Syllabus

MSc Chemical Engineering (M-CHE)

CPE Track

2016 / 2017 (version February 2017)

*Please note that even though the information in this syllabus is gathered with the utmost care, you can not derive any rights from this syllabus. At the moment of composing this syllabus not all course descriptions were available. **Please check Osiris regular for the most up-to-date information.**

CPE track Master CHE

	Quarter 1A	Quarter 1B	Quarter 2A	Quarter 2B
Core modules	**Advanced Chemical Reaction Engineering** (5 EC; Brilman)		**Lab Course Sustainable Process Technology** (5 EC; Kersten)	
	Process Intensification Principles (5 EC; Rivas/Gardeniers)		**Process Plant Design icl. Thermodynamics and Flowsheeting** (15 EC, van der Ham/van den Berg)	
		Advanced Molecular Separations (5 EC; de Vos/Schuur)		
		Advanced Catalysis (5 EC; Lefferts/Mul)		
Electives scheduled	**Multi-component Mass Transport** (5 EC; Benes)		**Process Equipment Design** (5 EC; Bramer)	**Multi-phase Flow** (5 EC; Luding)
	Transport Phenomena (5 EC; van der Meer)	**Cost Management & Engineering** (5 EC; Joosten)	**Transport in Chemically React. Flows** (5 EC; Kok)	**Intro to Computat. Fluid Dynamics** (5 EC; Lammertink)
	Colloids and Interfaces (5 EC, Lammertink)			
Elect. n.s.	**Theory of Phase Equilibria** (5 EC; van der Hoef)			
	Chemical Product Development (5 EC; Lammertink)			
	Contract Research (5 EC; Betlem)			
	Capita Selecta (5 EC)			

	Chemical & Process Engineering (M2)			
	Block 1A	Block 1B	Block 2A	Block 2B
Core modules	**Internship** (20 EC, Folkers)			
	Final project MSc (45 EC)			

Block structure

The MSc Chemical Engineering programme is a 2-year programme (120 EC). As all other BSc and MSc programmes at the University of Twente the year starts in September and ends at the beginning of July. Each year is divided into 4 blocks, which are referred to as 1A, 1B, 2A and 2B.

Block		**Weeks**	**Dates**
Block 1A	Instruction weeks	36 - 43	Sep 5 - Oct 28
	Exam weeks	44, 45	Oct 31 - Nov 11
Block 1B	Instruction weeks	46 - 51, 1, 2	Nov 14 - Dec 23, Jan 9 - Jan 20
	Exam weeks	3, 4	Jan 23 - Feb 3
Block 2A	Instruction weeks	5 - 7, 9 - 14	Feb 6 - Feb 17, Feb 27- April 7
	Exam weeks	15, 16	April 10 - April 21
Block 2B	Instruction weeks	17 - 25	April 24 - June 23
	Exam weeks	26	June 26 – June 30

Core modules

		Advanced Chemical Reaction Engineering
5 ec	**1A+1B**	
Lecturer(s)		dr.ir. D.W.F. Brilman
Objective		The course 'Advanced Chemical Reaction Engineering' focusses on the processes of mass transfer with chemical reaction in *multiphase* reaction systems (gas-liquid, gas-solid, gas-liquid-solid etc.). The interaction between mass transfer and reaction kinetics is a central theme. The objective is to be able to describe the performance of multiphase chemical reactors. Using fundamental mass and energy balances, mass transfer in combination with (homogeneous and heterogeneous) reactions will be analysed and mass transfer flux equations will be derived. These can be implemented in a reactor model to be able to calculate reactant conversion, selectivity and product yield, accounting for the effects of residence time distribution, mass transfer in combination with homogeneous or heterogeneous reaction kinetics, equilibria and heat effects.
Content description		The course 'Advanced Chemical Reaction Engineering' builds on and expands knowledge and skills developed in the 'Introduction Chemical Reaction Engineering' course, which targets *single phase* reaction systems and covers reaction kinetics and –equilibria, model reactors, residence time distribution, micro-mixing, conversion, yield and selectivity, mass and energy balances. The course starts with a short overview/recap of required prior knowledge on single phase reaction systems. Subsequently, mass transfer models (film-, penetration- and surface renewal model) will be discussed and the effect of chemical reactions on the mass transfer rate is analysed in detail, both for homogeneous and heterogeneous reaction systems. Enhancement of mass transfer by chemical reactions, effectiveness factors for heterogeneous catalysts, selection of appropriate mass transfer models, analysis of kinetic rate data and reactor selection are elements discussed within the course. Fundamental mass transfer flux expressions (in general and for limiting situations) are derived, which can be used in multiphase reactor models. With this, reactor performance in terms of reactant conversion and product yield can be calculated, taking into account reaction kinetics and – equilibria, mixing (residence time distribution), multiple reactions (product selectivity) and heat effects. The course comprises lectures, problem solving sessions and workshops. The course is completed with a written exam.
Course Material		Reader + Exercise bundle

201300049		Advanced Molecular Separations
5 ec	1B	
Lecturer(s)		Dr.ir. W.M. de Vos, dr.ir. B. Schuur
Objective		At the end of the course the students should: - Be able to list relevant industrial (advanced) separations, including those applied in the energy, bulk chemical, fine chemical, and pharmaceutical industries. Understand their working principles, molecular basis of separation and role within larger processes. - Be able to make a motivated decision for a separation technology based on the molecular properties of the molecules to be separated. - Be able to analyze a separation technology related case, asses the technical feasibility of different separation technologies, and develop a separation process. - For fluid separations and membrane based separations, be able to calculate mass transfer and thermodynamic properties within a separation process. Be able to design a functional extractant, adsorbant or membrane for a given molecular separation.
Content description		In Advanced Molecular Separations, separation technology is discussed starting from molecular properties up to full scale processes. The focus is on choosing a separation technology for given molecular properties, and the subsequent molecular design of more advanced separation technologies. For two separation technologies, fluid separations and membrane technology, the molecular design and separation process are treated in much greater detail, including a discussion on useful models to describe thermodynamics and mass transfer. The course will include two tests, one on fluid separations and one on barrier separations, but will also include two assignments on selecting the right separation technology for a given separation case.
Course material		Reader and Henley, Seader and Roper: “Separation Process Principles, Interntl Student Version, Third edition”. ISBN: 9780470646113 **(required)**

5 ec	1B	**Advanced Catalysis**
Lecturer(s)		Lefferts/Mul
Objective		This course will provide a more profound description of catalysis as compared to "Kinetiek en Katalyse", preparing students for both doing research in the field as well as for knowledge-based operation and troubleshooting of catalytic reactors.
Content description		- Physisorption and capillary condensation for catalyst characterization - Molecular bonding in chemisorption and heterogeneous catalysis on metals - Oxide and solid acid catalysts - Electro-photo- and plasma-catalysis - Catalytst characterization with electrons and photons - Temperature programmed techniques for characterization - Catalytic reactors and transport
Prior knowledge		Q5 Industrial Catalysis; thus BSc ST suffices
Course Material		- Handout, NIOK course chapter on heterogeneous catalysis - Atkins - Jens, Wasserscheid; Chemical Technology

5 ec	2A + 2B	**Lab Course Sustainable Process Technology**
Lecturer(s)		Kersten
Objective		1. Introduction to the following aspects of the (industrial) Research & Development: i) pilot plant laboratory safety, ii) recording and storing of measurement data (also in a way which is understandable to non-experimentalists), iii) failure analysis, iv) applied measurement & control techniques. 2. Commissioning of R&D setups (1 to 2 setups per team of 4 students). 3. Answering R&D issues, based on a measurement programme of a R&D set up which students have to formulate themselves. Here, of course, also theory/modelling must be deployed.
Content description		The course is an introduction to the R&D of process technology. It can be seen as a preparation for the internship, the master assignment, the professional practice. After we repeated a few basic things such as error analysis and recording/storing measurement data we focus on the safety aspects of a pilot plant and applied measurement & control techniques. These elements will be examined individual. Then we will start up an experimental R&D set-up (typically with a throughput of 1 kg/h) in groups of 4 students and prove that we can measure well. With the help of the theory, models, and the generated measurement data a R&D issue will be answered. The results are reported in a report and presented to fellow students.
Course material		Handouts

201500166		Process Intensification Principles
5 ec	1A	
Lecturer(s)		D. Fernandez Rivas
Objective		After following the course, the student can: **Theory** - Explain and name the four general and fundamental concepts of Process Intensification in the present Chemical Engineering activities. - Asses the relationship between the conventional technologies and PI proposition. **Soft skills and relation with current societal reality** - Debate about two current strategies (Miniaturization and Large scale-up) and how is possible to apply novel methods and processes for relevant markets. Impact on society and environment. **Research. Given relevant articles, the students can** - Discuss in detail with real-life examples on how these principles are applied in practice. **Project** - Work in a team and evidence their professional skills towards the final project simulating real-life scenarios - To design, formulate and combine their knowledge in scenarios given; identify potential uses of alternative energy sources used as activation techniques. - To criticize and judge the advantages and potentials of PI (considered by some a new paradigm?), defending their views on current literature and industrial examples
Content description		This is a very interactive course in which the students will have an active role together with the Instructor and invited scientists. The emerging field of Process Intensification provides a set of tools and routes that can aid the industry in our current world to meet the demands imposed by global competition, government oversight and social accountability, with vast applications in, among others, mechanical and chemical engineering. Professionals with new ways of thinking as well as problem-solving skills are required by companies and universities, in order to tackle the wide range of societal challenges in general, and current limitations in chemical engineering in particular. It is crucial for a young professional of the future to have knowledge on actual chemical processes involving liquid, gas, and multiphasic flows, for both small- and large-scale techniques. These professionals will be able to re-design existing plants or processes, or prepare “greenfield” solutions keeping the safety and ecological constrains in mind. All these elements are needed to convince management teams of the relevance to invest in these new solutions.
Course material		Recommended: - Re-engineering the chemical processing plant : process intensification / Stankiewicz, Andrzej

	- Modeling of process intensification / Keil, Frerich Johannes - Microreactor technology and process intensification / Wang, Yong - Process intensification : engineering for efficiency, sustainability and flexibility / Reay, David Anthony

201300045		Process Plant Design incl. Thermodynamics and Flowsheeting
15 ec	**2A**	
Lecturer(s)		Dr.ir. A.G.J. van der Ham
Objective		The objective of this process design course is to transfer a systematic method for process design. The method taught for the analysis and the design of chemical processes uses methods for “conceptual” design and “process systems design” which have been developed in the last twenty years. The lectures use fundamentals of this approach and translate them into applications.
Content description		The basic disciplines taught in the undergraduate curriculum will be recapped, integrated and expanded. Many aspects of doing an industrial project design will be practiced. Such as: - Systematic process design starting from "process overall" to conceptual design, Index Flowsheet and Process Flow Diagram (PFD) level; - Phasing and project organization, how to handle alternatives selection and evaluation of processes and technologies; - Systematic literature search; - Functional analysis of existing processes and how to create concepts for improved designs; - Introduction in process simulation tools, for instance software like UniSim; - Simulation of the investigated process in a flowsheeter (for instance UniSim); - Basics of heat exchanger selection and heat integration (pinch technology); - Equipment selection and design (down to basic dimensions needed for costing); - Detailed design of the reactor (in collaboration with MRT); - Basics and application of process control; - Basics and application of P&ID's; - Fundamentals and application of process safety; - Basics of process economics for economic evaluation; - Generation and evaluation of process alternatives on technical and economic feasibility; - Perspectives for future developments will be discussed; - If possible, the ACHEMA fair will be visited (2018). About 10 of the 15 EC is spent on the process design assignment, which is carried out in teams of four students in parallel to lectures and workshops. Each team will design a different process starting with a limited amount of information and submit their results in a final report, presentation (at the owner!) and an abstract for a conference (general NPS). The subjects are for each team and also each year

	different. Subjects are from industry and different research groups within the department. In general they are related to recent developments. The final mark is based on the quality of the tests, the progress meetings, final report, presentations and finally the participation in the lectures and workshops.
Prior knowledge	Only master students are allowed to participate. They should have finished CRE and Advanced Molecular Separation (or being in the process of finalizing these courses). It is also strongly advised to do the master course MRT and PED in parallel.
Course material	Recommended: - Chemical Engineering Design, 2nd edition by G. Towler and R. Sinnot - ISBN: 978-0-08-096659-5 - Product and Process Design Principles: Synthesis, analysis and Evaluation, 3rd edition by W.D. Seider, J.D. Seader, D.R. Lewin and S. Widagdo. ISBN: 978-0-0470-41441-5

193799009		**Internship**
20 ec	**-**	
Contact person		Ing. A. Folkers
Aims		- To perform an assignment applying the principles and methods of Chemical Engineering in a practical situation, - to gain insights into the functioning of a professional organization, - to obtain specific competencies necessary for working in a professional institute or company, - to gain insights about the field of Chemical Engineering.
Content description		The internship is an integral part of the Master of Science of Chemical Engineering programme. (Master's students with a preceding HBO-bachelor diploma have an adapted programme without an internship period. If these students wish, the may ask for an internship period as well as an additional course). The internship has to be scheduled in the first or the second year of the master, has to cover at least 13 weeks (20EC) and should be conducted preferably at a company but can also be conducted at a research institute or an university. Students may start the assignment after completing their bachelor Degree. The TNW master programmes offer several opportunities for adding an international dimension to the knowledge and the practical experience of a student. Therefore the internship may be carried out in the Netherlands or abroad. We believe a stay abroad is a valuable component of the study; therefore stimulating measures like the Twente Mobility Fund (TMF-fund) and the Erasmus-scholarship are available. The internship is coordinated by the internship coordinator. Orientation for internship has to start half a year prior to national internship and a year prior to international internship. This time is required for actual arrangements of the internship, such as getting an accommodation, visa and all formalities. Application for the internship has to be submitted to the Student Mobility System http://webapps.utwente.nl/srs/en/srsservlet

	All relevant information, internship posts and all required forms for the internship can be found on the Blackboard organization 'Internships TNW'. International students should also contact Rik Akse during the arrangement of the internship. (h.a.akse@utwente.nl)
More information	Blackboard Organizations: Internship TNW http://www.tnw.utwente.nl/che/education/internship

201300054 / 55 **25 / 20 ec** | -	**Master Thesis**
Contact person	dr.ir. B.H.L. Betlem
Description	The individual master assignment is the completion of the master's programme. The main objective of the assignment is that the student learns and proves that (s)he is able to define, perform, complete and reflect a research project at a large degree of independence. The four learning objectives of the 'reporting and general aspects' are defined below. The assignment is performed in one of the Chemical Engineering research chairs of the faculty of Science and Technology of the UT under the supervision of a mentor and the responsibility of a Master's Assignment Committee. Conditionally, the assignment can be done (partially) at another external UT-group or an external institute or organisation.
Content description	The student has to perform a substantial research or design project that meets scientific criteria. The level of profundity and complexity is defined by the chairman of the Master's Assignment Committee. The student completes the assignment with a written report (the MSc.-thesis) and an oral public presentation.
Assessment	The MSc.-assignment will be assessed with two marks. The first mark covers the quality of the research performance, whereas the second mark covers the other three mentioned objectives, concerning the reporting and general aspects of the research. For each mark a different course code has been assigned.
Codes	201300054 (25 ec): Master Thesis Scientific and Research Aspects (SRA) 201300055 (20 ec): Master Thesis Reporting and General Aspects (RGA)

Elective modules

xxxxxxxxx 5 ec	-	Capita Selecta (CPE track)
Description	All research groups offer 5 EC Capita Selecta (C.S.) modules, that you can take as an elective in your MSc program. For detailed information on these, please contact the group leader for more information on the format and content. Underneath is the list of available C.S. courses (with contact persons)
Available courses	C.S. Catalytic Processes and Materials (193765000) Prof.dr.ir. L. Lefferts, prof.dr. K. Seshan C.S. Inorganic Membranes (193737000) Dr.ir. N.E. Benes, prof.dr. H.J.M. Bouwmeester, prof.dr.ir. A. Nijmeijer, prof.dr. A.J.A. Winnubst C.S. Membrane Technology (193735000) Dr.ir. A.J.B. Kemperman, dr.ing. M.W.J. Luiten-Olieman, dr.ir. W.M. de Vos C.S. Mesoscale Chemical Systems (193780000) Prof.dr. J.G.E. Gardeniers C.S. Photocatalytic Systems (201000308) Prof.dr.ir. R.G.H. Lammertink, prof.dr. G. Mul C.S. Soft Matter, Fluidics and Interfaces (201000218) Prof.dr.ir. R.G.H. Lammertink C.S. Sustainable Process Technology (201200240) Dr.ir. D.W.F. Brilman, dr.ir. A.G.J. van der Ham, prof.dr. S.R.A. Kersten, dr.ir. G. van Rossum, dr.ir. B. Schuur

193735030 5 ec	-	Chemical product development
Lecturer(s)	dr.ir. W.M. de Vos , prof.dr.ir. R.G.H. Lammertink
Content description	The course covers the process from product idea to product or prototype. As such, the students proceed through the techniques used in designing and developing. Chemical engineers are often working in the development of new products where chemistry is often only one of the disciplines. Development is therefore mostly done in interdisciplinary teams. Understanding of costs, marketing and selling are therefore also important. The course is supported by lectures following the book of Hans Wesselingh et al. "Design and Develop". The main activities are carried out in small teams based on a product needs analysis.
Note	This course integrates a lot of the material you have been offered during the MSc and therefore is best followed in the end phase of your MSc.

Course material	Design and Develop, by J.A. Wesselingh, S. Zinck Kiil and M.E. Vigild
Assessment	Assignment, report

193735060		Colloids and Interfaces
5 ec	1A	
Lecturer(s)		Prof.dr.ir. R.G.H. Lammertink
Objective		Learning objectives of this course include: • Gain insight in important interfacial aspects including interfacial energy and surface potential. • Be able to explain and describe different interfacial phenomena, such as: wetting, colloidal stability. • Become familiar with experimental techniques for measurement of various colloidal and interfacial properties (ex. zeta potential, streaming potential, contact angle, etc.) and interpretation. • Understand the applicability and limitations of various colloid-related theoretical frameworks, such as DLVO. • Critically evaluate scientific literature on interfacial phenomena.
Content description		Description of colloids, surfaces and interfaces. All kinds of interfaces between different phases are treated. Thermodynamic descriptions of these interfaces are deduced. Several techniques for characterizing interfaces are discussed. During contact hours, the contents of will be presented and discussed, and exercises will be made and discussed. For each topic, a case assignment will be offered. Topics include: • Lifshitz-van der Waals Interactions • Polar/Acid-Base Interactions • Wetting and Contact Angles • Electrostatics • Electrokinetic Phenomena • Electrostatic and Polymeric Stabilization of Colloids • Colloidal Phenomena (Marangoni-Effect, Ouzo effect, etc.)
Course material		Handouts and other literature will be provided during the course

193799700		Contract research (for study trip)
5.0 ec	-	
Contact person		Dr.ir. B.H.L. Betlem
Objective		The objective is to conduct a research commissioned by an internal or external client. The project must be performed to the satisfaction of both the client and the supervisor. Both of them will evaluate the project and report.
Content description		This Contract Research Assignment is conducted by groups of 2 students and is for the financial support of the international study tour. Projects are coming from internal and external customers. The assignment is coached by a staff member selected on the basis of the subject of the assignment. He/she coaches and helps the students but also grades the final result which is almost always a report for the customer.

201400244 5 ec | 1B	**Cost Management and Engineering**
Lecturer(s)	dr. R.A.M.G. Joosten
Objective	After successfully completing the course, students will: - understand the basic theoretical concepts in Cost Management Engineering like cash flows, cost estimation and project input / output valuation techniques, Discounted Cash Flow analysis methods, cost of capital / choice of discount rate; - understand the basic problems and modeling techniques regarding uncertainty in long-horizon investment decisions or projects, and to understand and to cope fruitfully with informational challenges connected to this uncertainty; - be able to apply and integrate these concepts and techniques to perform basic economic evaluations of private sector and public sector projects; - have insight in several important differences in private and public sector projects and resulting differences in approach for the economic evaluation of private and the public sector projects; -have insight in important differences in the quality of financial data and be able to weigh their importance critically; - be aware of multi-attribute analysis as an alternative approach evaluation of projects and be able to use this method for (simplified) project evaluation; - be able to comment critically on the theoretical and practical validity of recommendations by third parties regarding investment decisions and surrounding issues as discussed; - be able to investigate simple applications of approaches taught independently and report in writing and in oral presentations their findings.
Content description	The course objective is to provide engineering students with the theoretical understanding and practical approaches as well as the tools and techniques for the economic and financial evaluation of stand-alone but also competing design solutions for processes, products, construction projects, services and the practical application of the approaches in more complex settings. Engineers must be able to model the economic impacts of their recommendations during the life cycle. The course will focus on monetary quantification, using different system boundaries and perspectives. Students are challenged to go out and gather information on real-life applications of cost management and engineering techniques.
Prior knowledge	It is obligatory to have completed one of the following courses: ST + international MSc - 373500 Membrane Technology, BME - 373504 Biomedical Membrane Applications 373500 C.S. Membrane Technology
Course material	“Engineering Economy”, WG Sullivan, EM Wicks, JT Luxhoj, Pearson Prentice Hall, ISBN 978-0133439274. (required)

193720040		Introduction to Computational Fluid Dynamics
5 ec	2B	
Lecturer(s)		Prof.dr.ir. R.G.H. Lammertink
Content description		The course introduction to Computational Fluid Dynamics (CFD) focuses on how fluid dynamics problems can be solved numerically. The course contains the full range from fundamental numerical methods to commercial CFD software. Initially, Matlab based routines will be used for discretized problems related to fluid flow. Subsequently, more integrated problems, containing momentum, mass and energy transport will be studied. Through practice sessions the student learns to implement flow problems in CFD software. The knowledge and skills of the student are tested through assignments / cases that will be performed in small groups. Towards the end of the course, a final assignment will be based on an experimental paper for which the numerical simulations need to be performed. The groups will present this in a poster session.
Prior knowledge		Required: Introduction to Physical Transport Phenomena (191370091); Physical Transport Phenomena (191370201)
Course material		Reader iCFD, R.G.H. Lammertink

201300050		Multi-component Mass Transport
5 ec	1A	
Lecturer(s)		Dr.ir. N.E. Benes
Objective		- Describe a number of limitations of the law of Fick, and mention physical processes for which these have implications; - Explain the concept of driving forces for mass transport by diffusion, and list 4 examples of driving forces; - Explain the concept of friction between molecules, and connect this to mobility and diffusion coefficient; - Explain the main concept of MS, and explain how the choice of type of flux and the Bootstrap relation relate to this; - Apply the MS theory (extend a Matlab code); - Think of relevant case study, based on literature; - Perform mass transport simulations and critically access the results; - Communicate work and findings to others
Content description		This course aims at understanding of mass transport in multi-component mixtures, based on a simplified version of the theory of Maxwell and Stefan. Main aim is for students to be able to understand the basic principles of diffusion in mixtures containing various different species, driven by a combination of different driving forces, and to apply this understanding in specific relevant chemical technology applications. Within the course a lot of attention is paid to contemplation and discussion, in order to consolidate the new knowledge and insights. Within this context, students are requested to give a lecture on one of the chapters in the book and to answer relevant case study, in which the multi-component characteristics of transport are evident. The case study involves the use, and stepwise extension, of an existing Matlab code, allowing the students to gradually and relatively independently simulate and study an eventually complex problem. The course relies on prior knowledge from: Equilibria II, Physical Chemistry, iFTV, FTV, Separation Technologies. The following topics are addressed: - Limitations of the law of Fick; - Driving forces for diffusion (potential gradients); - Friction between molecules; - Maxwell-Stefan (MS) concept; - Bootstrap; - Application of MS in relevant process (membranes, heterogeneous catalysis, transport at interfaces); - Extending Matlab code for relatively complex simulations.
Course material		"Mass Transfer in Multicomponent Mixtures", J.A. Wesselingh and R. Krishna ISBN 978-90-71301-58-2 (required)

201400300		Multiphase Flow
5 ec	2B	
Lecturer(s)		prof.dr. S. Luding
Objective		To reach in-depth insight into multiphase flows.
Content description		In fluid mechanics, multiphase flow is a generalisation of two-phase flow, i.e. cases where the phases are not chemically related (e.g. dusty gases, particles in fluid) or where more than two phases are present (e.g. propagating steam explosions, suspensions, aerosols, sprays, clouds, ...). More general, multi-phase flow involves the interaction of solids with fluids, or of different fluids with each other and is of utmost importance in many engineering and science fields. Each of the phases is considered to have a separately defined volume fraction (the sum of which is unity), and its own velocity field. Conservation equations for the flow of each species (perhaps with terms for interchange between the phases), can then be written down straightforwardly. The momentum equation for each phase is less straightforward. It can be shown that a common pressure field can be defined, and that each phase is subject to the gradient of this field, weighted by its volume fraction. Transfer of momentum between the phases is sometimes less straightforward to determine, and in addition, a very light phase in bubble form has a virtual mass associated with its acceleration. (The virtual mass of a single bubble is about half its displaced mass). These terms, often called constitutive relations, are often strongly dependent on flow regime.
Prior knowledge		Recommended is basic and advanced Fluid- and Solid Mechanics, as well as Transport Phenomena.
Course material		Lecture notes

201300155		Process Equipment Design
5 ec	2A	
Lecturer(s)		Prof.dr.ir. T.H. van der Meer, dr.ir. T.C. Bor, dr.ir. A.G.J. van der Ham, dr.ir. N.P. Kruyt
Objective		The objective of this course is the transfer of insight, knowledge and experience for the technological design of (chemical) process equipment. An industrial process consists mainly of a reactor, separation equipment (for instance distillation), heat exchangers and pumps/compressors. In this course you will learn to design a compressor or pump, a heat exchanger and a distillation column including mechanical aspects for a given industrial process. The course starts with lectures to discuss the design in general and the design of the different types of unit operation in detail. Also the mechanical aspects are discussed.
Content description		Topics of the different lectures: - design methodology in general, - equipment for momentum transport (pumps, fans, compressors), - equipment for heat transfer, with and without phase transition, - equipment for mass transfer: focus on distillation. - mechanical design aspects of process equipment.

	The course is finalized with a group design assignment of three types of unit operations for momentum, heat and mass transfer from an industrial scale process. The group consists in general of 3 students. Finally, the mark is based on the report and an oral exam about the (group)design assignment.
Prior knowledge	Needed: Introduction Fluid Mechanics (191154131) Fluid Mechanics and Heat Transfer (191154141) or Introduction Physical Transport Phenomena (191370091) Physical Transport Phenomena Lab Course (191370201)
Course material	"Chemical Engineering Design", R.K. Sinnott & Gavin Towler, 5th edition, ISBN 978-0-7506-8551-1 (recommended)
Assessment	Group assignment, oral examination.

193720050		**Theory of Phase Equilibria**
5 ec	**-**	
Lecturer(s)		Dr.ir. M.A. van der Hoef
Content description		The first part of this course consists of a recapitulation of elementary thermodynamics from a more formal viewpoint by using state functions, rather than from processes, as is common in most undergraduate courses. This formalism will then be applied to a description of phase-equilibria between two or more phases of single component systems. This is followed by a description of phase equilibria in two- and three-component systems, where the solutions are considered to be ideal. Finally, non-idealicity is introduced via excess functions and activity models. The most important application is found in the calculation of the P-x,y diagram of a binary system, starting from well-known excess state functions such as the Peng-Robinson and the RKS equation of state. This calculation will require some code development. ***This course is highly suitable for self study, where assistance from the lecturer can be obtained on an individual basis, preferably by appointment. In any case it is requested to get into touch with the lecturer before commencing. In the case of self-study, the course can be done the whole year round. If there is sufficient interest, a limited set of lectures will be given, in principle in block 2B.***

201400387		**Transport in Chemically Reactions Flows**
5 ec	**2A**	
Lecturer(s)		dr.ir. J.B.W. Kok
Objective		After the course, the student is able to: - Explain / describe numerical modeling approaches of transport in turbulent flows - Apply these modeling approaches in a commercially available CFD code - Describe and analyse the behavior of chemical reaction mechanics with many elementary reactions

	- Describe and analyse the modeling of a chemical reaction in a turbulent flow process - Solve numerically turbulent transport problems in process or power generation industry
Content description	The course targets the student to know about numerical modelling approaches of transport in turbulent flows, and how to use them in a commercially available CFD code. The student will know about, and how to analyse, turbulent flows with chemical reactions by means of models and numerical simulation. The student will be able to handle modeling off chemical reaction described by mechanisms with many elementary reactions. He will know how use and understand turbulent flow models in a RaNS and LES approach.. This knowledge will enable the student to solve numerically turbulent transport problems in for example the process industry or power generation industry.The course treats the transport in the turbulent flow of gaseous fluids composed of multiple species, by means of diffusion, convection or chemical reaction. Turbulence has a large effect on both convective transport and chemical reaction. The course intends to give an overview of the major processes, and a description by means of transport equations is presented. Numerical tools (Computational Fluid Dynamics) are used for product optimization and analysis. In the course several assignments in the use of numerical models for chemical reaction, turbulent convection and mixing and combustion will be given. The course will be finalized by means of a computer assignment using the CFD package CFX Ansys. A practical case with application on a combustion problem will be worked out. The marking will be done on basis of the assignment reports and an oral exam.
Course material	Theoretical and Numerical Combustion, 3rd edition, Th. Poinsot and D. Veynante, 2011, ISBN 978-2-7466-3990-4 (available in hard copy and e-book) **(required)** **Recommend:** Carey, W.J., New Developments in Combustion Research, Nova Science Publishers, NY, 2006, ISBN 1-59454-826-9 C.K. Law, Combustion Physics, Cambridge University Press, 2006, ISBN-13978-0521-187052-8

191141700		**Transport Phenomena**
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Lecturer(s)		Prof.dr.ir. T.H. van der Meer
Objective		After this course, the student is able to: - Translate a real life heat, mass or momentum transport problem into its mathematical formulation; - Solve the mathematical equation resulting from this translation; - Analyse the solutions found and their implications for the problem started with; - Communication with specialists involved in computational fluid dynamics, discuss the formulation of a problem and its numerical solution with this specialist.

Content description	This course uses the book Transport Phenomena written by Bird, Stewart and Lightfoot. The main author of this classical book is Byron Bird. He wrote the first edition of this book many years ago after his stay at Delft University, where he had been teaching transport phenomena. There are several ways to teach this material. Here the way of increasing mathematical complexity is chosen. It starts with stationary diffusion processes, then a source term is added, after which instationary diffusion is treated. Mathematically this means that is started with the ordinary differential equation, the Laplace equation. With instationary diffusion one deals with a partial differential equation in time and space. Next complexity is added by including convective transport. Since the transport of heat, mass and momentum show many similarities, throughout the course problems from all three transport mechanisms are solved. During the tutorials the students work in groups of 3 to 4 on real life problems. The groups have to formulate these problems into an analytical model. They have to make appropriate assumptions, define the solution domain, formulate the describing differential equation(s) with appropriate boundary conditions, and derive the solution. For some of the problems a numerical solution of the full problem without any assumption is available. With this numerical solution the students then analyse the influence of the assumptions made by them in finding the analytical solution. In this way they get understanding of the underlying transport mechanisms. Each 4 groups will be assisted by a tutor, who helps them during the whole process.
Prior knowledge	Needed: Introduction Physical Transport Phenomena II (B-ST)
Course material	“Transport Phenomena”, R. Byron, Warren E. Stewart, Edwin N. Lightfoot, 2nd Edition ISBN: 0-471-41077-2 (required)