Multiphase Flow, Master course, TME160-2021

PM – course info

Responsible teacher

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Multiphase flows

Multiphase flows exist in a great number of natural and technological systems. The term *multiphase flow* refers to any flow situation in which there is a simultaneous presence of multiple phases (gas, liquid or solid) or components in a domain of interest. The components are well mixed above the molecular level. The most straightforward classification of multiphase flows is according to the state of different phases or components and, therefore, one may refer to gas-solid, liquid-solid, liquid-liquid or gas-liquid flows. Alternatively, one uses terms such as gas-particle flows, bubbly flows etc. Understanding multiphase flows includes dealing with a wide spectrum of spatial and temporal scales, working within a broad range of engineering disciplines and using a multitude of different modelling and computational approaches. Challenges arise from complex interactions of many entities (e.g. bubbles, drops, or solid particles) suspended in a fluid, but also from phenomena such as a possible change of phase within a system (typically present in gas-liquid systems), turbulence etc.

Learning outcomes

After completion of this course, the student should be able to:

- comprehend the phenomenology and the underlying physics of flow problems involving a simultaneous presence of multiple phases in a flow domain.
- critically review the state-of-the-art of modelling and computational methods and procedures for studying multiphase flows.
- reflect on governing equations and underlying assumptions for a wide range of different techniques studied throughout the course.
- explain and apply on realistic situations specific numerical aspects related to performing computations of multiphase-flow problems.
- solve a number of industrially-relevant multiphase-flow problems using commercial or open-source CFD codes.

Qualifications for the enrolment

The course is intended for students with prior knowledge in fluid mechanics. If you are in one of the categories given below, you most likely fulfil the qualifications for the enrolment:

- you are already a master student at MPAME (Applied Mechanics), MPISC (Innovative and Sustainable Chemical Engineering) or MPSES (Sustainable Energy Systems) at Chalmers.
- you are enrolled in another master programme, but you have passed basic courses in Fluid Mechanics and/or Computational Fluid Dynamics (CFD) at the department of Applied Mechanics at Chalmers, or similar at other schools.

- you have studied at another school where you passed courses in the field of Fluid Dynamics and/or Computational Fluid Dynamics (CFD).

In case of any questions, please contact the responsible teacher.

Teaching material

- *Lecture notes* – to be given to students before the lectures.
- *Textbook* 'Multiphase Flows with Droplets and Particles' by Crowe, Sommerfeld and Tsuji. Other textbooks will also be mentioned.
- *Selected articles*: to be suggested (and made available) to students for various topics studied in the course.
- *Matlab, Python* or similar packages
- *Commercial and open-source computational codes* (no preferences made).

Teaching methods

- Lectures and calculation exercises
- Computer assignments. Results to be presented and discussed by the students.

Note: The course is planned to take place on campus. Due to special circumstances related to the current pandemics, it is not impossible that certain things will have to be changed during the course. In such a case, alternative channels for teaching will be formulated and methods will be suggested to facilitate discussion related to and during the lectures.

Computers rooms are booked for two occasions (November 18 and November 25) in order to give you assistance related to Assignment 1. Measures will be taken to fulfil recommendations for such events in the current pandemics. For Assignment 2 consultations will be offered on December 7.

Changes in the course from the previous occasion

The course material is always updated to include the latest developments in a number of modelling and simulation techniques.

Compulsory activities

- **Two out of three** computer assignments (**Assignments 1 and 2**) in the course are compulsory to be eligible for the exam. The students will write reports and defend their conclusions. The third assignment (**Assignment 3**) is not mandatory, but it will give credits for the exam. If the deadlines given below (see **Deliverables**) cannot be met due to objective reasons, the students will contact the responsible teacher. If the reasons are not deemed objective, a student will have to enrol in the course at another opportunity.

Individual and group work

Mandatory computer assignments and the related reports will be done individually (Assignment 1) or in groups (up to 4 for Assignment 2). Assignment 3 is also to be carried out individually.

Deliverables

- **Assignment 1 is mandatory**. Reports from **Assignment 1** should be handed in according to the dates indicated below.

Assignment	Hand-out date	Hand-in date
1	**Friday 12/11**	**Monday 29/11**

- **Assignment 2** is mandatory and will be given on **Friday, November 26**. The students will present their results on **Thursday, December 16**. Reports should be delivered on that day or upon agreement.

- **Assignment 3** is to be given in **week 7** of the course. This assignment is not mandatory, but it is highly relevant for your training on modelling and simulations of multiphase flows. In addition, it will give you credits for the final exam (up to 10 %).

Examination and grades

There is a written exam for the course, and it is planned to be organized in a pre-pandemic manner. As with the teaching, changes are possible if the situation demands. The students will be informed about such a change and prepared for the chosen form of the exam.
The grades are “failed”, “3”, “4” and “5”.

Course evaluation

A course evaluation group will be formed during the first teaching week. The course representatives will be randomly selected among the students enrolled in the course (if not given otherwise). Other students enrolled in the course can also participate in the group work. The exact dates and times for the meetings will be agreed between the responsible teacher and the group.

Detailed timetable, TME160 2021

Session	**Week 1** of the course; Calendar week 44, 2021	
1	Tue Nov 2 13.15-17 MA	Course objectives. General guidelines. Introduction to multiphase flows – Lecture 1 • Characterization, Basic definitions, properties of phases • Flow regimes
2	Thu Nov 4 13.15-17 MA	Introduction to multiphase flows – Lecture 1 • Averaging techniques, boundary conditions in multiphase flows
	Fri Nov 5	• Holiday

Session	**Week 2** of the course; Calendar week 45, 2021	
3	Tue Nov 9 13.15-17 MA	Lecture 2 • Equation of motion of an individual particle • Forces on individual particles
4	Thu Nov 11 13.15-17 MA	Lecture 2 • Equation of motion of an individual particle • Forces on individual particles (emphasis on bubbles) Lecture 3 • Multiscale modelling of multiphase flows (explanation of concept)
5	Fri Nov 12 13.15-15 MA	Lecture 4 • Lagrangian Particle Tracking – main principles and governing equations
Session	**Week 3** of the course; Calendar week 46, 2021	
6	Tue Nov 16 13.15-17 MA	Lecture 4 • Lagrangian Particle Tracking – models for particle-particle interactions
7	Thu Nov 18	• Computer lab (13.15-15), SB-D042 • Lecture 4 (15.15-17), MA
8	Fri Nov 19 13.15-15 MA	Lecture 5 • Multi-fluid (Eulerian) modelling of multiphase flows – main principles and derivation of governing equations
Session	**Week 4** of the course; Calendar week 47, 2021	
9	Tue Nov 23 13.15-17 MA	Lecture 5 • Multi-fluid (Eulerian) modelling of multiphase flows – formulation of closure models
10	Thu Nov 25	• Computer lab (if needed), 13.15-15, SB-D023, SB-D025 • Lecture 6: Numerical modelling of multiphase flows – Lagrangian particle Tracking (numerical schemes, interpolation, collision models), 15.15-17, MA
11	Fri Nov 26 13.15-15 MA	Lecture 6 • Numerical modelling of multiphase flows – Lagrangian Particle Tracking and Multifluid modelling (numerical schemes, convergence, conservation of mass and momentum).

Session	**Week 5** of the course; Calendar week 48, 2021	
12	Tue Nov 30 13.15-17 MA	Lecture 6 • Numerical modelling of multiphase flows –Multifluid modelling (numerical schemes, convergence, conservation of mass and momentum).
13	Thu Dec 2 13.15-17 MA	Lecture 6 • Numerical modelling of multiphase flows – Multifluid modelling (numerical schemes, convergence, conservation of mass and momentum). Lecture 7 • Direct Numerical Simulation (DNS) of multiphase flows – main principles and techniques. Volume of Fluid (VOF).
14	Fri Dec 3 13.15-15 MA	Lecture 7 • Direct Numerical Simulation (DNS) of multiphase flows – main principles and techniques. Volume of Fluid (VOF). Level Set, Front Tracking, Immersed Boundary

Session	**Week 6** of the course; Calendar week 49, 2021	
15	Tue Dec 7	• Lecture 7, 13.15-15, MA, Direct Numerical Simulation (DNS) of multiphase flows – main principles and techniques. Volume of Fluid (VOF), Level Set, Front Tracking, Immersed Boundary • Assignment 2 consultations, 15.15-17, offices of teaching assistants
16	Thu Dec 9 13.15-17 MA	Lecture 7 • Direct Numerical Simulation (DNS) of multiphase flows • Modelling of multiphase flows using mesoscopic frameworks – Lattice Boltzmann Method (LBM)
17	Fri Dec 10 13.15-15 MA	Lecture 7 • Modelling of multiphase flows using mesoscopic frameworks – Lattice Boltzmann Method (LBM), Smooth Particle Hydrodynamics (SPH)
Session	**Week 7** of the course; Calendar week 50, 2021	
18	Tue Dec 14 13.15-17 MA	Lecture 8 • Population balance modelling – principles and applications
19	Thu Dec 16 13.15-17 MA	• Student presentations (Assignment 2)
20	Fri Dec 17 13.15-15 MA	• Lectures 7 and 8 – extra material
Session	**Week 8**	
		Extra time