Master 2 Thermal Sciences and Energy

Syllabus

Fundamentals of Heat Transfer:

- Engineering Heat Transfer
- Physics of Heat Transfer
- Advanced Heat Transfer
  - Convection Heat Transfer
  - Radiative Heat Transfer

Experimental and Numerical Methods

- Experimental Methods
- Numérical Methods
- Inverse Problems

Fluid Mechanics

- Fundamentals
- Turbulence and Turbulent flow
- Hydrodynamic stability and Dynamical Systems

Heat Transfer In Solids and heterogeneous media

- Heat Transfer at Interfaces
- Heat Transfer In Polymers and Composite Materials
  - HT with Phase Change
  - Heat Transfer during Composite Injection

Fundamentals of Heat Transfer

Engineering Heat Transfer (EHT)

by A. Ould El Moctar

(15 h)

OBJECTIVE

The objectives of this first course in heat transfer is (i) to introduce the fundamentals of this subject, (ii) to establish the relationship of these origins to the behavior of thermal systems.

It should develop methodologies which facilitate application of the subject to a broad range of practical problems and it should give necessary tools to perform engineering analysis providing useful information concerning the design and/or performance of a system or process.

Table of contents:

Introduction
Conduction
    One-D steady-state Conduction
    Transient Conduction
Convection : Usual concepts and relationships (Correlations).
    External Flow
    Internal Flow
    Free Convection
Radiation
        Processes and Properties
        Exchange Between Surfaces

Physics of Heat Transfer (PHT)

by B. Garnier and B. Rousseau

(18h)

OBJECTIVE

The objectives of the " Physics of heat transfer" course are: (i) to show the physical basis of the laws governing heat transfer in solids and fluids (ii) to develop microscopic analysis (up to the particle scale) of the different heat transfer mode (iii) to present a synthesis on the various analytical solutions of heat transfer equation.

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Advanced convective heat transfer (CHT)

by H. Peerhossaini and J. Bellettre

(18h)

Objective

This course is designed based on the axiom that the engineering student should learn to reason from first principals to avoid being at loss when faced by new a problem. It aims at giving in depth and easily usable knowledge of convective heat transfer at graduate level. It is assumed that the student has a typical undergraduate background in applied thermodynamics, fluid mechanics and heat transfer.

Table of contents:

Momentum transfer in turbulent boundary layer

Heat transfer in turbulent boundary layer

Momentum transfer in turbulent flow in pipes

Heat transfer in turbulent flow in pipes

Radiative Heat Transfer (RHT)

by B. Rousseau

(9h)

OBJECTIVE

The objectives of the "Radiative Heat Transfer"course are: (i) to introduce the fundamental basis governing the exchange of energy with thermal radiation (ii) to make the link between the optical thickness and the properties of a given material (iii) to analysis the radiative exchanges in solid participating media (iii) to understand absorption and scattering by particles, fibers, and agglomerates

Table of contents:

Introduction (spectral intensity, black body, properties at interfaces, properties at volumes)
Mean penetration distance for different families of material (polymer, ceramic, metal,…)
Radiative Transfer Equation
Solution of the Radiative Transfer Equation in Participating Media
Mie scattering theory

Experimental and Numerical Methods

Experimental Methods (EM)

by B. Garnier and A. Ould El Moctar

(15h)

OBJECTIVE

The objective of this course is to initiate students about the different physical phenomena and frequently encountered errors in the measurement of temperature, heat flux and the velocity field, pressure and concentration in fluid flow. In each case the classical tools of measurement processing will be mentioned with the values and characteristics obtained and the constraints imposed on the signal processing quality.

Table of contents:

An overview of different techniques of measurement of the velocity in the isothermal and non-isothermal flows (hot wire, hot film, LDV, PIV) will be provided with an emphasis on the physical principle of the measurement to promote the choice of method and understanding of the uncertainties induced.
Most useful visualization methods in fluid flow will also be addressed by going from tracking of tracer in interferometry via shadowgraph methods. The use of these techniques to obtain the temperature field or pollutant concentration will be discussed as well as in situ measurements to obtain the composition or density of the fluid.

We also present the thermometric thermometry phenomena used in contact and contactless configuration (thermoelectric effect, electrical resistance heat, pyrometry and infrared imaging), methods of manufacture of sensors (including thermocouples), the errors due to on the one hand the physical phenomenon (inaccuracy on measuring the size, parasitic effects ...) and on the other hand to the disruption of local temperature field (analysis and modeling errors).
Finally, we recall the different methods of measuring heat flux (flux sensors or enthalpy gradient or power dissipation, microcalorimetry, inverse method) and the main techniques for measuring thermophysical properties of materials.

Numerical methods (NM)

by Y. Favennec

(12h)

OBJECTIVE

The objective of this course in numerical methods is to give some basic theoretical bases along with some practice skills for heat transfer modeling. The course shall begin with an introduction to potential applications with the usual related pitfalls. The major tools for solving linear matrix systems and differential equations and systems shall be presented, along with the necessary compromise between accuracy and time consumption. We will then go more deeply to the general method of finite differences, and then specially to the finite elements. We will emphasize on the relations between discretization and solution errors. All theoretical notions will be completed with basic practical applications during tutorials, probably on the open source environment Freefem++. The course will end with the use of the industrial computation tool Fluent for computing, step by step, the solution of a particular complex turbulent flow.

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Inverse Problems (RPI)

by Y. Favennec

(17h)

OBJECTIVE

The objective of this course in numerical methods is to give some basic theoretical bases along with some practice skills for inverse heat transfer. The course shall begin with an introduction to inverse problems and the main differences with the so-called direct problems. It will be shown that solving inverse problems may enhance the quality of direct problems after recovering lacking data. Different optimization methods (deterministic, stochastic) will be presented, but gradient-type methods shall be more deeply studied. It will be shown how regularization tools may enhance the quality of the solution, since the inverse problems are likely to be ill-posed. Different regularization methods will be presented according to specific cases. The whole theory will be applied on a relatively simple academic example, for which the numerical modeling have been developed in the previous course (numerical methods).

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Fluid Mechanics

Fundamentals (FFM)

by P. Dupont or A. Ould El Moctar

(12h)

OBJECTIVE

The objectives of this first course is to give an introduction to Fluid Dynamics. First, we will develop the concept of control volume. Then we will establish the differential equations of conservation. Some solutions of these equations will be developed for simple internal and external flows.

It should give the background required by more advanced courses in fluid mechanics and convective heat transfer.

Table of contents:

Introduction
Integral Approach
- Reynolds Transport Theorem
- Conservation of Mass
- Momentum Equation
- Energy Equation
- Bernoulli Equation

Differential Approach
- Equation of Mass Conservation
- Equation of Momentum
- Boundary Layer
- Internal flows

Turbulence and turbulent flow (TTF)

by M. Visonneau

(12h)

Objective

This course gives a solid background in the subject of turbulence, developing both physical insight and the mathematical framework needed to express the theory. The course begins with a review of the physical nature of turbulence, statistical tools, and space and time scales of turbulence. Then the basic theory is presented, illustrated by examples of simple flows and developed through wall bounded turbulent flows.

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Hydrodynamic stability and dynamical systems (HSDS)

by A. Valance

(15h)

Objective

After a short description of the notion of stability, we choose the Rayleigh-Bénard thermoconvective stability as an example on which we develope the *linear theory of stability*.

In the second part of the course, the notion of *dynamical systems* is introduces and theoretical tools for characterization of these systems are developed. We then proceed to the notion of chaos and use again the Rayleigh-Bénard thermoconvective system to develop the Lorenz model, which we study in details to introduce the notion of strange attractor and scenarios of transition to turbulence.

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Notion of hydrodynamic stability

The Bénard problem

The nature of the physical problem

The basic hydrodynamic equations

The Boussinesq approximation

The perturbation equations

The analysis into normal modes

The equations of marginal state

The cell patterns

Phenomenology of chaos

Theory of nonlinear dynamics and chaos

Three-dimensional state space and chaos

Measures of chaos

Lorenz model

Heat Transfer in Solids and Heterogeneous Media

Heat Transfer at Interfaces (CTI)

by B. Bourouga

(12h)

Objective

This course concerns the heat transfers at solid-solid interfaces, knowing that the contact can be static, dynamic or mobile (sliding, rolling or intermittent). The thermal boundary condition at solid-solid imperfect contact is of the third kind and the coefficient which relates the thermal gradient to the temperature at the interface is the thermal contact resistance. Moreover, when the interface is seat of heat generation, this boundary condition becomes inhomogeneous and the non-homogeneity is the product of the generated heat flux by a coefficient representing the share of the dissipation between the two faces in contact. The goal of this course is to present theoretical approaches which allow describing each one of the two parameters. These approaches are founded on three disciplines: the surfaces topography (rough surfaces), contact mechanics and heat transfers. The basic phenomena relative to each type of interface of contact are approached. We evoke successively the static, dynamic and moving contacts. The thermo-mechanical couplings specific to each type are underlined.

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Heat Transfer with Phase Change (TTCP)

by D. Delaunay

(12h)

Objective

This lecture aims to give students the required basic knowledge to analyze, model and simulate a problem involving a phenomenon of melting or solidification with coupled heat transfer. He acquires useful knowledges for many material forming processing (metals, plasma deposition,...), or in the field of energy (latent heat storage, new coolant fluids).

Content of lectures

1. General points on the phenomena of melting and solidification: Classification, Theoretical approach (nucleation and growth), Structures and morphologies, Coupling with heat transfer.

2. Thermophysical properties and phase change: Specific heat, Thermal conductivity, Kinetics of cristallization, State equations.

3.The classic problem of Stefan-Neuman.

4. Contact between two materials and phase change.

5. Boundary conditions during phase change (contact resistances)

6. Influence of the natural convection during melting and solidification.

7. Numerical modelling: The enthalpic method, the front tracking methods.

8.Some applications through examples: Energy storage systems, solidification of foundry ingots.

Heat Transfer during Composite Injection (Comp. Inj)

by V. Sobotka and N. Boyard

(12h)

Objective

The goal of this course is to study two techniques of thermoset composites moulding: Resin Transfer Moulding Process (RTM) and Bulk Moulding Compound process (BMC). The coupled physical phenomena involved with these processes are presented and modelled.

Content of lectures

-The RTM process:

- Presentation of the process technology.
- Analysis of heat transfer part/tool. Modelling of the filling of the part.
- Modelling of the curing of the part.
- Simulation issues.

-The BMC process:

- The BMC material and the features of its components.
- Analysis and interpretation applied to a specific part: pressure, temperature, heat flux.
- Simulation issues.