UNIVERSITÀ DEGLI STUDI DI PALERMO

DEPARTMENT	Ingegneria
ACADEMIC YEAR	2022/2023
BACHELOR'S DEGREE (BSC)	ENERGY ENGINEERING AND RENEWABLE ENERGIES
SUBJECT	THERMOHYDRAULICS
TYPE OF EDUCATIONAL ACTIVITY	B
AMBIT	50304-Ingegneria nucleare
CODE	07544
SCIENTIFIC SECTOR(S)	ING-IND/19
HEAD PROFESSOR(S)	DI MAIO PIETRO ALESSANDRO — Professore Ordinario — Univ. di PALERMO
OTHER PROFESSOR(S)	
CREDITS	9
INDIVIDUAL STUDY (Hrs)	144
COURSE ACTIVITY (Hrs)	81
PROPAEDEUTICAL SUBJECTS	
MUTUALIZATION	
YEAR	3
TERM (SEMESTER)	1° semester
ATTENDANCE	Not mandatory
EVALUATION	Out of 30
TEACHER OFFICE HOURS	**DI MAIO PIETRO ALESSANDRO** Monday 10:00 11:00 Dipartimento di Energia, Ingegneria dell'Informazione e Modelli Matematici - Edificio 6 - I Piano - Stanza 115 Wednesday 10:00 11:00 Dipartimento di Energia, Ingegneria dell'Informazione e Modelli Matematici - Edificio 6 - I Piano - Stanza 115 Friday 10:00 11:00 Dipartimento di Energia, Ingegneria dell'Informazione e Modelli Matematici - Edificio 6 - I Piano - Stanza 115

DOCENTE: Prof. PIETRO ALESSANDRO DI MAIO

PREREQUISITES	Knowledge of fundamentals of: - integral and differential calculus - classic physics - technical physics
LEARNING OUTCOMES	KNOWLEDGE AND UNDERSTANDING By the end of the course, the student will have acquired an adequate level of knowledge and understanding on the following topics: Part I – Heat Conduction •Derivation of the differential heat conduction equation from the first principle of Thermodynamics and Fourier's law. Extension to the general diffusion problem; Fick's law. • Thermodiffusive properties of solids and fluids. Density, thermal conductivity, specific heat, thermal diffusivity. Brief remarks on anisotropic diffusion. • Thermal boundary conditions and their classification (Dirichlet, Neumann, Cauchy). •Application to one-dimensional steady state problems, also in the presence of internal heat sources. Basic geometries (slab, cylinder, sphere). Brief remarks on multi-dimensional problems. Electric analogy and concept of thermal resistance / conductance. Series and parallel resistances. • Application to transient one-dimensional problems in the basic geometries (slab, cylinder, sphere). Use of dimensionless solutions. Biot and Fourier numbers. Eigenfunctions, eigenvalues and time constants. •Lumped-parameter treatment of heating and cooling problems. •Simple problems of conjugate heat transfer. Fins. Critical insulation thickness. Part II – Single-Phase Thermal-Hydraulics • Derivation of the differential governing equations for convective problems (continuity, Navier-Stokes, energy). Newtonian fluids. Compressible and dilatable fluids. • Thermophysical and transport properties of fluids. Reynolds and Prandtl numbers. Equations of state. •Distributed and concentrated head losses for constant-property fluids in the one-dimensional approximation. Friction and drag coefficients, Moody chart, laminar and turbulent flow, transition criteria. Hydraulic diameter. •Bernouilli equation and its applications to incompressible fluid dlow. • Convective heat transfer to and from constant-property fluids in the one-dimensional approximation. Definitions of bulk temperature, wall heat transfer, heat transfer coefficient, Nusselt number. Heat transfer correlations. Part III – Two-Phase Thermal-Hydraulics • Classification of multi-phase flows (solid-liquid, gas-solid, gas-liquid, liquid-liquid). Mechanical and thermodynamic equilibrium. • Gas-liquid two-phase flow: concepts of quality and void fraction. Slip ratio. Relations between the main quantities. Homogeneous and non-homogeneous models. • Gas-liquid two-phase flow regimes in horizontal, vertical and inclined pipes. One-dimensional equations governing the flow of gas-liquid mixtures (continuity, momentum, energy). • Gravitational, expansion and frictional pressure variations. Two-phase friction multipliers and their application. • Vaporization. Distinction between evaporation, subcooled boiling, saturated boiling. Distinction between pool boiling and flow boiling. Heat transfer to boiling fluids: nucleate, partial film, film boiling. Thermal crisis, departure from nucleate boiling and Nukiyama curve. Boiling heat transfer correlations. Brief remarks on condensation. • Flow rate – pressure drop correlation in heated boiling tubes. Ledinneg instability. Influence of inclination and flow direction. The evaluation will be done through oral examination. APPLYING KNOWLEDGE AND UNDERSTANDING By the end of the course, the student will be able to analyse and, whenever possible, to solve by simple methods, basic fluid mechanics and heat transfer problems. In particular, the student will be able to: • Identify the problem's nature (conductive, convective, mixed; steady-state or transient; laminar or turbulent). •Identify the problem's dimensionality (0-D, 1-D, 2-D, 3-D) and the possibility of reducing it by exploiting symmetries or by adopting appropriate simplifying assumptions. • Identify the correct boundary (and, if appropriate, initial) conditions corresponding to the problem's formulation. •Choose the most appropriate equations and correlations for the calculation of exact or approximate solutions to the problem submitted. •Compute such solutions or specify an algorithm to compute them.

	The evaluation will be done through oral examination. MAKING JUDGEMENTS By the end of the course, the student will have acquired the ability to make judgments on: • The applicability of a given correlation, simplifying hypothesis or equation to a prescribed problem in thermal hydraulics. • The possible correctness of a hypothetical solution proposed for a prescribed problem in thermal hydraulics. The evaluation will be done through oral examination. COMMUNICATION SKILLS By the end of the course, the student will be familiar with the technical language used in the context of thermal hydraulics, and will thus be able to interact with professionals and / or researchers of the subject. The evaluation will be done through oral examination. LEARNING SKILLS By the end of the course, the student will be able to study autonomously textbooks, articles and reports concerning thermal-hydraulics problems, extracting from them usable information and identifying their quality, reliability and relevance to a prescribed problem. The evaluation will be done through oral examination.
ASSESSMENT METHODS	The final evaluation is based on an oral exam evaluated in thirty. The minimum grade to pass the exam is 18/30. The exam lasts 40 to 50 minutes and consists of an interview, divided into at least three open-ended questions concerning the whole program of the course. It is aimed at verifying: - the level of knowledge, understanding and grasp of the course content (50% of final evaluation); - the ability to apply with independent judgment and methodological rigor knowledge and skills acquired to the analysis and solution of typical issues (30% of final evaluation); - the correct use of language and the clarity (10% of final evaluation); - the ability to critically revise the acquired concepts, placing them in the appropriate logical connection with the various issues addressed in the course and in those related to it (10% of final evaluation). EVALUATION METRICS - 30 - 30 cum laude (excellent): excellent knowledge and mastery of the course content illustrated with full language skills and clarity, strong aptitude to apply with independent judgment and methodological rigor skills acquired recasting them critically. - 27 - 29 (distinguished): full knowledge of the course content illustrated with language skills and clarity, ability to apply with good independent judgment and methodological rigor skills acquired. - 24 - 26 (good): good knowledge of the course content illustrated with language skills, modest aptitude to apply with a good autonomy skills acquired. - 22 - 24 (satisfactory): satisfactory knowledge of the main contents of the course illustrated with acceptable technical language, poor level of autonomy in the application of acquired skills. - 18 - 21 (sufficient): minimal knowledge of the essential contents of the course and of the relevant technical language, poor quality or no autonomy of application of acquired skills.
EDUCATIONAL OBJECTIVES	The course aims at providing the student with an adequate knowledge of convective-diffusive transport phenomena of mass, momentum and energy and of their pertaining governing equations in integral and/or differential formulation. The first part of the course will be dedicated to steady-state and transient heat conduction problems, including conjugate conductive-convective problems and problems concerning bodies with internal heat generation. Simple, one-dimensional geometries relevant to industrial and civil engineering will mainly be considered. The second part of the course will be dedicated to problems in fluid mechanics and convective transport. A special attention will be given to the computation of pressure losses in pipes, to the application of Bernouilli's equation to constant-property fluids and to the correct choice and application of heat transfer correlation via the use of dimensionless numbers. Finally, the last part of the course will regard simple, one-dimensional models of two-phase flow in pipes, with special reference to gas-liquid mixtures and boiling heat transfer. Several tutorials will be used to apply the concepts learned to the actual solution

	(exact or approximate) of thermal hydraulic problems in simple geometries.
TEACHING METHODS	The teaching activity is articulated in frontal lessons and computational exercises, mainly carried out with mathematical software tools.
SUGGESTED BIBLIOGRAPHY	- J. R. Welty, C. E. Wicks, R. E. Wilson, J. L. Rorrer, Fundamentals of Momentum, Heat and Mass Transfer, John Wiley & Sons Inc, 2008, ISBN: 0470128682 - F. P. Incropera, D. P. DeWitt, Fundamentals of Heat and Mass Transfer, John Wiley & Sons, 2006, ISBN: 0471457280 - H. S. Carslaw and J. C. Jaeger, Conduction Of Heat In Solids, Oxford University Press, U.S.A., 1986, ISBN: 0198533683 - Materiali ausiliari (tabelle, grafici, dispense) forniti dal docente.

SYLLABUS

Hrs	Frontal teaching
2	Derivation of the differential heat conduction equation from the first principle of Thermodynamics and Fourier's law. Extension to the general diffusion problem; Fick's law.
2	Thermodiffusive properties of solids and fluids. Density, thermal conductivity, specific heat, thermal diffusivity. Brief remarks on anisotropic diffusion.
2	Thermal boundary conditions and their classification (Dirichlet, Neumann, Cauchy). Convective boundary conditions.
4	Application to one-dimensional steady state problems, also in the presence of internal heat sources. Basic geometries (slab, cylinder, sphere). Brief remarks on multi-dimensional problems. Electric analogy and concept of thermal resistance / conductance. Resistances in series and in parallel.
4	Application to transient one-dimensional problems in the basic geometries (slab, cylinder, sphere). Use of dimensionless solutions. Biot and Fourier numbers. Eigenfunctions, eigenvalues and time constants.
2	Lumped-parameter treatment of heating and cooling problems.
4	Simple problems of conjugate heat transfer. Fins. Critical insulation thickness.
4	Derivation of the differential governing equations for convective problems (continuity, Navier-Stokes, energy). Newtonian fluids. Compressible and dilatable fluids.
4	Thermophysical and transport properties of fluids. Reynolds and Prandtl numbers. Equations of state.
4	Distributed and concentrated head losses for constant-property fluids in the one-dimensional approximation. Friction and drag coefficients, Moody chart, laminar and turbulent flow, transition criteria. Hydraulic diameter.
4	Bernouilli equation and its applications to incompressible fluid dlow.
4	Convective heat transfer to and from constant-property fluids in the one-dimensional approximation. Definitions of bulk temperature, wall heat transfer, heat transfer coefficient, Nusselt number. Heat transfer correlations.
2	Classification of multi-phase flows (solid-liquid, gas-solid, gas-liquid, liquid-liquid). Mechanical and thermodynamic equilibrium.
4	Gas-liquid two-phase flow: concepts of quality and void fraction. Slip ratio. Relations between the main quantities. Homogeneous and non-homogeneous models.
2	Gas-liquid two-phase flow regimes in horizontal, vertical and inclined pipes. One-dimensional equations governing the flow of gas-liquid mixtures (continuity, momentum, energy).
2	Gravitational, expansion and frictional pressure variations. Two-phase friction multipliers and their application.
2	Vaporization. Distinction between evaporation, subcooled boiling, saturated boiling. Distinction between pool boiling and flow boiling. Heat transfer to boiling fluids: nucleate, partial film, film boiling. Thermal crisis, departure from nucleate boiling and Nukiyama curve. Boiling heat transfer correlations. Brief remarks on condensation.
2	Flow rate – pressure drop correlation in heated boiling tubes. Ledinegg instability. Influence of inclination and flow direction.

Hrs	Practice
3	Steady-state conduction in 1-D slab geometry. Electric analogy.
3	Steady-state conduction in 1-D cylindrical geometry without internal heat generation. Pipe.
3	Steady-state conduction in 1-D cylindrical geometry with internal heat generation. Nuclear fuel rod. Case of T-dependent thermal conductivity.
3	Transient conduction in 1-D geometries.
3	Conjugate heat transfer (fins).
3	Pressure drop in pipes. Application of common correlations and of Moody's chart.
3	Applications of Bernouilli's equation in constant property fluids.
3	Convective heat transfer in ducts. Application of dimensionless correlations. Calculations for uniform imposed wall heat flux and for uniform imposed wall temperature.
3	Pressure drop and heat transfer calculations for gas-liquid two-phase flow in ducts.