COURSE DETAIL

FLUID MECHANICS AND TRANSPORT PHENOMENA

Country
Italy

Host Institution
University of Bologna

Program(s)
University of Bologna

UCEAP Course Level
Upper Division

UCEAP Subject Area(s)
Engineering

UCEAP Course Number
177

UCEAP Course Suffix

UCEAP Official Title
FLUID MECHANICS AND TRANSPORT PHENOMENA

UCEAP Transcript Title
FLUID MECH&TRANSPRT

UCEAP Quarter Units
6.00

UCEAP Semester Units
4.00

Course Description

This is a graduate level course that is part of the Laurea Magistrale program. The course is intended for advanced level students only. Enrollment is by consent of the instructor. The course consists of two parts. This course provides students with advanced tools for analyzing and modelling momentum, energy, and mass transport in fluid or solid media. Continuum mechanics approach is used to address the discussion of fluid mechanics, heat. and mass transfer problems. The course focuses on the role of local form of total mass, momentum, energy, and species balance equations.

The first part of the course discusses topics including: Eulerian and Lagrangian views. Local and material derivative. Microscopic mass balance. Microscopic momentum balance. Stress tensor in a fluid. Deformation rate tensor components. Constituive equations for the relation between stress and deformation rate for newtonian fluids, Bingham fluids and Power law fluids. Navier Stokes equation. Laminar flows: Couette flow for the different types of fluids, Falling film flow for the different types of fluids. Example on composite falling film (Bingham and Newtonian fluids): velocity profile, stress profile and flowrate. Poiseuille flow in rectangular and cylindrical channels: stress profile, velocity profile, flowrate for Newtonian, Bingham and Power Law Fluids. Consideration on the solution of the Navier Stokes equation in different cases: Couette, Poiseuille and falling films. Flow in an annulus. Velocity and stress profile for a newtonian fluid. Example: wire coating. Non dimensionalization of Navier Stokes equation. Creeping and Inertial flows. Reynolds and Strouhal number meaning. Application to the unsteady falling film problem. Examples of visocus, bidirectional, pseudo-steady flows. Determination of the velocity profile and force exerted on a squeezing-plate viscometer. Viscometry: viscometric kinematics and viscosity. Coeutte viscometer in planar and cylindrical case. Parallel disk viscometer: velocity profile and estimation of viscosity. Cone and plate viscometer:velocity profile and estimation of viscosity. Capillary viscometer for Newtonian fluids. Pressure profile in fluids in rigid-body rotation. Rabinowitsch treatment of capillary viscometer data: example of application to polymeric solution following power-law behavior. Lubrication theory: study of the velocity and pressure profile in a Michell Bearing, lift force applied. Example of the falling cylinder viscometer. Solution of unsteady laminar flow problems: semiinfinite medium. Solution of 2d problems using the stream function: Creeping flow around a sphere. Potential, inviscid and irrotational flow. Vorticity transport theorem. Euler's equation and Bernoulli's equation. Laplace's equation. Potential flow around a cylinder. D'Alembert paradox. Laminar Boundary layer around a flat plate: Blasius' derivation and numerical solution. Applications: entrance length in a duct. Friction factor. Turbulent flow: time smoothed quantities. Time smoothed version of the continuity equation and Navier Stokes equation with inertial stress. Friction factor as interfacial coefficient in internal flow, external flow and boundary layer: analogy with heat and mass transfer case. Dimensionless diagrams for friction factor in various cases. Flow in porous media: Darcy's law and Ergun equation. Application to the filtration process and fluidization point determination.

The second part of the course discusses topics including: Heat Transfer. Heat transfer: Fourier’s constitutive equation, thermal conductivity for isotropic and anisotropic materials; constitutive equations for internal energy; local energy balance equation. Heat conduction in solids and quiescent fluids: problem formulation, different initial and boundary conditions. Heat conduction in a semi-infinite slab with boundary conditions on temperature or on heat flux; analogy with penetration theory. Calculation of heat transfer coefficient, heat flux and total heat exchanged. Heat conduction in two semi-infinite slabs in contact at the interface. Two dimensional problems of steady heat conduction: use of conformal transformations. Heat conduction in fins; planar fins and efficiency. Bessel’s and modified Bessel’s equations and their solutions. Solution of heat transfer in cylindrical fins and calculation of efficiency. Solution of transient heat transfer problems in slabs and cylinders: methods of separation of variables and Laplace transform method for different boundary conditions. Solutions available in graphs. Heat transfer in fluids under different motion regimes: a) forced convection, non-dimensional equations, Péclèt number and dependence of Nusselt number on the relevant dimensionless numbers; b) free convection, non-dimensional equations, Grashof number and dependence of Nusselt number on Grashof and Prandtl numbers. Thermal boundary layer on flat surface: detailed solution, thickness, heat transfer coefficient, Chilton – Colbourn analogy. Discussion on analogy between heat transfer and fluid motion. Boundary layer on flat surfaces for liquid metals. Mass transfer. Relevant variables, velocity and flux of each species, diffusive velocities and diffusive fluxes. Local mass balances in Lagrangian and Eulerian form. Constitutive equation for the diffusive mass flux (mobility and chemical potential gradients); discussion. Fick's law, diffusivity in binary solutions; its general properties, dependence on temperature, pressure; typical orders of magnitude for different phases. Mass balance equation for Fickian mixtures; relevant boundary conditions. Discussion and analogy with heat transfer problems. Measurements of diffusivity in gases; Stefan problem of diffusion in stagnant film. Steady state mass transfer in different geometries (planar, cylindrical, and spherical) in single and multilayer walls. Transient mass transfer: problem formulation in different geometries. Solution for transient mass transfer problems: semi-infinite slab with different boundary conditions, films of finite thickness. Calculation of mass flux, of the total sorbed mass; “short times” and “long times” methods for the measurement of diffusivities. Transient permeation through a film: use of time lag and permeability for the determination of diffusivity and solubility coefficients. Transient mass transfer in ion implantation processes. Mass transfer in a falling film and calculation of the mass transfer coefficient. Mass transfer in a fluid in motion: dimensionless equations; dependence of the Sherwood number on the relevant dimensionless numbers: Reynolds and Prandtl in forced convection, Grashof and Prandtl in free convection. Analogy with heat transfer. Graetz problems. Boundary layer problems in mass transfer: mass transfer from a flat surface, mass transfer boundary layer thickness; explicit solution for the concentration profile and for the local mass transfer coefficient. Levèque problem formulation and solution. Chilton – Colbourn analogy; discussion on analogy among the different transport phenomena. Calculation of the mass transfer coefficient. Mass transfer with chemical reaction: analysis of the behavior of isothermal catalysts with different geometries (planar, cylindrical, and spherical), concentration profiles and efficiency dependence on Thiele modulus. Discussion on non-isothermal catalysts behavior and efficiency. Diffusion with surface chemical reaction: metal oxidation problems: general problem formulation and justification through order-of-magnitude analysis of the pseudo-steady state approximation; solution and oxide thickness dependence on time. Diffusion with chemical reaction in the bulk: concentration dependence on Damkholer number. Absorption with chemical reaction: determination of the mass transfer coefficient and of the enhancement factor for the case of instantaneous reactions, Hatta’s method. Calculation of mass transfer coefficient and enhancement factor for the case of slow and fast reactions; film theory. Elements of turbulent mass transport and on dispersion problems in laminar flows (Taylor-Aris dispersion) and in porous media.

Language(s) of Instruction
English

Host Institution Course Number
73511

Host Institution Course Title
FLUID MECHANICS AND TRANSPORT PHENOMENA

Host Institution Campus
BOLOGNA

Host Institution Faculty
ENGINEERING

Host Institution Degree

Host Institution Department
ENGINEERING

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