1EL7000 – Transport Phenomena

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Department: DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS
Language of instruction: ANGLAIS, FRANCAIS
Campus: CAMPUS DE PARIS - SACLAY
Workload (HEE): 60
On-site hours (HPE): 35,00

Description

The objective of this course is to teach the basic notions of mass, species, momentum and heat transfer necessary to the characterization and scaling of multiple systems. Due to the strong analogy between species transfer and heat transfer on the one hand and the intimate coupling between fluid dynamics and heat transfer inherent to the convection phenomenon on the other hand, this set of engineering sciences is very consistent and is part of the basic academic core in a large variety of industrial sectors covering energy (nuclear, fossil, renewable), transport (automobile, aircraft, aerospace), industrial processes (chemical, biomedical), health, building, … Moreover, a good knowledge of these transfer sciences is absolutely necessary in the booming domain of the optimization of industrial processes. Finally, several current environmental issues and challenges for society such as the reduction, the dispersion or the sequestration of pollutants or the climate change involve physical phenomena partly based on transfer sciences. To solve all the serious problems that humanity is facing in the beginning of this 21st century, many important developments and breakthroughs will have to be achieved in the domains of technology, health and environment. In this context, a good background in mass, species, momentum and heat transfer is a major advantage for engineering students, and this set of sciences is essential for the training of high level engineers.
The course is composed of a dense theoretical content (mass and species transfers, fluid dynamics, heat transfer by conduction, convection and radiation in diverse configurations: steady-state or transient, isolated or coupled phenomena, boundary layers), and after each lecture a practical engineering problem illustrating the notions introduced is solved in tutorial classes.

Quarter number

SG1 and SG3

Prerequisites (in terms of CS courses)
Basics of mathematics and thermodynamics (studied during the first 2 university years)

Syllabus

- THE BASICS OF RADIATION HEAT TRANSFER :
  Notions of opaque body and of transparent medium. Notions of emitted, absorbed, reflected, leaving, incident and radiative heat fluxes. Writing boundary conditions involving radiative heat exchanges. Notion of spectral directional intensity. General expression of a radiation heat flux. Notion of equilibrium radiation – Properties of the associated spectral intensity.

- RADIATIVE PROPERTIES AND RADIATIVE TRANSFER :
  Characterization of the surface of an opaque body : notions of emissivity, absorptivity and reflectivity. Notions of gray body, black body, and diffuse body. Simple models of radiative transfer between 2 opaque bodies separated by a transparent medium : (1) opaque, convex and isothermal body surrounded by an isothermal black body ; (2) opaque, convex, isothermal and small body surrounded by an opaque isothermal enclosure.

1. INTRODUCTION TO THE STUDY OF FLUID FLOW :
   Theorem Pi. Types of flows. Description of motion and material derivative. Velocity and acceleration of a fluid particle. Transport theorems. General local balance of mass. Description of species mixtures.

- SPECIES MASS TRANSFER – DIMENSIONAL ANALYSIS :
  Local balance equation of species mass. Species absolute velocity, mixture mass-average velocity, diffusion velocity. Analogy between heat and mass transfers (diffusion and convection). Fick's law (binary mixture, dilute gas or liquid). Physical origins, order of magnitude of the mass diffusivity. Boundary conditions – Discontinuous concentrations at interfaces. Dimensional analysis to carry out a priori approximations. Characteristic time and length scales. Link with Pi theorem. Similitude conditions.

- BALANCE OF MOMENTUM :
  General motion of a fluid particle. Strain rate tensor. Stresses in fluids. Relation between stress and strain rate tensors in Newtonian fluids. Local balance equation of momentum. Euler equations. Navier-Stokes equations. Dimensional analysis of Navier-Stokes equations. Local balance equation for kinetic energy.

- ENERGY BALANCE EQUATIONS :
  Local balance equation of energy. General formalism and similarities of transport equations for mass, species concentrations, momentum and energy.Bernoulli theorem and applications. Macroscopic balance of mechanical energy. Study of incompressible flows in pipes. Friction head losses. Moody diagram. Singular head losses. Pump and turbine efficiency.

- MACROSCOPIQUES BALANCES :
  Macroscopic balance of mass and species. Momentum theorem in steady flows. Moment of momentum theorem. Application to the determination of hydrodynamic forces and moments. Thrust of turboengines and rockets. Macroscopic balance of thermal energy.

- INTRODUCTION TO THE PHYSICS OF BOUNDARY LAYER :
  Boundary layer theory. A priori estimates of the laminar boundary layer thickness. Separation and transition. Definition of boundary layer thicknesses. The boundary layer equations for a laminar flow over a flat plate. Numerical solutions of equations of a laminar boundary layer on a flat plate without pressure gradient.

- EXTERNAL FORCED CONVECTION – 2D MECHANICAL AND THERMAL BOUNDARY LAYER MODEL :
  Approximate solutions of the boundary layer equations for a laminar flow over a flat plate with the integral method. Effects of pressure on boundary layers. Thermal boundary layer in external forced convection. General form of correlation formula for external forced convection. Simplifying hypotheses and simplified heat transport equation. Integral method applied to thermal boundary layer.

- NOTIONS OF INTERNAL FORCED CONVECTION :
  Elementary notions on the mechanical and thermal entrance zones and on the fully developed mechanical and thermal regimes. Notion of bulk velocity and bulk (or mixture) temperature. Determination of the velocity profile in fully-developed laminar regime. Expressions of the Nusselt number for laminar and turbulent flows and for a duct of circular cross-section. Internal convection in laminar and turbulent regimes. Notion of hydraulic diameter.

Class components (lecture, labs, etc.)

The course is given several times in French or English during the SG1 and SG3 sequences.

Sequence SG1

- Occurrence 1.1 (French) : Hervé Duval
- Occurrence 1.2 (English) : Gabi Stancu
- Occurrence BCPST (French) : Julien Colin

Sequence SG3

- Occurrence 1.3 (French) : Fabien Bellet
- Occurrence 1.4 (French & English) : Ronan Vicquelin, Antoine Renaud
    - Amphitheater + TD (French) : Ronan Vicquelin
        - *Default affectation in occurence 1.4 is in the French course*
    - One classroom (English) : Antoine Renaud
        - *Once the students are enrolled in occurence 1.4 (displayed as tough in French in the MyWay poll), they can choose afterwards to follow the English class.*

Eleven 3-hour sessions are scheduled.

Grading

A Continuous Exam (CC) grade is determined by evaluating the students through two mandatory short tests treated in class without any printed documents.
A Final Exam (FE) grade is determined though a 2h00-long written exam where printed documents are allowed.
The final grade obtained for the course is computed as the weighted grade NF = 0.33xCC + 0.67xCF

Course support, bibliography

• Provided course material
• Polycopié CentraleSupélec « Mécanique des Fluides » ; Tome I ; Sébastien Candel.
• « Transferts thermiques - Introduction aux transferts d’énergie » ; 5ème édition ; auteurs : Jean Taine, Franck Enguehard et Estelle Iacona ; Dunod, Paris, 2014.

Resources

• Teaching staff (instructor(s) names): Fabien Bellet, Julien Colin, Hervé Duval, Antoine Renaud, Gabi Stancu, Ronan Vicquelin
• Maximum enrollment (default 35 students): 100-120 per session, and 35 per tutorial class, which means 3 tutorial classes per session.

Learning outcomes covered on the course

At the end of the course, the student will be able to :

1. Identify different modes of heat and mass transfer taking place in a given configuration,
2. Write appropriate balances (mass, species, momentum, energy), jump conditions at interface, to determine the evolution of different fields (species concentrations, velocity, pressure, temperature),
3. Compute stresses, heat fluxes, forces, mechanical and thermal powers, efficiencies, head losses.
4. Model complex systems, a necessary step to their conception and optimization:

    - Make approximations and estimations,
    - Simplify an apparently complex system
    - Use fundamental balances to solve practical problems

Description of the skills acquired at the end of the course

The course is part of the C1 and C2 competencies of the CentraleSupélec engineering curriculum.

C1 : Analyse, design and build complex systems with scientific, technological, human and economic components

C1.1: Analyse : study a system as a whole, the situation as a whole. Identify, formulate and analyse a system within the framework of a transdisciplinary approach with its scientific, economic, human dimensions, etc.

C1.2: Model : use and develop appropriate models, choose the right scale of modelling and relevant simplifying assumptions

C2 : Develop an in-depth competence in an engineering field and in a family of professions

C2.1 : Go deeper into an engineering field or scientific discipline

Core skills in CentraSupélec curriculum :

- C1 (C1.1, C1.2) and C2 (C2.1)

C1 is validated if CF >= 10.
C2 is validated if NF >= 10.