments. Student are capable to steer the part-designing process to increase printability success, reduce material waste and post-processing time. With the taught knowledge of Additive Manufacturing and topology optimization, students are able to create sophisticated, topology-optimized models or re-design existing ones.

Literature

1. Redwood, Ben; Schöffer, Filemon; Garret, Brian: The 3D Printing Handbook: Technologies, Design and Applications, 3D Hubs B.V., Amsterdam, Netherlands, 2017, ISBN 978-90-827485-0-5
2. Gibson, Ian; Rosen, David; Stucker, Brent: Additive Manufacturing Technologies, 2. Aufl.; Springer Verlag, Berlin, Heidelberg, New York, 2015, ISBN 978-1-4939-2112-6.
3. Fastermann, Petra: 3D-Drucken, Springer Verlag Berlin, Heidelberg, New York, 2014, ISBN 978-3-642-40963-9
4. Gu, Dongdong: Laser Additive Manufacturing of High-Performance Materials, Springer Verlag Berlin Heidelberg, 2015, ISBN 978-3-46088-7

Remark
Theory of the lecture focuses on the whole 3D printing sector. Exercises and laboratory works focus on CAD, topology optimization, file preparation, printing with FDM and DLP, printer calibrations, part post-processing. Exercises are a must and they teach basics of FDM only. Participation in laboratory works is highly suggested. During semester, students must design, 3D print and assemble topology optimized bridge to compete with other teams, which bridge would hold the highest load. Perfect way to use knowledge acquired over semester.

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Related courses			
Rules for the choice of courses			
Due to limited lecture hall capacity, the number of participants will be limited to 20.			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
	2,0	Lecture	english
	1,0	Exercise	english

Title	Advanced Fluid Separation Processes		
Number	2541430	**Module version**	
Shorttext		**Language**	english
Frequency of offer	only in the summer term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	1	**Institution**	Institut für Chemische und Thermische Verfahrenstechnik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Stephan Scholl
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Recommended requirements	Basic knowledge in fluid separation processes, thermal separation processes, thermodynamics, heat and mass transfer		
Expected performance/ Type of examination	1 examination element: Written exam, 90 minutes or oral examination 30 minutes		
Course achievement			

Contents

The course covers the chemical engineering unit operations absorption, chromatography, drying and membrane processes. For an advanced understanding of the relevant processes 1st and 2nd Ficks law as well as the Stefan-Maxwell approach for mass transfer are presented and discussed. Finally the combination for reaction and component separation as hybrid or reactive separation processes are covered. Especially reactive absorption, reactive adsorption and reactive extraction are presented. In all cases the engineering approach and applied methods for the design and operation of new processes and its transfer to an appropriate equipment and plant design as well as the assessment of existing processes and equipment are covered. Exercise: In the tutorial typical problems are quantitatively calculated. With this, the students can acquire theoretical knowledge by practicing with practical examples.

Objective qualification

The students know the characteristics of the integration of reaction and separation. The processes of chemisorption, reactive distillation, reactive extraction (absorption and adsorption), chromatography, drying and membrane technology are known. Advantageous applications can be identified. Process design under operational and economical aspects and the implementation of equipment can be designed quantitatively. Students are able to elaborate and communicate these topics orally and in written form in english language.

Literature

- Goedecke, Ralf: Fluidverfahrenstechnik Band 1, Weinheim, Wiley-VCH 2006 - Goedecke, Ralf: Fluidverfahrenstechnik Band 2, Weinheim, Wiley-VCH 2006 - Mersmann, A., Stichlmair, J., Kind, M.: Thermische Verfahrenstechnik, Verlag Springer, 2005

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
	2,0	Lecture	english
	1,0	Exercise	english

Title	Instrumental Analysis and Testing in Surface Technology		
Number	2525030	**Module version**	
Shorttext		**Language**	german
Frequency of offer	only in the summer term	**Teaching unit**	Fakultät für Maschinen-bau
Module duration	1	**Institution**	Institut für Oberflächen-technik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Claus-Peter Klages
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements	Knowledge of differential and integral calculus, elementary understanding of physical relationships		
Expected performance/ Type of examina-tion	1 Examination element: written exam (90 min) or oral exam (30 min)		
Course achievement			

Contents

- Measurement of layer thickness (optical, electrical, magnetical)
- Surface topography (parameters, determination)
- Elemental composition (GDOES, EDX, WDX, XPS, SIMS)
- Inner structure (XRD)
- Mechanical properties (Nanoindentation)

Objective qualification

Students can apply the analytics and characterization of surfaces and thin. Students can use the knowledge of bachelor-level physics to multiple examples of practical importance.

Literature

- Nitzsche, K.: Schichtmesstechnik. Vogel-Verlag, 1996
- Sorg, H.: Praxis der Rauheitsmessung und Oberflächenbeurteilung, Hanser-Verlag, 1995
- Nowicki, B.: Multiparameter representation of surface roughness, Wear 102 (1985) 161
- Bubert, H. und Jenett, H.: Surface and thin film analysis: A Compendium of principles, instrumentation, and applications. Wiley-VCH, 2002
- Klug, H.P., Alexander, L.E.: X-ray diffraction procedures. Wiley-Interscience, 1974

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**

	2,0	Lecture	german
	1,0	Exercise	german

Title	Application of Commercial FE-Software		
Number	2529010	**Module version**	
Shorttext		**Language**	german
Frequency of offer	only in the winter term	**Teaching unit**	Fakultät für Maschinen-bau
Module duration	1	**Institution**	Institut für Mechanik und Adaptronik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Markus Böl
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Expected performance/ Type of examina-tion	1 examination element: written exam (120 min) or oral exam (60 min) in groups		
Course achievement			

Contents

- general structure of the FE-software
- meshing strategies
- material models
- FE-technology
- modelling techniques
- solution methods/solution algorithms
- contact problems
- interpretation and post-processing of the numerical results

Objective qualification

After completing the module attendees will be able to describe calculations that run in the background of commercial FE software and to display results graphically. Students are able to solve given problems inde-pendently in computer exercises. They can select and justify settings of commercial FE-tools and evaluate the strength of structures.

Literature

- O.C. Zienkiewicz & R.L. Taylor, The Finite Element Method (2 volumes), Buttherworth / Heinemann, Oxford u.a., 2000
- J. Fish & T. Belytschko, A First Course in Finite Elements, John Wiley & Sons Ltd, 2007
- T.J.R. Hughes, The Finite Element Method, Dover Publications, 2000

Remark

Lectures and exercises are offered weekly in both German and English.

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
	2,0	Lecture	german
	1,0	Exercise	german

Title	Characterisation of Surfaces and Thin Films		
Number	2525210	**Module version**	
Shorttext		**Language**	german
Frequency of offer	only in the summer term	**Teaching unit**	Fakultät für Maschinen-bau
Module duration	1	**Institution**	Institut für Oberflächen-technik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Claus-Peter Klages
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Recommended requirements	Knowledge of differential and integral calculus, elementary understanding of physical and chemical relationships		
Expected performance/ Type of examina-tion	1 examination element: written exam (90 min) or oral examination (30 min)		
Course achievement			

Contents

- Film thickness
- Mechanical and tribological properties
- Electrical properties
- Optical properties of thin films
- Wetting and surface tension
- Composition of thin films
- Layer structure: X-ray diffractometry (XRD)

Objective qualification

After finishing the module students can describe commonly used methods applied for characterizing mecha-nical, electrical, optical and wetting properties of thin and ultrathin films. They are able to select methods for measuring thickness, topography, composition and inner structure of surfaces and thin films.

Literature

- Nitzsche, K.: Schichtmesstechnik. Vogel-Verlag, 1996
- Bubert, H. und Jenett, H.: Surface and thin film analysis: A Compendium of principles, instrumentation, and applications. Wiley-VCH, 2002
- M. Ohring, The Materials Science of Thin Films, Academic Press, Inc., 1992

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
	2,0	Lecture	german
	1,0	Exercise	german

Title	Computer Aided Process Engineering 1 (Introduction)		
Number	2541500	**Module version**	
Shorttext		**Language**	english
Frequency of offer	only in the summer term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	1	**Institution**	Institut für Chemische und Thermische Verfahrenstechnik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Stephan Scholl
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Recommended requirements	• Good proficiency in English language and basic knowledge of technical English language in process engineering. • Required knowledge on thermal separation processes: 1. Physical properties and multi component multiphase systems; Single component properties; Multi component properties, composition of multicomponent and multiphase systems; component separation, partitioning, VLE, LLE, SLE 2. Heat transfer; Single and two-phase heating, cooling, evaporation and condensation; Energy balancing; Quantification of heat transfer; Temperature/enthalpy or temperature/heat flow-curves 3. Single stage separations; Evaporation and condensation; Equilibrium stage model 4. Multistage vapor / liquid separations; Knowledge about distillation, rectification, absorption and desorption; Thermodynamic modeling of these processes, e.g. McCabe-Thiele model and plot; Design of multistate countercurrent separations, e.g. calculating of theoretical and practical stages 5. Practical equipment design; Knowledge about different design options and flow arrangements for I. Heat exchangers II. Pumps III. Mixers IV. Phase separators V. Columns		
Expected performance/ Type of examination	2 examination elements: 1. term paper on simulation applications (to be weighted 2/5 in the calculation of module mark) 2. written exam (60 min) or oral exam (30 min) (to be weighted 3/5 in the calculation of module mark)		
Course achievement			
Module grade composition	2 examination elements: 1. term paper on simulation applications (to be weighted 2/5 in the calculation of module mark) 2. written exam (60 min) or oral exam (30 min) (to be weighted 3/5 in the calculation of module mark)		
Contents			
Based on the theory for thermal separation processes as presented in #Grundoperationen der Fluidverfahrenstechnik# or equivalent classes the typical workflow for process design and optimization is demonstrated. Commercial software products are employed for modelling and simulation of the following tasks: Physical properties and phase equilibria: Data retrieval, regression of experimental data, parameter estimation· Two phase flash: Single stage separations, integral vs. differential operation mode· Rigorous modelling of a rectification column: Binary mixture, multicomponent mixture, design specifications· Flow sheet simula-			

tion for multistage separation: Feed forward, recycles· Equipment design: Selection and sizing for distillation columns, heat exchangers, reboilers, condensers· Costing, process optimization. The lecture as well as the exam are conducted in English language.
Objective qualification
Students can select physical property and phase equilibrium information, which are needed for modelling and simulation of fluid separation processes, especially vapor-liquid based separations. They are able to distinguish and weigh between parameters in addition to create a physical property data file. For a given process flow sheet or separation problem they are able to develop an appropriate reflection in a flow sheet simulation based on the equilibrium stage model. For selected equipment types, such as heat exchangers and distillation columns, they are able to perform a cost-optimum selection and sizing. Overall, they know the typical workflow for fluid process design in the framework of Computer Aided Process Engineering. Students are able to communicate and deliver the above in English language orally and in writing.
Literature
[1] H. Schuler (Ed.): Prozesssimulation. Wiley VCH, Weinheim, 1995. [2] C. D. Holland, A. I. Liapis: Computer Methods for Solving Dynamic Separation Problems. McGraw-Hill, New York, 1983. [3] D. M. Bates, D. G. Watts: Nonlinear Regression Analysis and its Applications. John Wiley & Sons, New York 1988

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
	1,0	Exercise	english
	2,0	Lecture	english

Title	Computer Aided Process Engineering 2 (Design of Process Plants)		
Number	2541270	**Module version**	
Shorttext		**Language**	german
Frequency of offer	only in the winter term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	1	**Institution**	Institut für Chemische und Thermische Verfahrenstechnik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Stephan Scholl
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Recommended requirements	lecture "Introduction to Computer Aided Process Engineering".		
Expected performance/ Type of examination	2 Examination elements: 1. written exam (90 min) or oral exam (30 min) (to be weighted 3/5 in the calculation of module mark) 2. presentation of a lecture accompanying project (to be weighted 2/5 in the calculation of module mark)		
Course achievement			
Module grade composition	2 Examination elements: 1. written exam (90 min) or oral exam (30 min) (to be weighted 3/5 in the calculation of module mark) 2. presentation of a lecture accompanying project (to be weighted 2/5 in the calculation of module mark)		

Contents

The lecture gives the basic concepts in plant design which will be elaborated in a project work, designing a complete, common process from process industries. The flowsheet simulation is done using an established software tool for the process industries. Major contents of the lecture are: Process data acquisition (e.g. physical properties, safety, capacity) Process development using chemical equations Heat-/mass -balances Flowsheet simulation Sizing of process devices using nondimensional parameters Choosing and detail sizing of suitable process devices (e.g. columns, heat exchangers) Computer Aided Process Engineering Cost estimation Legal aspects (e.g. environmental requirements, approval procedures)

Objective qualification

The students can explain the basic process steps in development and design of a typical processes. They know and are able to gather the required information for the design of a process plant (material, safety-related, reaction-related, etc.) and can derive this information from suitable sources. Using a process simulation tools they are able to conceive a quantitative process design. They can select suitable designs for the main apparatus (e.g. heat exchangers, columns) and dimension them according to requirements. Taking into account logistical and safety aspects, they can prepare a plant design and present it in a suitable form.

Literature

Bernecker, Gerhard: Planung und Bau verfahrenstechnischer Anlagen: Projektmanagment und Fachplanungsfunktion. 4. Aufl. 2001, Springer Verlag, Berlin
Hirschberg, Hans Günther: Handbuch Verfahrenstechnik und Anlagenbau: Chemie, Technik, Wirtschaftlichkeit. 1999, Springer Verlag, Berlin

VDI-Wärmeatlas: 11. Aufl. 2013, Springer Verlag, Berlin
Vogel, Herbert: Verfahrensentwicklung: Von der ersten Idee zur chemischen Produktionsanlage. 2002, Wiley-VCH Verlag, Weinheim

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
	2,0	Lecture	german
	1,0	Exercise	german

Title	Data Science in Fluid Mechanics		
Number	2512000080	**Module version**	
Shorttext		**Language**	english
Frequency of offer	only in the summer term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	1	**Institution**	Institut für Strömungsmechanik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. David Rival
Workload (h)	150		
Class attendance (h)	48	**Self studying (h)**	102
Compulsory requirements			
Expected performance/ Type of examination	1 examination element: Homework with presentation		
Course achievement			

Contents

- Fourier transform
- Correlation function and spectra
- Statistical principles
- Statistical error
- Geometric error
- Estimator
- expectation
- variance and variability
- Propagation of error
- Vortex detection
- Proper orthogonal decomposition
- Dynamic mode decomposition

Objective qualification

With the aid of several applied exercise sessions using MATLAB, the students can classify and quantify the various types of uncertainties and their propagation. The students are capable to identify and quantify the main sources of these uncertainties and of reducing them. Using Tecplot software, the students can visualize fluid flows using different approaches and identify the best one to extract the most visual information from flow snapshots. By learning and applying various spectral-decomposition techniques, the students can identify the most relevant and dominant modes and physically interpret them. Using real numerical and experimental data and implementing different uncertainty and spectral analysis methods, the students are exposed to realistic scientific data-analysis scenarios that enable them to investigate and extract the most relevant physical information from any fluid flow data.

Literature

- Tropea, Cameron, Alexander L. Yarin, and John F. Foss, eds. Springer handbook of experimental fluid mechanics. Vol. 1. Springer, 2007.
- Coleman, Hugh W., and W. Glenn Steele. Experimentation, validation, and uncertainty analysis for engineers.
- John Wiley & Sons, 2009. Bendat, Julius S., and Allan G. Piersol. Random data: analysis and measurement procedures. Vol. 729. John Wiley & Sons, 2011.

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
Data Science in Fluid Mechanics	3,0	Lecture/Exercise	english

Title	Digital Electronics		
Number	2538090	**Module version**	
Shorttext		**Language**	german
Frequency of offer	only in the winter term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	1	**Institution**	Institut für Mikrotechnik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Andreas Dietzel
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Recommended requirements	Knowledge of electronic components and circuits as well as of the corresponding physical fundamentals is assumed. The module Applied Electronics in the Bachelor's programme (MB-MT-18, MB-MT-19) conveys this knowledge.		
Expected performance/ Type of examination	written exam (120 min) or oral exam (30 min)		
Course achievement			

Contents

Starting with the description of digital signals, implementation possibilities for digital processing systems are presented. The best known number systems are presented and their conversion is practiced. The arithmetic of adding, subtracting, multiplying and dividing is applied to the dual system (dual arithmetic). Another focus is Boolean algebra and its realization with logic gates. This includes the Karnaugh-Veitch diagram and the Quine-McClusky method for simplifying switching networks. Furthermore, coding methods for data and code converters are treated. The design of flip-flop circuits, counter circuits, multiplexers and optoelectronic components is examined in relation to the application. The design and control of semiconductor memory elements are also presented. In the field of signal conversion, analog-to-digital and digital-to-analog converters as well as data bus systems are presented.

Objective qualification

Students are able to apply number systems and Boolean algebra and analyse the results. They can transfer methods for simplifying electronic circuits and data processing to previously unknown application examples. Furthermore, they are able to select and use different methods for the theoretical and practical realization of logic, toggle, counter and calculation circuits according to their needs. They can describe, apply and examine the production of printed circuit boards.

Literature

- U. Tietze, Ch. Schenk: Halbleiterschaltungstechnik, Springer, 12. Aufl. 2002, ISBN 3-540-42849-6
- R. C. Jaeger, T. N. Blalock: Microelectronic Circuit Design, McGraw-Hill, 3rd ed. 2007, ISBN 0-073-30948-6
- W. Groß: Digitale Schaltungstechnik, Vieweg, 1994, ISBN 3-528-03373-8
- R. Weißel, F. Schubert: Digitale Schaltungstechnik, Springer, 1995, ISBN 3-540-57012-8
- www.elektronik-kompendium.de

Remark

The module Microprocessor Technology (MB-MT-10) is a good supplement to the contents covered here.

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
	2,0	Lecture	german
	1,0	Exercise	german

Title	Digital Technologies in Process Engineering		
Number	2541450	**Module version**	
Shorttext		**Language**	german
Frequency of offer	only in the summer term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	1	**Institution**	Institut für Chemische und Thermische Verfahrenstechnik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Stephan Scholl
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Expected performance/ Type of examination	written exam (90 min) or oral exam (30 min) - presence or digital		
Course achievement			

Contents

Lecture:
- terms, definitions and thematic allocations for digitization in general and in the context of Industry 4.0, with a focus on process engineering applications
- basics of hardware components, such as measurement and sensor technologies, as well as requirements for future sensor technologies and process plants
- data-driven, hybrid modeling
- methods and techniques of machine learning (supervised, unsupervised learning)
- data mining and data analysis (CRISP-DM, feature extraction, -selection, clustering, visualization)
- basics of neural networks and deep learning
- drivers, potentials and initiatives of the chemical industry in the context of digital transformation
- presentation of practical examples from industry and research

Exercise:
- Programming in Python
- Computer exercises for feature extraction, selection and evaluation

Objective qualification

Lecture:
Students will be able to explain and differentiate the essential terms in the context of digitization and Industry 4.0. They can define and explain methods of machine learning and apply known procedures. Students can argue which method would be suitable for a given problem. They know the general procedure of data analysis and can describe and apply known algorithms. The algorithms used can be analyzed and evaluated with regard to their prediction accuracy. Typical model errors can be identified and evaluated by the students.
Exercise: The students are able to abstract the acquired knowledge to practical examples. They can select and apply the programming environment necessary for data preparation and visualization as well as familiar tools. Students can program and execute simple algorithms for statistical data analysis and machine learning. Furthermore, the students are enabled to work successfully in a group, to communicate efficiently and

to develop solutions independently. By working with other people (group members, supervisors) this promotes the students in their communication skills and social competence.
Literature
• S. Richter. #Statistisches und maschinelles Lernen#, 2019. • C. M. Bishop. #Pattern Recognition and Machine Learning#, 2006. • J. VanderPlas. #Python Data Science Handbook: Essential Tools for Working with Data#, 2016.

↑

Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
	2,0	Lecture	german
	1,0	Exercise	german

Title	Energy Efficiency in Production Engineering		
Number	2522930	**Module version**	v2
Shorttext		**Language**	english
Frequency of offer	only in the summer term	**Teaching unit**	Fakultät für Maschinen-bau
Module duration	1	**Institution**	Institut für Werkzeugma-schinen und Fertigungs-technik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Christoph Herr-mann
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Expected performance/ Type of examina-tion	written exam+ (120 min) or oral exam+ (30 min)		
Course achievement	presentation and/or written report in the context of a teamproject (On application, the result of the course achievement is taken into account in the assessment of the writ-ten examination+ or of the oral examination+, respectively, and can account maxi-mum 20% of the respective grade.)		

Contents

- Background and methods for the holistic planning, design and development of sustainable production systems
- Definition of the term and origin of sustainability in production
- Technologies and procedures for industrial data acquisition
- Energetic evaluation of production processes on the basis of various key figures
- Data analysis of production processes using Sankey diagrams in theory and practice
- Analysis of production processes based on an (energy) value stream analysis
- Analysis of the different levels of consideration of factories (production processes, technical building equipment, building envelope) and relevant material, energy and information flows
- Guest lectures from industry on relevant topics of sustainable production systems
- Gaining knowledge about energy flexibility in production
- Practice-oriented application of various methods to increase energy efficiency in the IWF's learning fac-tory

Objective qualification

The students...

- ... explain the planning, design and development of sustainability-oriented production systems in different contexts
- ... assess different strategies (e.g. efficiency strategy) and principles (e.g. avoidance principle) of sustainable development in defined use cases on a laboratory scale
- ... evaluate existing production systems in economic, ecological and social dimensions
- ... are able to illustrate the results of various efficiency strategies to non-experts and to apply relevant assumptions, restrictions and framework conditions correctly
- ... design their own research questions within the team project, evaluate experiments and derive a pre-sentation of the results of the research
- ... organize themselves in a team project and gain experience in relevant soft skills such as teamwork, communication and presentation skills
- ... analyze sustainability-oriented production systems within a given topic

- ... are able to select relevant fields of action and measures for sustainable production

Literature

Vorlesungsskript "Energy Efficiency in Production Engineering" mit ausführlichen Quellenangaben für das Selbstudium

Herrmann, Christoph: Ganzheitliches Life Cycle Management, Berlin 2009

Dyckhoff, H. (2000): Umweltmanagement # Zehn Lektionen in umweltorientierter Unternehmensführung, Berlin: Springer-Verlag Berlin Heidelberg, 2000.

Günther, H.-O.; Tempelmeier, H. (2005): Produktion und Logistik. 6., verb. Aufl., [Hauptbd.], Berlin: Springer-Verlag Berlin Heidelberg, 2005.

Eversheim, W.; Schuh, G. (1999): Gestaltung von Produktionssystemen, VDI-Buch Nr. 3, Berlin: Springer-Verlag Berlin Heidelberg, 1999.

Remark

The course "Energy Efficiency in Production Engineering" is targeted in particular at students of mechanical engineering, industrial engineering, sustainable energy engineering, technology-oriented management, environmental engineering and other related courses.
This lecture is held in English.

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Related courses

Rules for the choice of courses

Both courses have to be attended.

Compulsory attendance

Name of the course	SWS	Eventtype	Language
	2,0	Lecture	english
	1,0	Team Project	english

Title	Energy Turnaround – Industrial Hydrogen Applications		
Number	2521000010	**Module version**	
Shorttext		**Language**	english
Frequency of offer	only in the summer term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	1	**Institution**	Institut für Partikeltechnik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Sabrina Zellmer
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Expected performance/ Type of examination	written exam (90 min) or oral exam (30 min)		
Course achievement			

Contents

H2-General
- Chemical properties, energy density, storage possibilities (Compression and Liquidation)
- How do these properties affect hydrogen as an energy carrier?
- How does the transport take place?

H2-Generation
- Hydrogen – Generation (green, blue, grey hydrogen)
- Technology overview electrolysis
- Decision basis for suitable technologies in different industrial applications

H2-Economy
- Status quo (Today's H2 generation and application); H2 as an energy carrier
- Green H2 demand (Europe, DE); European/national H2 strategy targets
- Green H2 requirements: electrolysis in DE + regulatory & legislation (EEG)

Power Generation
- Targets
- Electricity generation costs
- Technology overview: Photovoltaics, wind power, …

H2-Conversion
- H2 storage media: ammonia, methanol, CH4, LOHC
- H2 storage media: energy demand (electricity, heat)

H2-Storage
- Overview of storage options, state of the art (e.g., LH2 tank)

H2-Transport
- Truck, train, pipeline, ship: overview, advantages/disadvantages, transportability
- Existing transportation options: Truck and pipeline

H2-Usage

- Overview H2 use in industry, mobility and quarters
- Examples: Steel industry, fabric transformation, fuel cells in different applications
- Fuel cells- Types

Objective qualification

Students will gain knowledge in the field of H2 generation, economics, storage, transport and utilization. After completing the lecture and exercise, the students will be able to name possible applications of H2 and describe the general interrelationships along the entire value chain, recognize the relevance of H2 on the path to climate neutrality by 2030, name and explain relevant technologies in the context of hydrogen, as well as discuss and reflect on essential characteristics regarding the transformation of the energy sector.

Literature

1) Stolten, Detlef, ed. Hydrogen and fuel cells: fundamentals, technologies and applications. John Wiley & Sons, 2010.
2) Hosseini, Seyed Ehsan. Fundamentals of hydrogen production and utilization in fuel cell systems. Elsevier, 2023.
3) Stetson, Ned T., Robert C. Bowman Jr, and Gregory L. Olson. "Overview of hydrogen storage, transportation, handling and distribution." Handbook of hydrogen energy 26 (2014).

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Related courses

Rules for the choice of courses

Block course

Compulsory attendance

Name of the course	SWS	Eventtype	Language
Energy turnaround – Industrial hydrogen applications	2,0	Lecture	english
Energy turnaround – Industrial hydrogen applications	1,0	Exercise	english

Title	Formulation Technology for Components of Battery and Hydrogen Systems		
Number	2521000110	**Module version**	
Shorttext		**Language**	english
Frequency of offer	only in the winter term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	1	**Institution**	Institut für Partikeltechnik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Arno Kwade
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Recommended requirements	Fundamentals of mechanical process engineering, basic knowledge of the structure and function of battery and fuel cells		
Expected performance/ Type of examination	1 examination element: Written exam (90 min) or oral exam (30 min)		
Course achievement			

Contents

The production of components for sustainable battery and hydrogen systems involves complex process chains consisting of a large number of different unit operations. Following an introduction to these components, this lecture will present the fundamental principles of formulation process engineering (e.g. particle-particle-interactions, rheology, powder flow), knowledge and models for formulating the components and their intermediate and precursor products, i.e. for designing material formulations and choosing process parameters. Practical examples are used to show how the products of battery and hydrogen systems can be produced in a targeted manner by selecting parameters and process sequences. Sophisticated formulations, stable disperse systems and reproducible process conditions are essential for the performance and safety of the final products.
The lecture first introduces the basics of dispersed systems in order to understand the flow behavior and processing of emulsions, suspensions and powders in battery and hydrogen applications. It then delves into the production and properties of liquid and solid formulations and their significance for functional layers, electrodes, membranes and bipolar plates. Building on this, students learn about the processes used (e.g. extrusion, coating) to achieve tailor-made product properties for different battery and hydrogen components. The lecture thus conveys both the broad fundamentals of formulation technology and its implementation in key industrial applications, with particular reference to current challenges in the process engineering production of components for battery and hydrogen systems.

Objective qualification

In this module, students acquire in-depth engineering and scientific skills enabling them to reliably design, apply and evaluate recipes, processes and procedures for the process engineering manufacture of components for battery and hydrogen systems. In addition to in-depth fundamentals, they learn to classify current trends and research results, design suitable unit operations, processes and production methods, and systematically solve complex challenges. They also develop the ability to flexibly transfer their knowledge to industrial applications in the battery and hydrogen sector.

Literature

- Mollet, H., Grubenmann, A. (2008). Formulation Technology: Emulsions, Suspensions, Solid Forms. Deutschland: Wiley-VCH.

- Kwade, A., Haselrieder, W., et.al. (2018). Current status and challenges for automotive battery production technologies, Nature Energy, 2018, 3, 290-300

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
Formulation Technology for Components of Battery and Hydrogen Systems	2,0	Lecture	english
Formulation Technology for Components of Battery and Hydrogen Systems	1,0	Exercise	english

Title	Fuel Cell Systems		
Number	2536230	**Module version**	
Shorttext		**Language**	english
Frequency of offer	only in the winter term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	1	**Institution**	Institut für Verbrennungskraftmaschinen und Brennstoffzellen
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Peter Eilts
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Expected performance/ Type of examination	1 examination element: written exam (90 min) or oral exam (30 min)		
Course achievement			

Contents

The topic of the lecture "Fuel Cell Systems" first deals with the different types of fuel cells, PEM, AEM, SOFC, etc. from the point of view of their physical-chemical properties, as well as the manufacturing processes also related to the overall system. Subsequently, the various layers and components of the fuel cell systems are dealt with in detail, especially with regard to the degradation of catalysts, GDLs and MEAs. Hydrogen in itself is not a primary energy carrier - wherever it is consumed, it must first be produced, which is why great attention is paid here to CO2-neutral production, especially through so-called high-temperature cells. The circular economy of the various components is explained in more detail and the special features of the respective layers and components are addressed.

Objective qualification

The lecture deals with the future-relevant topic of fuel cell systems. By participating, students will be able to outline a production cycle of the individual components and set objective standards for its ecological realisation in the mobility sector. They are able to name the basic physical and chemical properties of the components. The students are able to independently apply thermodynamic properties and related kinetic calculations as well as efficiency calculations. The students are able to explain and analyse the forms of special fuel cells (systems) in addition to the established formats. The students are able to assess the advantages and disadvantages, especially in relation to the battery-electric drive in the mobility sector, and also the comparison with the combustion of hydrogen can be analysed and distinguished which form is energetically more favourable. Detailed discussions of relevant system aspects are described by the students and thus round off the qualification objectives.

Literature

Dicks, Andrew L., and David AJ Rand. Fuel cell systems explained. John Wiley & Sons, 2018

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
Fuel Cell Systems	2,0	Lecture	english
Fuel Cell Systems	1,0	Exercise	english

Title	Ceramic/Polymer materials		
Number	2524120	**Module version**	
Shorttext		**Language**	german
Frequency of offer	only in the summer term	**Teaching unit**	Fakultät für Maschinen-bau
Module duration	2	**Institution**	Institut für Werkstoffe
Hours per Week / ECTS	2 / 5,0	**Module owner**	Dr. Martin Bäker
Workload (h)	150		
Class attendance (h)	28	**Self studying (h)**	122
Compulsory requirements			
Recommended requirements	Basic knowledge in materials science is needed to successfully participate in this module.		
Expected performance/ Type of examina-tion	2 examination elements: a) ceramics: written exam (60 min) or oral exam (20 min) (to be weighted 1/2 in the calculation of module mark) b) polymers: written exam (60 min) or oral exam (20 min) (to be weighted 1/2 in the calculation of module mark)		
Course achievement			
Module grade composition	2 examination elements: a) ceramics: written exam (60 min) or oral exam (20 min) (to be weighted 1/2 in the calculation of module mark) b) polymers: written exam (60 min) or oral exam (20 min) (to be weighted 1/2 in the calculation of module mark)		

Contents

Ceramics:
- Non-metallic, anorganic materials, powder production routes, molding, sintering and application, proper-ties, materials testing and design criteria
- silicate ceramics:
  - materials: cordierite, steatite, porcelain
  - applications in electronics, heat engineering and catalysts
- oxide ceramics
  - materials: Al2O3, ZrO2; Al2TiO
  - applications in electronics, mechanical engineering, automotive industry and fuel cells
- Non-oxide ceramics
  - materials, production and properties: SiC, Si3N4, AlN
  - applications in mechanical engineering, heat engineering, and electronics
- design criteria
- Active ceramics:
  - materials, production and properties: piezo-ceramics and ferrites
  - application in electronics

Polymers:
- Composition, production and processing of polymers including energy consumption needed for polymer production
- Deformability of polymers, mechanical, physical and chemical properties, especially their weatherability and chemical stability

- Design criteria with respect to differences to metallic materials, maintenance of polymer parts, failure analyses and prevention of failures

Objective qualification

The students are able to list the different technical porcelains, ceramics and polymers (thermoplasts, elastomers and duromers) and can describe their chemical, physical and mechanical properties. The students are able to classify a non-metallic material (with respect to the classes given above). The students are able to name the different production chains for ceramic materials and polymers und explain which production process should be applied to produce a dedicated component. The students are able to name, understand and analyse the design principles for ceramic materials at component examples. The students are able to perform a correct selection of a non-metallic material for a given application. The students understand which non-metallic material can be used for a given application and are, therefore, able to work with these materials in their future jobs.

Literature

Keramische Werkstoffe:
- D. Munz, T. Fett, "Mechanisches Verhalten keramischer Werkstoffe", Springer, 1989
- CeramTec, #Technische Keramik#, Süddeutscher Verlag onpact, 2010
- Es steht ein ausführliches Skript und ein Handbuch für keramische Werkstoffe zur Verfügung.

Polymere:
- Menges / Schmachtenberg / Michaeli / Haberstroh: Werkstoffkunde Kunststoffe, ISBN 3-446-21257-4, Carl Hanser Verlag 2002
- Oberbach: Saechtling Kunststoff Taschenbuch, ISBN: 3-446-22670-2, Carl Hanser Verlag 2004
- Frank: Kunststoff-Kompendium, ISBN: 3-8023-1589-8, Vogel Fachbbuchverlag 2000
- Braun: Kunststofftechnik für Einsteiger, ISBN 3-446-22273-1, Carl Hanser Verlag 2003
- Braun: Erkennen von Kunststoffen, Qualitative Kunststoffanalyse mit einfachen Mitteln, Carl Hanser Verlag 2003
- Gächter / Müller: Kunststoff-Additive, ISBN: 3-446-15627-5, Carl Hanser Verlag 1989
- Bargel / Schulze: Werkstoffkunde, Springer Verlag 2004
- Potente: Fügen von Kunststoffen, Grundlagen, Verfahren, Anwendung, ISBN: 3-446-22755-5, Carl Hanser Verlag 2004

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Related courses

Rules for the choice of courses

Both lectures have to be attended.
Lecture Polymers: winter term
Lecture Ceramics: summer term.

The order of assignment is optional.

Compulsory attendance

Name of the course	SWS	Eventtype	Language
	1,0	Block course	german
	1,0	Lecture	german

Title	Life Cycle Assessment for Sustainable Engineering		
Number	2545020	**Module version**	v2
Shorttext		**Language**	english
Frequency of offer	only in the winter term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	1	**Institution**	Institut für Werkzeugmaschinen und Fertigungstechnik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Christoph Herrmann
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Recommended requirements	• Ideally, students have prior knowledge about matrix calculations (e.g. matrix multiplication) • Students know the empirical formulae of common substances (e.g. CO2, H20		
Expected performance/ Type of examination	written exam+ (120 min) or oral exam+ (30 min)		
Course achievement	presentation and/or written report in the context of a teamproject (On application, the result of the course achievement is taken into account in the assessment of the written examination+ or of the oral examination+, respectively, and can account maximum 20% of the respective grade.)		

Contents

- Necessity for quantifying environmental impacts
- Concept of life cycle thinking
- Sensitization for problem shifting
- Foundations and application of the life cycle assessment methodology
- Structure of an LCA according to the ISO 14040/14044
- Advantages and disadvantages of the methodology, applications and configurations

Objective qualification

Students...

- are able to conduct a Life Cycle Assessment (LCA) according to the ISO 14040/14044 standard
- are able to analyze an existing LCA study regarding the strength of its results and potential weaknesses of the study
- communicate LCA results to laypeople, and include relevant assumptions, limitations and boundary conditions in their communication
- know the modeling choices which need to be made as part of a LCA, and what should inform their decisions regarding these choices
- are able to identify, comprehend, refine and present relevant information regarding a given topic within the domain of LCA
- can, provided with adequate data, use LCA software to produce meaningful LCA results
- know how to organize themselves within a group project, which includes effective communication, sharing of workloads and the timely completion of tasks

Literature

- HAUSCHILD, Michael Z.; ROSENBAUM, Ralph K.; OLSEN, Stig Irvin. Life cycle assessment. Springer, 2018.

- ISO 14040:2006 Environmental management — Life cycle assessment — Principles and framework

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
	2,0	Lecture	english
	1,0	Exercise	

Title	Material Cycles of Energy Storage Systems and Converters		
Number	2521000060	**Module version**	
Shorttext		**Language**	english
Frequency of offer	only in the summer term	**Teaching unit**	Fakultät für Maschinen-bau
Module duration	1	**Institution**	Institut für Partikeltech-nik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Sabrina Zell-mer
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Expected performance/ Type of examina-tion	1 examination element: written exam (90 min) or oral exam (30 min)		
Course achievement			

Contents

Ressource – General
- Importance of resource availability
- Knowledge of resource availability and extraction areas
- Classification in the energy storage and conversion sector
- Assessment of ecological and economic aspects of resource extraction

Ressource - Economy
- Status Quo
- Raw material requirements (Europe, DE, worldwide); objectives of European/national strategies
- Requirements for raw materials/resources: regulation & legislation (Europe, DE, worldwide)

Dismantling and processing
- Mining (machines, energy supply, ...)
- Raw material processing
- Material synthesis
- Product manufacturing

Materials - Utilisation / areas of applicationMaterialien - Nutzung / Einsatzbereiche
- Overview of energy storage systems and converters
- Design of energy storage systems and converters depending on the materials used
- Structure and materials of today's battery cells and systems
- Brief overview: Energy storage and conversion process chain

Recycling (End-of-Life)
- Dismantling
- Mechanical and thermal processing methods
- Hydro- and pyrometallurgical treatment processes
- Direct vs. indirect recycling

Recycling (Scrap recycling)Ausschuss)
- Definition and origin of production waste
- Preparation process for production waste

Recirculation/Resynthesis
- Resynthesis / Reconditioning
- Product manufacture from secondary materials

Characterisation / traceability
- Tracking and tracing
- Analysis methods for evaluating, among other things, the country of origin (e.g. isotope analysis)
- Battery passport

Objective qualification

Students will gain knowledge of the extraction of raw materials and the processing of materials into components for the production of energy storage systems and converters. On the one hand, the focus is on the different countries in which raw materials are extracted, the processes of raw material extraction (including mining), the traceability of materials (traceability, transport chains) and the processing methods to produce suitable materials for energy storage systems and converters. On the other hand, the focus is on the return of materials from use, i.e. at the end of their life cycle. Different recycling processes (dismantling, mechanical, thermal, hydro- and pyrometallurgical treatment processes) and the subsequent return of the recycled materials to production processes of lower, equal or higher value are covered.
Upon completion of the lecture and the tutorial, students will be able to: identify mining, production and recycling processes and describe the general interdependencies along the entire value chain; recognise the importance of raw material recycling and traceability of raw materials along the supply chain; identify and explain relevant technologies; and discuss and reflect on key characteristics of factors influencing the transformation of the energy sector.

Literature

- Müller, Melanie, et al. "From competition to a sustainable raw materials diplomacy: Pointers for European policymakers." (2023): 48.
- Barman, P.; Dutta, L.; Azzopardi, B. Electric Vehicle Battery Supply Chain and Critical Materials: A Brief Survey of State of the Art. Energies 2023, 16, 3369. https:// doi.org/10.3390/en16083369
- Wang, Yun, et al. "Materials, technological status, and fundamentals of PEM fuel cells–a review." Materials today 32 (2020): 178-203.

Remark

The language of the lecture will be set each semester at the start of the lecture.
The course material is available in English.

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Related courses

Rules for the choice of courses

Compulsory attendance

Name of the course	SWS	Eventtype	Language
Material Cycles of Energy Storage Systems and Converters	2,0	Lecture	english german
	1,0	Exercise	english german

Title	Methods of Process Modelling and Optimization		
Number	2520460	**Module version**	
Shorttext		**Language**	german
Frequency of offer	only in the winter term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	1	**Institution**	Institut für Energie- und Systemverfahrenstechnik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Daniel Schröder
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Expected performance/ Type of examination	1 Examination element: Written exam (120 min) or oral examination (30 min)		
Course achievement	1 Course achievement: Project portfolio for the team project		

Contents

Lecture:
- Introduction to process modelling
- Physical deterministic process modelling
- Empirical process modeling and system identification
- Stochastic modelling
- Process optimization

Exercise: In the exercise the theory from the lecture will be applied to process engineering and bioengineering problems. Example calculations of modelling and optimization problems will be performed. Additionally, the implementation and simulation of the aforementioned process models in Matlab will be practiced by the students.

Objective qualification

Students can explain the differences between deterministic physical, empirical and stochastic modeling. They are able to analyze process engineering, chemical and biotechnological processes and select suitable model approaches for answering specific questions. Students know different types of empirical process models and can apply them to calculate model parameters based on given data. They can also design and analyze stochastic models for simple example systems. Students can independently develop physical models from a process description and use them to evaluate and optimize processes. Furthermore, they can implement the models in the Matlab software and analyze and interpret the simulation results.

Literature

- B. Roffel, B. Betlem, Process Dynamics and Control: Modeling for Control and Prediction, 2007, Wiley
- B. Ogunnaike, W.H. Ray, Process Dynamics, Modelling, and Control, 1994, Oxford University Press
- S. Skogestad, Chemical and Energy Process Engineering, 2008, CRC Press
- D. M. Imboden, S. Koch, Systemanalyse: Einführung in die mathematische Modellierung natürlicher Systeme, 2008, Springer R. Isermann, Identifikation dynamischer Systeme Bd. 1, 1992, Springer
- H. Bungartz et al. Modellbildung und Simulation, 2009, Springer
- M. Papageorgiou et al., Optimierung: statische, dynamische, stochastische Verfahren für die Anwendung, 2012, Springer

- Umdruck zur Vorlesung

↑

Related courses
Rules for the choice of courses
The additional tutorial course is a voluntary offer so that students can receive support in learning a programming language; it is only offered if necessary and is not essential for achieving the learning goals.
Compulsory attendance

Name of the course	**SWS**	**Eventtype**	**Language**
	2,0	Lecture	german
	1,0	Exercise	german
	0,5	Tutorial	german

Title	Microscopy and Particle Measurement in Micro- and Nanoscale		
Number	2521080	**Module version**	
Shorttext		**Language**	german
Frequency of offer	only in the winter term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	1	**Institution**	Institut für Partikeltechnik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Arno Kwade
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements	none		
Recommended requirements	none		
Expected performance/ Type of examination	1 Examination: written exam (90 min) or oral exam (30 min)		
Course achievement			

Contents

The lecture deals with the principles of different microscopy methods and presents techniques for particle size analysis. The following microscopy methods are covered:

- Light microscopy (including fluorescence and confocal microscopy)
- Electron microscopy (including sample preparation)
- Scanning probe microscopy (STM and AFM).

In the field of particle size analysis, the following contents are covered:

- Calculation, display and conversion of particle size distributions
- Sedimentation process (e.g. disc centrifuge)
- separation processes (e.g. sieve analysis, field-flow fractionation)
- Counting methods (e.g. image analysis, scattered light counter)
- Surface processes (e.g. flow-through processes like Blaine)
- Methods that use the influence of waves (e.g. laser diffraction spectrometry, photon correlation spectrometry, ultrasonic spectrometry, etc.)
- Development of a particle size analysis method

During the exercise, the contents learned are consolidated through repetitions, practical exercises and sample calculations.

Objective qualification

After completing the module, students will be able to describe the setup and operation of optical microscopes and explain the relationship between beam path and image generation or contrasting. Based on this, they will be able to select suitable microscopic techniques and parameters for biological as well as technical applications. The students are able to sketch the setup of electron microscopes and explain the functionalities of the individual modules. They will be able to reproduce the individual interactions that occur when electrons strike matter and link them to the various detectors of the instrument. Students will know the requirements for electron microscopic specimens and be able to select appropriate preparation techniques. Students will be able to explain the function of all common methods for particle size analysis and will be able to derive criteria for selecting a measurement method based on the material system under investigation. They will be able to convert obtained particle size distributions and calculate characteristic values. The students know the construction and the mode of operation of selected scanning probe microscopes (STM and AFM) and can explain different measuring modes. They are able to critically evaluate measurement results and interpret the results. The students are able to prepare and present work results in groups.

Literature

- Bonnell, D. (2001) Scanning Probe Microscopy and Spectroscopy - Theory, Techniques, and Applications, Wiley-VCH, New York
- Flegler, S. L.; Heckman, J. W. und Klomparens, K. L. (1995) Elektronenmikroskopie, Grundlagen Methoden Anwendungen, Spektrum Akademischer Verlag
- Heidelberg. Stieß, M. (1992), Mechanische Verfahrenstechnik 1, Springer Verlag, Berlin. Vorlesungsskript

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Related courses

Rules for the choice of courses

Compulsory attendance

Name of the course	SWS	Eventtype	Language
	2,0	Lecture	german
	1,0	Exercise	german

Title	Modeling and Simulation of hydrogen-based Energy Systems		
Number	2519000020	**Module version**	
Shorttext		**Language**	english
Frequency of offer	only in the winter term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	1	**Institution**	Institut für Thermodynamik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Thomas Koller
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Expected performance/ Type of examination	1 examination element: oral exam (30 min) or written exam (120 min)		
Course achievement			

Contents

Lecture:

- Overview of hydrogen-based energy systems (e.g., fuel cell and electrolysis systems, hydrogen storage systems and refueling stations, hydrogen liquefaction plants), their components, and dynamic modes of operation
- Overview of relevant fluids (including hydrogen and possible derivatives such as ammonia, relevant reactants and products, heat transfer fluids), their thermophysical properties, and corresponding calculation methods and model libraries
- Overview of relevant balance equations and transport processes for heat, mass, and momentum transport, including relevant calculation procedures
- Derivation and parameterization of complex system models using existing building blocks (e.g., component and subsystem models) based on system flowsheets and component data
- Implementation of control loops for steady-state and dynamic operation
- Exemplary simulation of various hydrogen-based energy systems to address questions regarding performance, efficiency, and mode of operation
- Options for visualizing simulation results in dedicated presentation formats

Exercise: Using selected examples, students apply the theoretical principles learned in the lecture and solve the problems presented in the exercises on the computer.

Objective qualification

Students will#...

- gain a comprehensive understanding of hydrogen-based energy systems and their dynamic operation.
- gain an overview of relevant fluids in hydrogen-based energy systems (including hydrogen and possible derivatives, relevant reactants and products, heat transfer fluids), their thermophysical properties, and ways to incorporate these properties into system simulation models.
- gain an overview of relevant balance equations and transport processes (especially heat and mass transport) and their representation in system simulation models.
- gain an overview of relevant components of hydrogen-based energy systems and their operating principles.

- are able to create and parameterize complex system models based on system flowsheets using existing building blocks (e.g., component and subsystem models) and implement associated control loops.
- are able to answer given questions using the system models and independently derive further questions.
- are able to critically evaluate the simulation results generated and derive optimization measures for the system and its dynamic operation (e.g., with regard to performance, efficiency, and operating strategy).
- are able to prepare and document the simulation results in a suitable manner, both graphically and in text form.

Literature

Über weiterführende Literatur wird in der Vorlesung informiert.

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Related courses

Rules for the choice of courses

Compulsory attendance

Name of the course	SWS	Eventtype	Language
Modeling and Simulation of hydrogen-based Energy Systems	2,0	Lecture	english
Modeling and Simulation of hydrogen-based Energy Systems	1,0	Exercise	english

Title	Modern Batteries for BHT		
Number	2520000020	**Module version**	
Shorttext		**Language**	english
Frequency of offer	every term	**Teaching unit**	Fakultät für Maschinen-bau
Module duration	1	**Institution**	Institut für Energie- und Systemverfahrenstech-nik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Daniel Schrö-der
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Expected performance/ Type of examina-tion	1 examination element: written exam (90 min) or oral exam (30 min)		
Course achievement			

Contents

In the beginning of the course, key quantities and units, terminology, redox reactions, and Faraday's laws are introduced briefly. Building on this, electrochemical fundamentals such as electrolytes, galvanic and electrolytic cells, theoretical cell voltage, and half-cell/electrode potentials are explained. Subsequently, electrochemical kinetics are discussed and explained for porous electrodes. Furthermore, the importance of material selection and development for the production of modern battery systems is illustrated using selec-ted examples. In addition, selected characterization methods are presented, which are potentially used in material and electrode development as well as battery performance assessment, thereby enabling the deve-lopment of new modern batteries. A strong focus is thereby on materials and fundamentals of lithium ion batteries.

Objective qualification

With regard to energy storage in batteries, students acquire knowledge of the thermodynamic and kinetic fundamentals necessary to understand and describe electrochemical reactions happening at electrode-elec-trolyte interfaces. They become familiar with the key concepts and approaches of electrochemistry as well as important aspects of materials science and engineering, and learn how these are applied in selected applications, e.g., for lithium ion batteries. Furthermore, students gain the knowledge required to characte-rize materials and electrodes using selected, appropriate methods, enabling them to identify and optimize new materials and processes for modern batteries.

Literature

- C.H. Hamann, W. Vielstich, Electrochemistry, 4th edition, 2005, Wiley-VC
- C. Daniel, J.O. Besenhard, Handbook of Battery Materials, 2nd edition, 2011, Wiley-VCH
- T. Reddy, Linden's Handbook of Batteries, 5th edition, 2019, McGraw-Hill
- G. Wittstock, Lehrbuch der Elektrochemie, 1st edition, 2023, Wiley-VCH

Remark

This course is usually offered as block seminar over the course of one week with full-day teaching within the semester.

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
Modern Batteries for BHT	3,0	Lecture	english

Title	Molecular Simulation		
Number	2519060	**Module version**	
Shorttext		**Language**	german
Frequency of offer	only in the summer term	**Teaching unit**	Fakultät für Maschinen-bau
Module duration	1	**Institution**	Institut für Thermodyna-mik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Gabriele Raabe
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements	none		
Recommended requirements	none		
Expected performance/ Type of examina-tion	1 examination element: wtitten exam (90 min) oral exam of (30 min)		
Course achievement			

Contents

1. Fundamental concepts of statistical thermodynamics: ensembles, partition functions, partition function of the ideal gas, Maxwell-Boltzmann distribution of velocities;
2. Monte Carlo Simulation: Inportance Sampling, simulations in different ensembles, algorithms for phase equilibria simulations, biased sampling;
3. Molecular dynamics: finite- difference methods, computation of transport properties, simulations in diffe-rent ensembles, thermostats and barostats, simulation of molecules;
4. Molecular models: intra- and intermolecular interactions and their description, different force field approa-ches;
5. Simulation technics: setting up, periodic boundary conditions, neighbour lists, Ewald summation, running and analysing molecular simulations

Objective qualification

After completing this course, the students are able to explain the fundamental physical concepts of molecu-lar simulation and of the derived simulation algorithms. They can evaluate different simulation techniques and concepts of molecular modelling regarding their applicability for different simulation tasks. With the gai-ned knowledge, the students are able to perform both Monte Carlo and molecular dynamics simulations, and to analyse the simulation output to derive thermophysical and structural properties. They have acquired the skills to deepen their knowledge in a student's thesis in this field.

Literature

- Vorlesungsfolien als Umdruck
- Raabe, G. Molecular Simulation Studies on Thermophysical Properties, Springer 2017
- Allen, M. P., Tildesley, D. J.: Computer Simulation of Liquids. Oxford Science Publication, 2005
- Frenkel, D., Smit, B.: Understanding Molecular Simulation. From Algorithms to Applications. Academic Press, 2002
- Haile, J. M.: Molecular Dynamics Simulation. Elementary Methods. Wiley-Interscience, 1997

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
	2,0	Lecture	german
	1,0	Exercise	german

Title	Numerical simulation of reactive flows		
Number	2518000000	**Module version**	
Shorttext		**Language**	english
Frequency of offer	only in the winter term	**Teaching unit**	Fakultät für Maschinen-bau
Module duration	1	**Institution**	Institut für Flugantriebe und Strömungsmaschi-nen
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Jens Friedrichs
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Expected performance/ Type of examina-tion	2 Examination elements: 1. written exam (90 min) or oral exam (30 min) (to be weighted 3/5 in the calculation of the module grade) 2. written report on simulation applications (to be weighted 2/5 in the calculation of the module grade)		
Course achievement			
Module grade composition	2 Examination elements: a) Oral exam, 30 Minutes or written exam, 90 Minutes (to be weighted 3/5 in the calculation of the module grade) b) Written report on simulation applications (to be weighted 2/5 in the calculation of the module grade)		

Contents

1. Introduction on Linux basics commands
2. Introduction on the open-source tool Cantera
3. Hand-on training for calculation of thermodynamic properties and chemical kinetics using Cantera with Python interface
4.Overview of the finite volume method
5. Introduction to OpenFoam® code structure, library organization, and compilation environment
6. Overview of the simulation setup, boundary conditions, solver and postprocessing utilities
7. Hands-on training on 1D and 2D inert and reacting flow simulations
8. Hands-on training on implementation of additional transport equations
9. Post-processing with Paraview and validation of results

Objective qualification

Attending the course, the students will be able to:
- compute thermophysical properties and chemical kinetics of gas mixtures;

- understand fundamentals of the finite-volume method;
- generate meshes of simple geometrical configurations;
- perform 1D and 2D simulations of reacting flows;
- perform serial and parallel simulations;
- evaluate the results in a critical way by visualization and postprocessing flow features.

Literature

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Related courses

Rules for the choice of courses

Compulsory attendance

Name of the course	SWS	Eventtype	Language
Numerical simulation of reactive flows	3,0	Lecture/Exercise	english

Title	Numerical Methods of Differential Equations		
Number	2543020	**Module version**	
Shorttext		**Language**	german
Frequency of offer	only in the summer term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	1	**Institution**	Institut für Akustik und Dynamik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Sabine Langer
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Expected performance/ Type of examination	1 examination element: written exam (90 min)		
Course achievement			

Contents

Systems of linear equations, direct solvers, iterative solvers, interpolation, interpolation errors, quadrature formulas, numerical differentiation, one-step and multi-step methods for ordinary differential equations, convergence, consistency, partial differential equations

Objective qualification

The students are able to
1. name different solution strategies for solving differential equations.
2. explain the differences between the existing methods using a given example.
3. select suitable solution methods for given case studies.
4. calculate solutions of example problems with the a forementioned solution methods.
5. evaluate the calculated results based on reference solutions.
6. describe the validity limits of their solutions on the basis of the underlying assumptions and derive possible improvements.

Literature

- Hanke-Bourgeois, M. (2009). Grundlagen der Numerischen Mathematik und des Wissenschaftlichen Rechnens (3. aktualisierte Auflage.). Wiesbaden: Vieweg+Teubner Verlag / GWV Fachverlage GmbH, Wiesbaden.
- Bärwolff, G. (2016). Numerik für Ingenieure, Physiker und Informatiker (2. Auflage.). Berlin: Springer Spektrum. Dahmen.
- W., & Reusken, A. (2008). Numerik für Ingenieure und Naturwissenschaftler (2. korrigierte Auflage.). Berlin, Heidelberg: Springer-Verlag Berlin Heidelberg.

Remark

From the summer semester 2020, this module will replace the module "Modellierung und Numerik von Differenzialgleichungen" in the master#s courses of the Fakultät für Maschinenbau.

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
	2,0	Lecture	german
	1,0	Exercise	german

Title	Numerical Simulation (CFD)		
Number	2520140	**Module version**	
Shorttext		**Language**	german
Frequency of offer	only in the winter term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	1	**Institution**	Institut für Flugantriebe und Strömungsmaschinen
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Jens Friedrichs
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Recommended requirements	Fundamentals of fluid mechanics, turbulent flows		
Expected performance/ Type of examination	1 Examination element: Written exam (90 min) or oral examination (30 min)		
Course achievement			

Contents

lecture:
- system of balance equations
- fundamentals of turbulence modeling
- fundamentals of two phase flow
- discretization and numerical solving methods
- finite volume methods for solving balance equations
- solution of systems of algebraic equations
- boundary and initial conditions
- convergence and stability

exercise:
- overview concerning CFD codes
- workflow for preparation CFD simulations
- practical exercises using FLUENT
- evaluation of gained results
- validation and verification

Objective qualification

The students acquire a deeper knowledge of the mathematical principles of discretization and the numerical solution of the system of balance equations of technical flows and are able to explain them. They are able to establish physical connections to the discretization methods from the conservation equations and to classify the basic concepts of numerical methods. The students are able to name and explain the basic requirements for the use of numerical methods in practice. The students learn to apply appropriate models to solve complex flow problems and to evaluate the quality of computer simulations based on these models.

Literature

- Numerische Strömungsmechanik, Autoren: Ferziger, Joel H., Peric, Milovan, DOI 10.1007/978-3-540-68228-8

- Numerische Strömungsberechnung, Autor: Lechler, Stefan, DOI 10.1007/978-3-658-05201-0
- Numerical Computation of Internal and External Flows, Autor: Hirsch, Charles, ISBN: 978-0-7506-6594-0
- Statistical Turbulence Modelling for Fluid Dynamics # Demystified, Leschziner, Michael, ISBN: 978-1-78326-661-6

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
	2,0	Lecture	german
	1,0	Exercise	german

Title	Orientation Services Management		
Number	2201000000	Module version	
Shorttext		Language	english german
Frequency of offer	every term	Teaching unit	Carl-Friedrich-Gauß-Fakultät
Module duration	1	Institution	Institut für Automobilwirtschaft und Industrielle Produktion - Lehrstuhl für Dienstleistungsmanagement
Hours per Week / ECTS	4 / 5,0	Module owner	Prof. Dr. David Woisetschläger
Workload (h)	150		
Class attendance (h)	56	Self studying (h)	94
Compulsory requirements			
Expected performance/ Type of examination	1 portfolio or 1 take-home exam		
Course achievement	for Organization, Governance, Education / MA Social Sciences instead of the examination performance: 1 portfolio or 1 take-home exam		

Contents

Contents - depending on the course selection:

Strategic Brand Management & Brand Strategy Bootcamp
Contents of the lecture include
- Brand understanding and the importance of brands
- Measurement of brand associations
- Secondary brand associations
- Instruments for building brand associations
- Brand strategy and positioning
- Brand architecture
- Measuring brand performance
- International brand management
- Internal brand management
- Organizational aspects of brand management
- Sectoral specialties in retail, industrial goods and the luxury sector.

Contents of the exercise are:
Working on a real practical problem in the field of brand management in cooperation with a company partner.

Business Model Innovation & Service Innovation
Contents of the lecture include:
- Relevance, importance and understanding of business model innovations
- Organizational success factors and barriers
- Transformation of existing business models
- Methods of business model innovation
- Building blocks of business model innovation and related methods
- Sectoral aspects such as innovation in mobility

Contents of the exercise are:
Application of service innovation methods on a practical example.

Customer Relationship Management & Customer Analytics
Contents of the lecture include:
- Relevance, importance and understanding of customer relationship management
- Theoretical foundations of CRM
- Target indicators of CRM
- Lifecycle perspective of the customer relationship
- Acquisition and new customer management
- Customer loyalty programs
- Types and management of switching barriers
- Customer evaluation and segmentation
- Expansion of customer relationships
- Complaint management
- Termination prevention and reactivation management
- Customer data and privacy

Contents of the exercise include learning and applying methods
- to calculate customer value
- to evaluate the customer relationship (e.g. satisfaction, loyalty, recommendation)
- to calculate customer churn or the probability of churn
- to evaluate the success of promotions and reactivation measures

Objective qualification

Depending on the selected courses:

After successful participation, students will have a basic understanding of brands and knowledge of which aspects play a role in branding. In addition, they will understand and be able to critically discuss how brands are developed and positioned and which instruments are suitable for this. They can argue on the basis of theory why certain brand-related measures can be expected to have an effect and have methodological knowledge in order to measure the brand and quantify influencing factors. Students will be able to formulate precise problems and research questions based on a complex practical issue in the field of brand management and develop a solution to the problem using the content and methods learned in the lecture.

After successful participation, students have a basic understanding of business model innovation and know which factors play a role in the development of business model innovations. In addition, they will understand and be able to critically discuss how innovations are developed and which methods are suitable for this. They can argue on the basis of theory why certain corporate measures can be expected to have an effect on the success of innovation and have methodological knowledge to develop, evaluate and critically reflect on business model innovations themselves. Students can formulate precise problems and research questions based on a complex practical issue in the field of innovation management and develop solutions to problems using the content and methods learned in the lecture and taught in the exercise.

Students have an understanding of issues that arise in the context of recording, designing and evaluating customer relationships. Based on the concepts and methods they have learned, students will be able to independently record, conceptually structure and analyze customer relationship management issues in various industry contexts. They have methodological and application knowledge for the qualitative and quantitative analysis of customer and company data required to answer customer relationship management tasks.

Literature

Strategic Brand Management & Brand Strategy Bootcamp
- Keller, Kevin L. und V. Swaminathan (2019): Strategic Brand Management - Building, Measuring, and Managing Brand Equity, 5th ed., Prentice Hall
- Supplementary journal paper per chapter
- Lecture notes for download.
- Supplementary information and literature as bibliography and/or download for the exercise.

Business Model Innovation & Service Innovation

- Textbooks and further literature will be announced in the lectures
- Supplementary literature (PDF documents, lecture notes for download)

Customer Relationship Management & Customer Analytics

- Kumar, V. and Werner Reinartz (2018): Customer Relationship Management: Concept, Strategy, and Tools, 3. ed., Springer.
- Textbooks and further literature will be announced in the lectures
- Supplementary literature (PDF documents, lecture notes for download)

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Related courses

Rules for the choice of courses

Students must choose a course from the following program:

- Strategic Brand Management & Brand Strategy Bootcamp
- Business Model Innovation & Service Innovation
- Customer Relationship Management & Customer Analytics

Compulsory attendance

Name of the course	SWS	Eventtype	Language
Business Model Innovation: Concepts and Applications	4,0	Lecture/Exercise	english
Strategic Brand Management: Concepts and Applications	4,0	Lecture/Exercise	german
Customer Relationship Management and Customer Analytics	4,0	Lecture/Exercise	german

Title	Process Technology of Nanomaterials		
Number	2521500	**Module version**	
Shorttext		**Language**	english
Frequency of offer	only in the winter term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	1	**Institution**	Institut für Partikeltechnik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Georg Garnweitner
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Expected performance/ Type of examination	1 examination element: written exam (90 min) or oral exam (30 min)		
Course achievement			

Contents

Lecture and exercise:

- Introduction into the world of nanomaterials (types, structures, applications)
- fundamentals: size distributions, morphology, surface properties, stability, composition, properties of nanomaterials (size and surface effects, intrinsic properties)
- Characterization of nanomaterials
- fabrication methods (comminution, pyrolysis, plasma techniques, precipitation, sol-gel, nonaqueous syntheses) and engineering aspects about these methods
- stabilization of nanoparticles (mechanisms, experimental realization, characterization techniques, chemical fundamentals)
- functionalization of nanoparticles (customizing particle properties, phase transition, intelligent functionalization)
- application of nanomaterials (established applications as well as envisioned future applications)
- risks and toxicology of nanomaterials
- Special aspects of nanomaterials.

Objective qualification

After completion of this module, the students possess comprehensive knowledge about nano-materials and their process technologies for engineering of nanomaterials: They are able to define different categories of nanomaterials and nanoparticles, and explain the properties and benefits of nanomaterials for various applications. The students are capable of describing different production processes (specifically comminution, gas- and liquid-phase synthesis) and applying optimizations to these processes.

Literature

- H.-D. Dörfler: Grenzflächen- und Kolloidchemie; VCH-Verlag
- Weinheim G. Schmid (Ed.): Nanoparticles; Wiley-VCH Verlag
- Weinheim C.N.R. Rao, P.J. Thomas, G.U. Kulkarni: Nanocrystals - Synthesis, Properties, and Applications; Springer Verlag, Berlin.

Remark

This lecture will be held in English. Supplementary lecture notes are available in both English and German.

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Related courses			
Rules for the choice of courses			
alternative to MB-IPAT-23			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
	2,0	Lecture	english
	1,0	Exercise	english

Title	Production Technologies for Electromobility		
Number	2522540	**Module version**	
Shorttext		**Language**	german
Frequency of offer	only in the summer term	**Teaching unit**	Fakultät für Maschinen-bau
Module duration	1	**Institution**	Institut für Werkzeugma-schinen und Fertigungs-technik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Klaus Dröder
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Recommended requirements	Students know the fundamental relationships between electrical circuits		
Expected performance/ Type of examina-tion	1 Examination element: Written exam (120 min)		
Course achievement			

Contents

- Introduction to electric mobility
- Forms of electric mobility
- Overview of production technology
- Principles of production technology
- Focus of research and development of production technology
- Production of vehicles
- Comparison of the electric power unit and the combustion engine
- Types of electric vehicles
- Production of electric cars (Focus lightweight construction / power unit)
- Demands and challenges in the production of battery systems
- Functionalities and types of battery cells
- Components and hierarchy of high volt systems
- Production of battery cells Production of battery modules and #systems
- Production of electric engine
- Focus on assembly systems for HV components
- Safety and Protection
- Lightweight construction for the casing of a battery system
- Design of a battery system and associated production system

Objective qualification

Students are able to
#
- differentiate the specific components of an electric car from the components of a conventional car #
- deduce the effects of new components on the supply chains of the OEM and the automotive suppliers #
- plan basic production processes for the electric drivetrain taken into consideration the challenges in production technologies for electric vehicles #
  identify potentials for optimisation of assembly and disassembly of traction batteries #
- assign tasks in assembly according tot he qualification of the employees #

- name new production technologies for lightweight construction an the electric power unit, assign them to the correct position in the process chain, identify safety relevant tasks and take risk-reducing measures #
- work in multi-disciplinary teams

Literature

- Braess, Hans-Hermann; Seiffert, Ulrich (Hg.) (2013): Vieweg Handbuch Kraftfahrzeugtechnik. 7., aktual. Aufl. 2013. Wiesbaden, s.l: Springer Fachmedien Wiesbaden Dyckhoff,
- Harald; Spengler, Thomas S. (2010): Produktionswirtschaft. Eine Einführung. 3., überarb. und erw. Aufl. Berlin: Springer Friedrich,
- Horst E. (Hg.) (2013): Leichtbau in der Fahrzeugtechnik. Wiesbaden, s.l: Springer Fachmedien Wiesbaden Kampker,
- Achim; Vallée, Dirk; Schnettler, Armin (2013): Elektromobilität. Grundlagen einer Zukunftstechnologie. Berlin, Heidelberg: Springer Klein,
- Bernd (2013): Leichtbau-Konstruktion. Berechnungsgrundlagen und Gestaltung. 10., überarb. u. erw. Aufl. 2013. Wiesbaden, s.l: Springer Fachmedien Wiesbaden.
- Korthauer, Reiner (Hg.) (2013): Handbuch Lithium-Ionen-Batterien. Berlin, Heidelberg, s.l: Springer Berlin Heidelberg.
- Ponn, Josef; Lindemann, Udo (2011): Konzeptentwicklung und Gestaltung technischer Produkte. Systematisch von Anforderungen zu Konzepten und Gestaltlösungen. 2. Aufl. Berlin, Heidelberg: Springer-Verlag Berlin Heidelberg (VDI-Buch).
- Siebenpfeiffer, Wolfgang (Hg.) (2013): Energieeffiziente Antriebstechnologien. Hybridisierung - Downsizing - Software und IT. Dordrecht: Springer Wallentowitz,
- Henning; Freialdenhoven, Arndt (2011): Strategien zur Elektrifizierung des Antriebsstranges. Technologien, Märkte und Implikationen. 2., überarbeitete Auflage. Wiesbaden: Vieweg+Teubner Verlag / Springer Fachmedien Wiesbaden GmbH Wiesbaden

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Related courses

Rules for the choice of courses

Compulsory attendance

Name of the course	SWS	Eventtype	Language
	2,0	Lecture	german
	1,0	Exercise	german

Title	Plant and Process Safety		
Number	2541460	**Module version**	
Shorttext		**Language**	german
Frequency of offer	only in the summer term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	1	**Institution**	Institut für Chemische und Thermische Verfahrenstechnik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Stephan Scholl
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Expected performance/ Type of examination	1 examination element: written exam (90 min) or oral exam (30 min)		
Course achievement			

Contents

Lecture:
- Incidents and their causes
- risk management
- hazardous materials
- control of exothermic chemical reactions
- safety in process plants
- explosion protection.

Exercise:
Using case studies to develop practical issues. In a full-day excursion to an industrial plant manufacturer or operator of chemical plants, case studies can be practically comprehended.

Objective qualification

On completion of this module, students have knowledge of the safe and environment-friendly manufacture of chemical products. They have a basic knowledge of the recognition and assessment of hazards, building on a methodical approach to risk management. They can identify potential hazards based on systematic process and plant considerations and mitigate them through various plant safety measures. The students know the basic laws, ordinances and technical rules on plant safety. They acquire knowledge of the safe and competent handling of hazardous substances and of the fundamentals of technical fire and explosion protection.

Literature

- Trevor A. Kletz, Process Plants: A Handbook for Inherently Safer Design (Chemical Engineering)
- Lars Oliver Laschinsky, Explosionsschutz in der Praxis: Kozeption, Betrieb, Instandhaltung, Prüfung
- Alfons Mersmann et al., Thermische Verfahrenstechnik: Grundlagen und Methoden, Sringer Verlag, Berlin
- Vorlesungsscript

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
	3,0	Lecture/Exercise	german

Title			
Number	2541000000	**Module version**	
Shorttext		**Language**	english
Frequency of offer	only in the summer term	**Teaching unit**	Fakultät für Maschinen-bau
Module duration	1	**Institution**	Institut für Chemische und Thermische Verfah-renstechnik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Stephan Scholl
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Recommended requirements	Basic knowledge on the fundamentals of thermal separation processes: • concept of thermodynamic and chemical equilibrium • equilibrium-based and non-equilibrium mass transfer • concept of driving forces / gradients • two-film model • fundamentals of sorption processes (isotherms, adsorption/desorption, physisorp-tion, chemisorption) • properties of multi-phase systems • heat transfer, evaporation, condensation		
Expected performance/ Type of examina-tion	written exam (90 min) or oral exam (30 min)		
Course achievement			
Contents			
Based on the fundamentals of thermal or fluid separation processes or equivalent courses and the corre-sponding fundamentals covered therein, this lecture takes an in-depth look into the unit operations for sepa-ration and purification of fluid energy carriers. A short introduction covers common energy carriers, com-monly used production processes and resulting impurities. Specific use cases of separation and purification as well as their corresponding and specific challenges are discussed. Selected unit operations relevant for separation and purification of fluid energy carriers, such as adsorption, membrane-based separations, cryo-genic distillation and catalytic or electrochemical purification processes, are discussed in detail. The lecture is concluded with a primer on common analysis technologies used to determine mixture composition and impurities.			
Objective qualification			
The students are able to elaborate on the fundamentals of common unit operations used for separation and purification of energy carriers. They know the fundamental working principles, basic engineering and design methods and are able to select suitable unit operations based on mixture properties (composition, product specification) the separation task. They can work out a conceptual process and equipment design for a given separation task. Furthermore, the students know about common analysis methods, are able to elabo-rate on the underlying working principles and select suitable methods for a given mixture. Students are able to communicate their approach, rational and results in written and oral form.			
Literature			

J. D. Seader, E. J. Henley, K.D. Roper: Separation Process Principles. John Wiley & Sons, 2019.

H. Schön: Handbook of Purified Gases. Springer, 2015.

F. G. Kerry: Industrial Gas Handbook. CRC Press, 2007. • L. Kohl, R. Nielsen: Gas Purification. Gulf Publishing, 1997.

M. R. Rahimpour, M. A. Makarem, P. Kiani: Hydrogen Purification and Separation. CRC Press, 2024.

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
	2,0	Lecture	english
	1,0	Exercise	english

Title	Numerical Methods in Particle Technology		
Number	2521390	**Module version**	
Shorttext		**Language**	german
Frequency of offer	only in the winter term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	1	**Institution**	Institut für Partikeltechnik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Arno Kwade
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Expected performance/ Type of examination	1 Examination: written exam (90 minutes) or oral exam (30 minutes)		
Course achievement	1 course achievement: Participation at the practical simulation course.		

Contents

The lecture gives an overview of the different possibilities to describe processes with particles numerically and teaches the respective basics. In addition, the combination of the different methods for the application of multiphysics and multi-scale simulations is shown. Two of the most important methods, the Discrete Element Method and the Population Balance Method, are discussed in detail in order to be able to carry out own simulations based on them. In particular, the calibration of the model parameters and the model validation will be discussed.

The lecture is structured as follows:
- Overview of numerical methods of particle technology
- general balance equation
- population balances
- Computational Fluid Dynamics (Introduction)
- Discrete Element Method
- Finite Element Method (Introduction)
- Multi-physics and multi-scale models

In the exercise, the different numerical methods are deepened and the setting up of model equations for different processes, as well as the calibration of the model parameters and model validation are practiced.

In the simulation practical course, two DEM software packages "Rocky" and "EDEM" are used to simulate simple processes of particle technology. The possibilities of model calibration and validation are also tested.

Objective qualification

After completing the module, students are able to classify the simulation methods taught in this course into the appropriate size and time scales. They can name the models on which the simulation methods are based and discuss their applicability to real problems in particle technology. Furthermore, they are able to describe schematically the processes and algorithms involved in the implementation of the taught simulation methods. They can independently apply the concepts of the discrete element method to their own problems. They have the ability to analyze the influence of input variables on given force models by means of calculations. Various force and potential curves can be described by the students by means of sketches. The stu-

dents are also able to name the terms of given basic equations in numerical fluid mechanics, CFD-DEM coupling and population balance methods in the context of particle simulation and to explain their meaning.
Literature
Stein, E., De Borst, R., Hughes, T. J. R.: Encyclopedia of Computational Mechanics. WILEY-VCH, 2004 Wriggers, P.: Computational Contact Mechanics. Springer, 2006 Mohammadi, S.: Discontinuum Mechanics: using Finite and Discrete Elements. Computational Mechanics, 2003

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Related courses
Rules for the choice of courses
The course achievements are necessary to complete the module, but not a prerequisite for participation in the exam. The overall grade of the module is only calculated from the examination performance.
Compulsory attendance

Name of the course	SWS	Eventtype	Language
	1,0	Lecture	german
	1,0	Exercise	german
	1,0	Internship	german

Title	Smart Sensing in Fluid Dynamics		
Number	2512000110	**Module version**	
Shorttext		**Language**	english
Frequency of offer	every term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	1	**Institution**	Institut für Strömungsmechanik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. David Rival
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Expected performance/ Type of examination	1 examination elemnt: oral exam (30 min) (to be weighted with 30% in the calculation of module mark)		
Course achievement	2 course achievements: a) Lab report (to be weighted with 40% in the calculation of module mark); b) project presentation (to be weighted with 30% in the calculation of module mark)		

Contents

Advanced Measurement techniques:
- Particle image velocimetry (PIV) and Lagrangian tracking (Tomo-PIV, Shake-The-Box (STB))
- Pressure- and temperature-sensitive paints (PSP/TSP) for surface flow measurements
- Event based cameras (EVB-cameras) – principles and applications
- Sparse sensing

Advanced Post-Processing:
- Image processing and image enhancement
- Uncertainty quantification and error analysis

Advanced Data Treatment:
- Optimal design of experiments (DoEs) and active learning (AL)
- Reconstruction of sparse data via machine-learning techniques
- Using modal decomposition techniques (POD, DMD) to analyze flow structures
- Algorithms for online data assimilation
- Information fusion from heterogeneous experimental and numerical sources (multi-fidelity sensing)

Capstone Project:
- Students will design, execute, and analyze an independent measurement experiment using the techniques learned in the course

Objective qualification

By attending the module, students will be able to:
- Understand the physical principles, advantages, and limitations of state-of-the-art and emerging measurement techniques
- Gain hands-on experience with related experimental methods and setups
- Work with cutting-edge experimental tools to capture high-fidelity data
- Learn best practices for equipment calibration, data acquisition, and signal pre-processing

- Develop expertise in advanced post-processing methods, including spectral analysis, modal decomposition, and uncertainty quantification and error analysis
- Use advanced data treatment techniques including sparse reconstruction, data assimilation and multi-fidelity sensing

Literature

1. Raffel et al. (2018): Particle Image Velocimetry
2. Liu et al. (2021): Pressure and Temperature Sensitive Paints
3. Brunton and Kutz (2019): Data-Driven Science and Engineering: Machine Learning, Dynamical Systems, and Control

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Related courses

Rules for the choice of courses

Compulsory attendance

Name of the course	SWS	Eventtype	Language
Smart Sensing in Fluid Dynamics	2,0	Lecture	english
Smart Sensing in Fluid Dynamics	1,0	Laboratory	english

Title	Specialisation Law		
Number	2216360	**Module version**	V3
Shorttext		**Language**	german
Frequency of offer	every term	**Teaching unit**	Carl-Friedrich-Gauß-Fakultät
Module duration	1	**Institution**	Institut für Rechtswissenschaften
Hours per Week / ECTS	4 / 5,0	**Module owner**	Prof. Dr. Anne Paschke
Workload (h)	150		
Class attendance (h)	56	**Self studying (h)**	94
Compulsory requirements			
Expected performance/ Type of examination	1 exam (120 min) or 1 take-at-home exam		
Course achievement	for Organisation, Governance, Education / MA Social Sciences instead of the examination: 1 written exam (120 min) or 1 take-at-home exam		

Contents

The content depends on the choice of specialisation:

In the Public Law specialisation, the basic principles of energy law are taught in Energy Law I and Energy Law II.
The Energy Law I course serves to present the fundamentals of energy law at European and German level. At the beginning of the course, the development of energy law in recent decades is presented. The lecture focuses on the regulation of grid operation and related topics such as unbundling, grid connection, grid utilisation and grid utilisation fees. The main contractual structures of energy supply relationships and the position of end consumers in the energy industry will be the subject of the course. A further focus is on the supply of end consumers, e.g. basic supply and contract adjustment options. The lecture is designed to be interactive and offers the opportunity for discussion. The topics discussed will be illustrated using numerous practical cases.

The Energy Law II lecture is primarily dedicated to the law of the ‘energy transition’. It complements the Energy Law I lecture - however, it is not essential to have attended Energy Law I beforehand. One focus of the lecture is the introduction to the law of renewable energies (EEG) including historical developments and European references, including expansion targets, connection and feed-in priority, tenders/tariffs and financing, as well as an in-depth look at the specific legal situation of onshore and offshore wind turbines (including planning and approval, contract design). The event will also cover the most important legal foundations for the expansion of the electricity grid (from the Energy Industry Act, EnLAG, NABEG, BBPlG). Finally, there will be an opportunity to look at current developments in energy law, e.g. with regard to sector coupling or green hydrogen. The lecture is designed to be interactive and offers the opportunity for discussion. The topics discussed will be illustrated using numerous practical cases.

Depending on the students' choice, the Civil Law specialisation teaches content from public procurement law, patent and trademark law and IT security law.
In the Patent and Trade Mark Law lecture, students learn the basics of German and European patent law, the relevant patenting requirements and procedures at the German Patent and Trade Mark Office (DPMA) and the European Patent Office (EPO). The requirements for patenting and the corresponding case law are then applied and analysed in particular to computer-implemented inventions, i.e. especially inventions that

contain a substantial amount of software. To a lesser extent, utility models and their differences to patents as well as registered designs and Community designs are also discussed.

The lecture on public procurement law deals with the scope and procedure of public procurement procedures as well as the legal protection options under public procurement law. It is based on the regulations of EU procurement law (cartel procurement law) in accordance with Part 4 of the GWB and the VgV. However, excursions into sub-threshold procurement law and the special procurement regimes of sector contracts, defence and security-related contracts and concessions will be made at appropriate points. An initial focus of the lecture is on the question of the cases in which public procurement law is applicable and, if applicable, which public procurement law regime is to be applied. On the basis of upper-threshold procurement law, an overview of the procedure is given, starting with the possible types of procedure, the requirements to be met by bidders and the subject matter of the contract, the necessary notices, through to the evaluation of bids and the conclusion of the award procedure. Finally, the legal protection options under public procurement law (primary and secondary legal protection) are dealt with in detail. The lecture takes into account current developments in public procurement law and deals with the respective topics using examples from public procurement law practice.

The IT security law lecture examines one of the key areas of the coming decades from a legal perspective. Students will learn about the legal framework conditions that govern the introduction and maintenance of appropriate IT protection standards. They will also learn how IT security risks are distributed at a contractual level. The unit conveys a holistic approach and enables students to independently develop scientific and practice-orientated solutions together with the relevant specialist literature in order to supervise the necessary information technology steps.

Objective qualification

The courses teach the following theoretical legal content in order to enable graduates to independently identify the relevant legal standards in their respective specialist area and to make subject-related legal decisions taking into account the current legal situation and to present these in a scientific and practice-oriented manner in writing and orally. Only the application-orientated integrative consideration of legal requirements and technical processes enables legally compliant company/product/production design (compliance).

After completing the module in the Public Law specialisation, students will be able to independently deal with the specialist laws in energy law and identify relevant legal norms. Here, technical examples from other lectures are taken up and jointly assessed on the basis of the existing legal situation. They will also learn the sector-specific "state of the art" with examples from technical practice.

After completing the module in the specialisation Civil Law, students will be able to independently find the specialist laws and relevant standards relevant to them and solve legal issues in public procurement law, patent and trademark law and/or IT security law by working with the law. After completing the module, students are sensitised to the content of the lectures in order to be able to participate in public procurement procedures and are sufficiently qualified to ask the right questions in practice in the context of patent and trademark law procedures.

Literature

For the Public Law specialisation:

Legal texts:
- Energierecht, dtv. Beck, 17. Aufl. 2022

Textbooks:
- Kühling/Rasbach/Busch, Energierecht, 5. Aufl. 2022
- Baumgart, Energierecht, 2022

For the civil law specialisation:

Legal texts:

Public procurement law, dtv. Beck, 25th ed. 2022
Patent and design law, dtv. Beck, 16th ed. 2022
Competition law, trade mark law and antitrust law, dtv. Beck, 44th ed. 2022
Textbooks:
Naumann, Public Procurement Law, 2nd ed. 2022
Burgi, Public Procurement Law, 3rd ed. 2021
Samer, The new patent law, 2022
Ann, Patent Law, 8th ed. 2022
Hornung/Schallbruch (ed.) IT Security Law, 2020

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Related courses

Rules for the choice of courses

One of the two specialisations must be chosen (the same specialisation that was taken in the orientation must be chosen).

Public law:
Energy Law 1
Energy Law 2
Civil law: (2 of the 3 courses must be chosen)
IT security law
Patent and trade mark law
Public procurement law

Students on the Sustainable Energy Technology Master's programme can only choose the Public Law specialisation.

Compulsory attendance

Name of the course	**SWS**	**Eventtype**	**Language**
Energy Law 1	2,0	Lecture	german
Energy Law 2	2,0	Lecture	german
IT Security Law	2,0	Lecture	german
Patent Law and Trademark Law	2,0	Lecture	german

Literature

- Patent and Design Law (dtv-Beck)
- Competition and Antitrust Law (dtv-Beck)

Procurement Law	2,0	Lecture	german

Title	Materials engineering for the Circular Economy		
Number	2537000020	**Module version**	
Shorttext		**Language**	german
Frequency of offer	only in the summer term	**Teaching unit**	Fakultät für Maschinen-bau
Module duration	1	**Institution**	Institut für Füge- und Schweißtechnik
Hours per Week / ECTS	3 / 5,0	**Module owner**	Prof. Dr. Klaus Dilger
Workload (h)	150		
Class attendance (h)	42	**Self studying (h)**	108
Compulsory requirements			
Expected performance/ Type of examina-tion	1 Examination element: written exam (120 min)		
Course achievement			

Contents

Consolidation of fundamentals and applications considering the Circular Economy for materials with the fol-lowing focus:
- Emission reduction
- Sustainable and conventional material extraction

Reuse of materials:
- Resource efficiency through composite materials
- Application in Industry

Emission reduction:
- REX Methods (reduce, reuse, repurpose, repair, remanufacture, recycle, and recover)
- Classical and numerical process optimisation (Lean Six Sigma, Optimisation using artificial intelligence (AI))
- Life Cycle Analysis

Sustainable and conventional material extraction:
- Innovative and climate-friendly methods for metal extraction (e.g., green steel, magnesium continuous casting)
- Plastics and other non-metals

Reuse of materials:
- Plastics (thermoplastics, elastomers, thermosets)
- Light metals (aluminum, titanium, magnesium)

Ressource efficiency through composite materials:
- Fiber-reinforced composites and sandwich composites:
- Coatings

Application in industry:
- E-Mobility
- Packaging industry

Objective qualification
After the completion of this module, the students should be able to master the theoretical basics for the usage of common engineering materials in the circular economy. The hereby gained knowledge should enable students the assessment and application of production methods. Furthermore, the students should be able to optimise production processes under consideration of technological and ecological aspects and put conventional processes in regard to more sustainable alternatives.

Literature
1. Deutsche Normungsroadmap Circular Economy. Online verfügbar unter https://www.din.de/resource/blob/892606/06b0b608640aaddd63e5dae105ca77d8/normungsroadmap-circular-economy-data.pdf vom 02.09.2024. 2. Habenicht, G.: Kleben - Grundlagen, Technologien, Anwendungen. Springer Verlag, 2006 3. Brockmann, W., Geiß, P.L., Klingen, J., Schröder, B.: Klebtechnik - Klebstoffe, Anwendungen und Verfahren. Wiley - VCH Verlag, 2005 4. Müller, B., Rath, W.: Formlierung von Kleb- und Dichtstoffen. Vincentz Verlag, 2004 5. Mulvaney, Dustin; Richards, Ryan M.; Bazilian, Morgan D.; Hensley, Erin; Clough, Greg; Sridhar, Seetharaman (2021): Progress towards a circular economy in materials to decarbonize electricity and mobility. In: Renewable and Sustainable Energy Reviews 137, S. 110604.

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
Materials engineering for the Circular Economy	1,0	Exercise	german
Materials engineering for the Circular Economy	2,0	Lecture	german

Laboratory A

Title	Interdisciplinary Research Lab Battery		
Number	2520000010	**Module version**	
Shorttext		**Language**	english german
Frequency of offer	every term	**Teaching unit**	Fakultät für Maschinen-bau
Module duration	1	**Institution**	Institut für Thermodyna-mik
Hours per Week / ECTS	4 / 6,0	**Module owner**	Prof. Dr. Thomas Koller
Workload (h)	180		
Class attendance (h)	56	**Self studying (h)**	124
Compulsory requirements			
Expected performance/ Type of examina-tion	1 examination element: term paper		
Course achievement	1 Course Achievement: colloquium		
Module grade composition	The three module parts are graded based on the oral test before laboratory and the respective section of the final report. Each section is graded by the individual insti-tute. Each student is responsible for a certain section and he / she will prepare and write his / her respective section as the final report. For the part of InES, students must write this report and take the oral test in English. The final grade of every student is individually determined by his / her oral test and section report.		

Contents

This research module aims to strengthen a further understanding of energy engineering and chemical engi-neering. To both train students# theoretical and practical research abilities, we provide production process, experimental characterization and simulation in this module. In detail, the module is divided into 3 sections: Firstly, students will manufacture electrodes, and characterize them and assemble cells at iPAT; secondly, students test battery performances experimentally and simulate them at InES; in the end, students do a thermal simulation and measurement in ifT to validate and understand thermal behavior of lithium-ion batte-ries.

Objective qualification

Students will learn the production chain for manufacturing batteries. By conducting experiments and simula-tion, students will gain knowledge of properties and processes in batteries. In the project, they will improve their ability of communication, teamwork and professional expression, besides laboratory working skills.

Literature

Beispiele:

- Birke, Kai Peter, Max Weeber, and Michael Oberle, eds. Handbook on smart battery cell manufacturing: the power of digitalization. World Scientific, 2022.
- Kanamura, Kiyoshi, ed. Next generation batteries: realization of high energy density rechargeable batte-ries. Springer Nature, 2021.

Remark
The three module parts are graded based on the oral test before laboratory and the respective section of the final report. Each section is graded by the individual institute. Each student is responsible for a certain section and he / she will prepare and write his / her respective section as the final report. For the part of InES, students must write this report and take the oral test in English. The final grade of every student is individually determined by his / her oral test and section report.

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
Interdisciplinary Research Lab Battery	4,0	Laboratory	english german

Title	Interdisciplinary Research Lab Hydrogen		
Number	2521000100	**Module version**	
Shorttext		**Language**	english german
Frequency of offer	every term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	1	**Institution**	Institut für Partikeltechnik
Hours per Week / ECTS	4 / 6,0	**Module owner**	Prof. Dr. Michael Heere Prof. Dr. Sabrina Zellmer
Workload (h)	180		
Class attendance (h)	70	**Self studying (h)**	140
Compulsory requirements			
Recommended requirements	Module "Hydrogen Technology and Laboratory Hydrogen Escape Room" (2521000040		
Expected performance/ Type of examination	1 examination element: term paper		
Course achievement	1 course achievement: colloquium		

Contents

The laboratory teaches practical research topics and industrial application examples along the hydrogen value chain, linked to real infrastructures: The NFF Braunschweig has a complete infrastructure for the construction of fuel cells with various components (MEA and BPP manufacturing). After the actual assembly of the fuel cells and corresponding preliminary tests, experimental investigations are carried out on a single-cell fuel cell test bench. Specifically, the investigations include conditioning, running-in, and a range of electrochemical characterization methods. At the same time, students develop a mathematical model to describe fuel cell performance and learn to validate their models using the measurement data they have obtained themselves. ML methods are provided to the students here, for example, to perform a temporal estimation of degradation. At the Hydrogen Campus Salzgitter, the stacking system for fuel cell stacks, the AEL electrolyzer assembly line, and a learning station on the hydrogen value chain, which also enables energy network simulation and thus a systemic view of industrial interrelationships, are available.

Objective qualification

After completing this module, students will be able to professionally assemble, condition and operate fuel cells. They will understand the complex interrelationships in operation that result from the interaction of temperature, humidity, pressure and electrical power, and will be able to record and adjust the parameters specifically with regard to the performance, efficiency and service life of the cell. Students will also be able to set up, validate and simulate simple fuel cell models based on the parameters mentioned.

Literature

- Praktikumsunterlagen
- Dhanasekaran, P., et al. "Current Status and Future Development in Fuel Cells: An Industrial Perspective." Handbook of Energy Materials. Singapore: Springer Nature Singapore, 2026. 1767-1792.
- Qasem, Naef AA, and Gubran AQ Abdulrahman. "A recent comprehensive review of fuel cells: history, types, and applications." International Journal of Energy Research 2024.1 (2024): 7271748.

Remark
Group assignments are made according to language preference.

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**
Interdisciplinary Research Lab Hydrogen	4,0	Laboratory	english german

Integrated Courses

Title			
Number	2599000080	**Module version**	
Shorttext		**Language**	english german
Frequency of offer	every term	**Teaching unit**	Fakultät für Maschinen-bau
Module duration	abhängig von gewählter Veran-staltung	**Institution**	
Hours per Week / ECTS	0 / 13,0	**Module owner**	
Workload (h)	420		
Class attendance (h)	420	**Self studying (h)**	0
Compulsory requirements			
Expected performance/ Type of examina-tion			
Course achievement	a) English language course at C1 level (CEFR): Depending on the module chosen (4 ECTS) and b) German language course at B1 level (CEFR): Depending on the module chosen (4 ECTS) and c) Other elected courses, depending on the modules chosen (5 ECTS)		
Contents			
Depending on elected courses			
Objective qualification			
Language courses: Depending on elected courses Students will be able to categorise their subject in social, historical, legal or career-orientated contexts (depending on the focus of the course). They are able to recognise, analyse and evaluate overarching sub-ject-related connections and their significance. Students gain an insight into the networking possibilities of the subject and the application of their subject in professional life.			
Literature			

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<table>
<tr><td colspan="4">Related courses</td></tr>
<tr><td colspan="4">Rules for the choice of courses</td></tr>
<tr><td colspan="4">German and/or English language courses need to be completed to the set extent and at the set language proficiency level according to the Admissions Committee's decision.

Further courses in the field of interdisciplinary qualification can be selected from the range of courses offered by the TU Braunschweig or, during a study visit abroad, from the range of courses offered by the foreign university and must be concluded with an examination element.</td></tr>
<tr><td colspan="4">Compulsory attendance</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Name of the course</td><td>SWS</td><td>Eventtype</td><td>Language</td></tr>
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Student Research Project

Title	Student Research Project		
Number	2599870	**Module version**	
Shorttext		**Language**	german
Frequency of offer	every term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	1	**Institution**	
Hours per Week / ECTS	2 / 15,0	**Module owner**	
Workload (h)	450		
Class attendance (h)	30	**Self studying (h)**	420
Compulsory requirements			
Expected performance/ Type of examination	2 examination element a) Written elaboration (to be weighted 13/15 in the calculation of module mark) b) oral examination in the form of a presentation (to be weighted 2/15 in the calculation of module mark)		
Course achievement			
Contents			
Depending on the individual topic.			
Objective qualification			
Students are able to, - familiarise themselves with a complex topic, - analyse the topic in order to define the necessary goals for successful processing and select appropriate work steps for this purpose - illustrate interdisciplinary approaches and concepts in order to be able to successfully master a given task - to transfer non-technical knowledge to a current task and to evaluate and apply it in the course of working on the task, both alone and in possible teams based on division of labour, in which the student research project can be written. - to formulate work results both in writing and orally and to present them critically in the context of an examination situation.			
Literature			

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Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**

Master's Thesis

Title	Master's Thesis		
Number	2599000070	**Module version**	
Shorttext		**Language**	german
Frequency of offer	every term	**Teaching unit**	Fakultät für Maschinenbau
Module duration	0	**Institution**	
Hours per Week / ECTS	0 / 30,0	**Module owner**	
Workload (h)	900		
Class attendance (h)	0	**Self studying (h)**	900
Compulsory requirements	Only students who • have passed the examinations in all modules of the core, profile, laboratory and elective area, • have successfully completed the course work, • have proven that they have passed all course work can be admitted to the Master's thesis.		
Expected performance/ Type of examination	2 examination elements a) Written elaboration (to be weighted 9/10 in the calculation of module mark) b) oral examination in the form of a presentation(to be weighted 1/10 in the calculation of module mark)		
Course achievement			

Contents

Depending on the individual topic.

Objective qualification

Students are able to
- independently investigate a complex, subject-specific problem,
- analyse the subject matter in a scientifically sound manner and explore theses independently
- define goal-oriented measures for successful processing and organise the optimal work steps for this purpose
- independently design interdisciplinary approaches and define concepts in order to be able to successfully master a given task
- combine non-technical knowledge with technical knowledge in the course of the work and to use it to carry out and document the work
- present the results of the research in writing on the basis of independently researched relevant literature as well as orally and to discuss them critically within the framework of a presentation.

Literature

Remark

The final module consists of the written processing of the assignment (Master's thesis, 28 LP) including literature research and a presentation (2 LP) of the elaborated results according to § 3 Para. 9. Both parts must be passed separately. If the written processing is not passed, the entire final module must be repeated.

↑

Related courses			
Rules for the choice of courses			
Compulsory attendance			
Name of the course	**SWS**	**Eventtype**	**Language**