2EL1410 – Heat Transfer

Instructors: Benoît Goyeau, Gabi-Daniel Stancu
Department: DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS
Language of instruction: FRANCAIS, ANGLAIS
Campus: CAMPUS DE PARIS - SACLAY
Workload (HEE): 60
On-site hours (HPE): 35,00
Elective Category : Engineering Sciences
Advanced level : Yes

Description

Heat transfer covers broad scientific and technical domains. The field of application of this discipline is characterized, among other things, by considerable spatial and temporal scales: from the nanometer (thematic of the heat transfer at nano-scale) to interstellar distances (astrophysics), from the femtosecond (thermal response of a ultra-short laser) to the characteristic time of the genesis of the universe (thermal evolution of stars). Heat transfer concerns also society subjects and major challenges such as energy (energy optimization of industrial processes, thermal insulation of buildings, ...), environment (global warming, atmospheric greenhouse effect, etc.) or transport (optimization of thermal engines, fuel cells and hydrogen sector, ...). It is inherently a discipline in which the physical phenomena are of very different natures, coexist and are coupled.

This course develops and extends the concepts of heat transfer introduced in the courses "Transport phenomena" and "Modeling and simulation of unsteady heat transfer". Furthermore, the emphasis here is on the achievement of basic notions (via simple exercises - EAI) and on the techniques of physical modeling of the heat transfer (via synthesis problems-PbS).

Domain interests:
Design, master and control any system or process in any field where heat transfers appear such as residential and tertiary housing, transport, industry, energy production, etc.. Some universe sciences (meteorology, geophysics, ...) as well as the environmental sciences also rely partly on the control of heat transfers.

Teaching objective:
Address the main heat transfer modes in simple cases. This scientific training is intended for future generalist engineers, a priori not specialists in the discipline.
This is a basic teaching of: steady and unsteady conduction; radiation between opaque bodies in a transparent environment; forced, natural,

laminar and turbulent convection (phenomenological approach).The treatment of exercises and problems during tutorials is an opportunity to apply the knowledge introduced during lectures and to develop simple energy balance models. It involves solving concrete industrial, environmental or metrological problems (using an inductive approach). Using simple examples, some exercises of a didactic character introduce fundamental notions in heat transfer. Synthesis problems are proposed at the end of the course. In these, the main difficulty is to build the thread of the solution (confrontation with unclear and uncertain).
In addition, many exercises are treated in the course book. They are an excellent training.

Quarter number
SG6 and SG8

Prerequisites (in terms of CS courses)
Ideally, the students have taken the courses "Transport Phenomena" (elective course 1A, SG1or SG3) and "Modeling and simulation of unsteady heat transfer" (specific course in energy 1A, ST2). However, students who have not taken the two courses will be able to follow this elective but they will have, before the sessions, to work the courses that are available on the E-learning platform "E-SELF-LEARNING".

Syllabus
• Session 1 Lecture BASICS OF HEAT TRANSFER: Conduction, convection, radiation. Introduction to conducto-convective transfer.Steady state energy balance of a fixed system at rest. Electrical analogy.
o Tutorial (EAI) Wall between two fluids; Temperature profile in a 1D-system; (PbS) Insulation of a cryogenic container
• Session 2 Lecture FIN AND FIN APPROXIMATION
o Tutorial (EAI) Heated plate; Cooling of an electronic circuit; (Pbs) Efficiency of an home radiator; Liquid temperature measurement - glove finger (home work)
• Session 3 Lecture BASICS OF THERMAL RADIATION: Concept of: opaque body, transparent medium, emitted, absorbed, reflected, leaving, incident and radiative fluxes. Boundary conditions in the presence of radiative exchanges. The concept of directional spectral intensity. First expression of the radiative flux. Concept and properties of the equilibrium radiation.
o Tutorial (EAI) Calculations of solid angles and fluxes; Spectral integral calculations of Planck's law; (PbS) Principle of infrared remote sensing of a body
• Session 4 Lecture RADIATIVE PROPERTIES AND RADIATIVE TRANSFER: Characterization of the surface of an opaque body: notions of emissivity, absorptivity and reflectivity.Concept of: gray body, black body and body with isotropic radiative properties. Simple models of radiative transfer: (i) isothermal convex opaque body surrounded by an isothermal black body; (ii) isothermal convex opaque body of small dimensions surrounded by an opaque isothermal enclosure.

o Tutorial (EAI) Radiation between two spheres; (PbS) Temperature of a body exposed to solar radiation

• Session 5 Lecture GENERAL METHOD OF RADIATIVE TRANSFER BETWEEN OPAQUE BODIES IN TRANSPARENT ENVIRONMENT: Basic assumptions of the method. Expression of the leaving and incident fluxes. Expression of the leaving energy rate. Concept of view factor - properties. Equations for a closed enclosure made up of gray surfaces. Generalization to non-gray surfaces.

o Tutorial (EAI) Radiation « face to face »; (PbS) Radiative screen - temperature measurement by a thermocouple

• Session 6 Lecture UNSTEADY DIFFUSION: HEAT CONDUCTION (1/2): Energy balance equation and boundary conditions. Notion of thermal diffusivity. General theorems: superposition and Π theorems. Application to a semi-infinite geometry (response to short times): problems of imposed temperature, imposed flux and forced periodic excitation

o Tutorial (EAI) Modeling of a 2D unsteady conduction problem; 1D unsteady conduction - analytical solution in case of imposed flux; (PbS) Thermal inertia of a building (1/2)

• Session 7 Lecture UNSTEADY DIFFUSION: HEAT CONDUCTION (2/2): Application to a semi-infinite geometry (response to short times - continued): problem of the thermal contact of two bodies. Case of finite media. Conductive and conducto-convective characteristic times, Biot number – recall the fin approximation

o Tutorial (EAI) Cooling of a transparent ball (PbS) Thermal inertia of a building (2/2); Laser treatment of steel

• Session 8 Lecture PHENOMENOLOGICAL APPROACH OF EXTERNAL FORCED CONVECTION: Diffusion (at wall) and convection (far from wall) fluxes. Concept of fluid viscosity. Problem of the plate at imposed temperature. Dimensional analysis. Correlation general form for external forced convection. Introduction and physical meanings of characteristic dimensionless numbers. Similarity notions in forced convection. Criteria of transition between laminar and turbulent regimes in standard configurations. Evolution of the local transfer coefficient along a plate; leading edge effect.

o Tutorial (EAI) Bay window on forced external convection; (PbS) Conductor, prudence !

• Session 9 Lecture INTERNAL FORCED CONVECTION: Basic notions on establishments of mechanical and thermal regimes and on established regimes in ducts of constant cross-section. Concept of mixing temperature. Nusselt number expression in laminar and turbulent regimes for flows in circular cross-section; physical discussion of results. Cases of ducts of non-circular cross-section; concept of hydraulic diameter.

o Tutorial (EAI) Calculation of the transfer coefficient in a semicircular channel; (PbS) Helium as a heat-exchanging fluid; Circulation of water in a tube (home work)

• Session 10 Lecture DIMENSIONAL ANALYSIS OF NATURAL CONVECTION: Physical phenomenon - approximation of Boussinesq. Mechanical and

thermal boundary layers. Dimensional analysis - similarity. Criterion of transition between laminar and turbulent regimes. Expressions of transfer coefficient. Specificities of internal natural convection. Iterative character of the natural convection calculation.
o Tutorial (PbS) Thermal study of double glazing
• Session 11
o Tutorial SYNTHESIS PROBLEMS (PbS) Energy recovery for residential tertiary; Air conditioning of a building in a hot and sunny region (home work)
• Session 12 FINAL EXAM

Class components (lecture, labs, etc.)
The course is proposed in SG6 (in English) and in SG8 (in French) in the format of 11 sessions of 3 hours duration.

Grading
The first two learning outcomes constitute the minimum level of knowledge expected for any student who has taken this course. They will be evaluated during the course by short multiple-choice tests. These unrated tests will allow students to self-assess and teachers to measure the level of understanding of some fundamental notions and to detail the difficult points. Regarding the modeling activity of thermal systems, it is a complex skill to acquire. Students will learn this progressively during tutorials classes. The last session of the teaching will be an opportunity to consolidate all the modeling achievements. The learning outcomes will be assessed in the final exam (2H), which will consist of two parts. The first will focus on the assessment of the first two learning outcomes. In the second, students will be subjected to a complex modeling problem in order to evaluate the learning outcome modeling of thermal systems.
The core skill C1.2 is validated if the student accomplishes at least 50% of the part 2 of the final exam. The core skill C2.1 is validated if the student accomplishes at least 50% of the part 1 of the final exam. The final grade is the average of the grades of the two parts of the exam.

Course support, bibliography
• Book in English: « A first course in heat transfer » J. Taine, E. Iacona Editions Dunod 2011.
• Book in French: « Transferts Thermiques » Partie 1, J. Taine, F. Enguehard, E. Iacona, Dunod 2014.
• Platform « E-Self-Learning « in English : http://e-mentor-en.ecp.fr/ course presented by G.D. Stancu.
• Platform « E-Self-Learning « in French : http://e-mentor2.ecp.fr/ course presented by J. Taine.

Resources
•Teaching staff (names of instructors): Gabi Daniel Stancu, Benoit Goyeau

• Size of tutorial (TD) classes: 35
• Platforms « E-Self-Learning « in French and in English
• Software tools and number of licenses needed: non
• Experimental rooms (department and capacity): non

Learning outcomes covered on the course
At the end of this course, the students:
o Will be able to identify the different heat transfer modes present in a given configuration,
o Will be able to write and use appropriate energy balances in their local and global forms and continuity equations at the interfaces, thus, will be able to determine thermal fluxes and temperature fields in a system, and therefore will be capable to calculate local and global characteristics needed for the design of thermal systems
o Will have acquired modeling skills of thermal systems:
- List exhaustively the heat transfer phenomena present in a given system,
- Use scale analysis: (i) to make orders of magnitude estimates in order to discriminate predominant phenomena from those that can be ignored; (ii) to simplify problems a priori in three-dimensional geometries and / or unsteady towards models with analytical solutions,
- Use an inductive problem-solving approach: make appropriate and justified hypotheses which will be validated a posteriori by the resulting solutions,
- Reformulate a multi-physical and multi-scale problem with complex coupling phenomena, in a simplified version in which only the predominant phenomena have been considered,
- Model complex thermal systems and use fundamental energy balances to solve engineering problems.

Description of the skills acquired at the end of the course

• C1.2 « Choose the appropriate model (among several possible) for a given problem thanks to the right choices of modeling scale and simplifying assumptions »
• C2.1 « Deepen all knowledge in a chosen field, via the courses of the 2nd year»