MEG611: Multiphase Thermal Fluids in Power and Energy Technologies

Program and Course Code	Mechanical Engineering Program MEG611
Course Title	Multiphase Thermal Fluids in Power and Energy Technologies
Credit Hours	3
Instructor	Dr. TieJun (TJ) Zhang
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Office Hours	Two hours for every hour of class, TBA in beginning of semester
Bulletin Course Description	This course aims to present a state-of-the-art understanding about phase-change phenomena in nature, power and energy industries. It covers different levels of phase-change principles from fundamental liquid-vapor interfacial behavior, to interfacial liquid-vapor transport dynamics, to evaporation and condensation characteristics, and to transient analysis of thermal-fluid cycles. Rigorous mathematical analysis, experimental and numerical videos are given to help students probe complicated multiphase thermal-fluid physics. Vivid examples are introduced to show the importance of advanced thermal-fluid research to power and energy innovation. Students completing this course are able to conduct independent research in this field.
Pre-requisites	MEG501 - Advanced Fluid Mechanics, MEG507 - Advanced Heat Transfer
Co-requisites	None
Course Objectives (Learning Outcomes of the Course)	After taking this course, students will be able to: • strengthen their understanding of heat and mass transport principles • strengthen their understanding of thermal-hydraulic behavior of key components in thermal/nuclear/solar power industries • obtain both mathematical and physical insights of transient energy transport through interdisciplinary studies • capture more physics of interfacial transport phenomena in nature • use first-principles models to design high-performance devices for emerging power and energy applications • develop quantitative techniques for control and optimal operation of complex power and energy systems

Week	Course Topics and Contents
1	Introduction, Motivation, and Review of thermal-fluid principles (thermodynamics, fluid mechanics, conduction/convection/radiation heat transfer)
2	Overview of fundamental mass/energy/momentum conservation principles (single-phase flow) and laminar boundary layer analysis
3	Fundamentals of liquid-vapor interfacial phenomena (surface tension, contact angle, wettability, cohesion and adhesion, capillary forces)
4	Liquid-vapor interfacial transport dynamics (Kelvin-Helmholtz and Rayleigh-Taylor instabilities), intrinsic phase stability and homogeneous bubble nucleation
5	Heterogeneous bubble nucleation (criteria for onset of nucleate boiling) and ebullition cycle (dynamics of bubble growth in liquid pools/ near heated surfaces, bubble departure)
6	Pool boiling (boiling curve and regimes, physical modeling of critical heat flux, film boiling and Leidenfrost phenomenon)
7	Internal two-phase flow (flow regimes, void fraction, annular flow with/without entrainment) and flow boiling (saturated/subcooled boiling, ONB, CHF, post-CHF boiling)
8	Evaporating and condensing flow and heat transfer characteristics (two-phase pressure drop

	and heat transfer correlations)
	Mid-Semester Break
9	Lumped dynamics of evaporator and condenser: converting PDEs to lumped subcooled/two-phase/superheated flow models (ODEs) with the moving boundary method
10	Distributed dynamics of evaporator, condenser, oil/gas pipeline-riser processes: discretizing spatial distribution of homogeneous/separated-flow and two-fluid models (PDEs)
11	Two-phase thermal-fluid transient analysis (Ledinegg flow excursion, pressure-drop and density-wave flow oscillations, thermal oscillation, parallel-channel flow maldistribution)
12	Characteristics of compressor/expander/pump/expansion valve/control valve and transient analysis of two-phase thermal-fluid cycles (Rankine power / refrigeration cooling cycles)
13	Multiphase thermal fluids in emerging energy systems (supercritical Brayton cycle for nuclear/ solar power generation, transcritical vapor compression cycle for refrigeration cooling, two-phase microchannel cooling of electronics, overview of solid-gas flows for power generation)
14	Project presentations
15	**Final Exam**

Relationship of course objectives to IDDP program outcomes	
Program Outcome 1	Demonstrate appropriate depth and breadth of knowledge that is at the frontier of their disciplines (thermal fluids)
Program Outcome 2	Understand and value diverse approaches to solving critical problems in research and to creating new knowledge judged by international standards
Program Outcome 3	Work effectively in a multidisciplinary collaborative environment using highly developed cognitive and creative expert skills and intellectual independence
Program Outcome 4	Communicate effectively, in written and oral forms, their research results and/or critique highly complex and diverse matters to diverse audiences

Out-of-class assignments	
Homework	Ten homework assignments, each due at the end of the week following its assignment date
Course Project	A theoretical and numerical simulation project confirmed before mid-semester break (self-chosen or assigned) and final report due in the last week of classes

Course Grading	
Homework	20 %
Midterm quiz	20 %
Course project	30 %
Final Exam	30 %
Total	100 %

Class/Laboratory schedule and Methodology	
Class	The class meets 15 weeks, 2 lectures per week, 75 minutes each.
Laboratory	Computer laboratory used for software applications (Matlab, EES, Refprop). Experimental laboratory used to help understand principal physics.
Teaching and learning methodologies	A combination of white board use, power-point slide presentation, and interactive class discussions to encourage student participation and enhance the learning.

Course Materials	
Textbook(s)	• V. P. Carey, *Liquid-Vapor Phase-Change Phenomena, 2nd ed.*, Taylor & Francis, New York, 2008.
Recommended Readings	• Recent journal papers published in *Nature Material, Langmuir, International Journal of Heat and Mass Transfer, ASME Journal of Heat Transfer, International Journal of Multiphase Flow*. • J. G. Collier and J. R. Thome, *Convective Boiling and Condensation, 3rd ed.* Oxford University Press, 1996. • S. Kandlikar, S. Garimella, D. Li, S. Colin, and M. R. King, *Heat transfer and fluid flow in minichannels and microchannels*, Elsevier Science, 2006. • N. E. Todreas, M. S. Kazimi, *Nuclear Systems, Volume 1 Thermal Hydraulic Fundamentals, 2nd Ed.*, CRC Press, 2012.
Instructional material and resources	A course website will be set at the beginning of the semester where all necessary course material will be posted including course notes, homework assignments and solutions, property lookup function and manual, computer code, further reading.
Relevant Courses at US Universities	• Prof. Jacopo Buongiorno, *Thermal Hydraulics in Power Technology*, Departments of Mechanical Engineering and Nuclear Science & Engineering, Massachusetts Institute of Technology (MIT), Spring 2.59J/22.313J, 2007. • Prof. Michael Z. Podowski, *An Introduction to Multiphase Flow and Heat Transfer*, Department of Mechanical, Aerospace, and Nuclear Engineering, Rensselaer Polytechnic Institute (RPI), Fall MANE 6840, 2009.