PennState College of Engineering | MECHANICAL ENGINEERING

ME 410: Heat Transfer

Summer 2022

Department of Mechanical Engineering
The Pennsylvania State University

Course description: ME 410 Heat Transfer is an undergraduate course on the three modes of heat transport: conduction, convection, and radiation; additionally, the fundamentals of heat exchanger design and numerical methods are studied. One-dimensional steady and transient conduction methods are developed for planar, cylindrical, and spherical geometries. Analytical and numerical methods are presented for two-dimensional conduction problems, including the analysis of extended surfaces. Convection heat transfer is studied in both formats, forced and natural, in internal and external conditions and under laminar and turbulent flow regimes. Radiation heat transfer is studied by considering both, the general characteristics of radiation and the properties of radiating surfaces, under simplifications that allow for easy directional and spectral analyses. Methods for solving multi-mode heat transfer are presented throughout the course. Heat exchangers and heat transfer from extended surfaces are two applications studied in this course.

Course objectives: After taking this course, students should be able to:

- Distinguish between the heat transfer modes and make simplifications to formulate multimode heat transfer problems.
- Generate mathematical models of one-dimensional heat transfer in steady and transient state.
- Use convection correlations for different kinds of geometries and flow conditions.
- Use the concept of thermal resistance to analyze radiation between surfaces.
- Size and predict the performance of heat exchangers operating in single-phase conditions.

Prerequisites: Fluid mechanics: AERSP 308, AERSP 311, BME 409, CE 360, ME 320.
Programming in engineering: CMPSC 200 or CMPSC 201.
Ordinary differential equations: MATH 220 or NUCE 309; MATH 251.

Textbook: T. L. Bergman and A. S. Lavine, *Fundamentals of Heat and Mass Transfer*, **7th ed.**, John Wiley & Sons (2017).

Instructor: Dr. Bladimir Ramos-Alvarado, Assistant Professor, Department of Mechanical Engineering.
Reber Bldg., Room 301D, Email: bzr52@psu.edu

Office hours/ recitations: Dr. Ramos: MWF, 2:00 – 3:00 pm. EST, Zoom meetings (see the Zoom tab in Canvas).
Office hours by appointment can be scheduled by appointment too.

Web resources:

- *Canvas*: lecture notes, homework assignments, solutions, and other materials.
- *Virtual Desktop Infrastructure* (vdilab.engr.psu.edu): virtual desktop that allows you to have access to specialized software, such as Matlab, ANSYS, **EES**, Mathematica, and SolidWorks.
- *WebApps* (webapps.psu.edu)*:* online access to specialized software, a bit slower than VDI.

Class time and format Remote asynchronous. Video lectures, worked out examples, quizzes, and all other materials will be released weekly on Canvas.

Course Evaluation

Homework: Homework will be assigned approximately every other week and posted on Canvas under Assignments and **GradeScope***. Six to seven assignments are expected. Homework will involve conceptual questions, detailed analytical, and/or numerical solutions of different heat transfer problems.

- *Submission*: Calculations, graphs, codes, analytical formulations, and everything necessary to evaluate homework should be uploaded to **GradeScope** as a single PDF.
- *Late submission policy*: NO LATE submissions are accepted, except for a pre-approved excuse.

***GradeScope** is an online platform for the submission and grading of homework assignments. I will create an account for every student enrolled in the class.

Exams: Three equally weighed exams will be administered through Canvas and will be based on theory and simple calculations tailored towards assessing the learning outcomes of each module. These are closed book/notes quizzes and you are not allowed to work with anyone. See the Tentative Course Schedule for dates and modules included in the exams.

Weekly quizzes: A brief quiz on the topics covered per week will be administered through Canvas. These will be weekly checkpoints to help you keep on track. You will have three attempts to get the right answers.

Final exam: An optional cumulative final exam will be administered to students that are not satisfied with their score by the end of the semester. If opted out, students will get their course grade based on their HW, Exams, and Quizzes scores, i.e., 100*(TOTAL POINTS/70).

Grading percentage:

Homework:	30% (6-7 Assignments)
Exams:	30% (3 Exams)
Quizzes:	10% (12 Weekly quizzes)
Final exam	30% (Optional)

Letter grade score cutoffs are given in the following table:

Score Cut-off	93	90	87	83	80	77	70	60	Under 60
Letter Grade	A	A-	B+	B	B-	C+	C	D	F

Academic honesty: Academic integrity and honesty are essential to achieve high-quality education and to keep the prestige of the institution. I will not tolerate any academic misconduct, such as cheating or other violations of the Penn State code: http://senate.psu.edu/policies-and-rules-for-undergraduate-students/47-00-48-00-and-49-00-grades/#49-20. Cheating includes, but it is not limited to: copying directly from unauthorized source, such as friends, classmates or a solutions manual; allowing another person to copy your work; taking an exam in someone else's name, or having someone else take an exam in your name; or asking for regrade of a HW that has been altered from its original form.

Grade appeal: If you feel that there is an error in the grading on a homework or quiz, a regrading request should be submitted on **GradeScope (for HWs) or to Dr. Ramos (quizzes)** with a brief description of the error within one week of being handed back. Scores will not be reconsidered after one week.

Late drop deadline – July 23rd: As a reminder, you may drop the course until July 23rd. A WP (passing), WF (failing), or WN (no grade) will be entered on your academic record depending on your performance prior to dropping the course. Typically, a 70% average is sufficient to obtain a WP.

Tentative Course Schedule

Week	Lectures/Due	Topic(s)	Reading assignment	Practice problems, 7th Ed
1 5/16 – 5/20	 Lecture 1 Lecture 2 Lecture 3 **Quiz#1 5/20**	Module 1: *Introduction to heat transfer* Introduction, heat transfer, thermal energy Heat transfer modes The energy conservation principle and heat transfer	Ch. 1.1 - 1.7	Ch. 1: 1, 5, 9, 12, 22, 35
2 5/23 – 5/27	 Lecture 4 Lecture 5 Lecture 6 Lecture 7 **HW#1 – 5/23** **Quiz#2 5/27**	Module 2: *Conduction* Section 1 - Introduction to conduction: Fourier's law and thermal properties Section 1 - The heat diffusion equation and boundary conditions Section 2 - Steady state one-dimensional conduction: the plane wall and the thermal resistance concept. Section 2 - Steady state one-dimensional conduction: radial systems and composite walls	Ch. 2.1 - 2.5 Ch. 3.1 - 3.4	Ch. 2: 6, 8, 18, 19, 22, 44
3 5/30 – 6/3	 Lecture 8 Lecture 9 Lecture 10 **HW#2 – 5/30** **Quiz#3 6/3**	Module 2: *Conduction* Section 2 - Steady state one-dimensional conduction: conduction with internal generation Section 2 - Steady state one-dimensional conduction: extended surfaces and the fin equation Section 2 - Steady state one-dimensional conduction: performance assessment metrics and fin arrays	Ch. 3.5 - 3.6	Ch. 3: 3a, 5, 16, 45, 47, 57, 59, 64, 74, 86, 92, 99, 104a, 114a, 115, 125
4 6/6 – 6/10	 Lecture 11 Lecture 12 Lecture 13 **Quiz#4 6/10** **Exam #1**	Module 2: *Conduction* Section 3 - Transient conduction: the lumped capacitance method Section 3 - Transient conduction: the one term approximation Section 3 - Transient conduction: semi-infinite solid **Exam#1: Module 1 to Module 2 – Section 2. Can be taken any day of this week.**	Ch. 5.1 - 5.7	Ch. 5: 6, 11, 16, 38, 53, 59, 67, 70, 88, 106
5 6/13 – 6/17	 Lecture 14 Lecture 15 Lecture 16 **HW#3 – 6/13** **Quiz#5 6/17**	Module 3: *Convection* Section 1 - Introduction to convection: velocity and temperature boundary layers, local and average heat transfer coefficients. Section 1 - Introduction to convection: laminar and turbulent flow, the boundary layer equations and similarity analysis. Section 2 – External flow: empirical methods and scale analysis	Ch. 6.1 - 6.6	Ch. 6: 1, 5, 6, 15, 18, 29, 30
6 6/20 – 6/24	 Lecture 17 Lecture 18 Lecture 19 **Quiz#6 6/24**	Module 3: *Convection* Section 2 – External flow: similarity solution Section 2 – External flow: turbulent flow and utilization of convection correlations Section 2 – External flow: convection in cross flow	Ch. 7.1 - 7.5	Ch. 7: 10, 16, 19, 40, 41, 66, 72
7		Module 3: *Convection*	Ch. 8.1 - 8.6	

6/27 – 7/1	Lecture 20 Lecture 21 Lecture 22 **HW#4 – 6/27** **Quiz#7 7/1**	Section 3 – Internal flow: brief review of fluid dynamics Section 3 – Internal flow: thermal entrance length Section 3 – Internal flow: heat transfer to fully developed flow		Ch. 8: 2, 8, 10, 16, 17, 27, 38, 49, 63
8 7/4 – 7/8	 Lecture 23 Lecture 24 Lecture 25 **Quiz#8 7/8** **Exam#2**	Module 3: *Convection* Section 4 – Natural convection: physical mechanisms, boundary layer equations, similarity analysis. Section 4 – Natural convection: similarity solution and correlations for isothermal flat plates. Section 4 – Natural convection: horizontal and inclined plates, and radial systems. **Exam#2: Module 2 – Section 3 to Module 3 – Section 3. Can be taken any day of this week.**	Ch. 9.1 - 9.6	Ch. 9: 7, 15, 24, 26, 28, 41, 48, 52
9 7/11 – 7/15	 Lecture 26 Lecture 27 Lecture 28 **HW#5 – 7/11** **Quiz#9 7/15**	Module 4: *Heat exchangers* Heat exchanger types and the overall heat transfer coefficient The log-mean temperature difference method (LMTD) The effectiveness-NTU (ε-NTU) method	Ch. 11.1 - 11.5	Ch. 11: 2a-b, 7, 8, 10, 15, 16, 30, 32, 41
10 7/18 – 7/22	 Lecture 29 Lecture 30 Lecture 31 **Quiz#10 7/22**	Module 5: *Radiation* Section 1 - Fundamentals of radiation: concepts and radiation fluxes Section 1 - Fundamentals of radiation: radiation intensity and emission, irradiation, and radiosity Section 1 - Fundamentals of radiation: black body radiation and radiation in bands.	Ch. 12.1 - 12.4	Ch. 12: 1, 3, 4, 9, 10, 12, 15, 29
11 7/25 – 7/29	 Lecture 32 Lecture 33 Lecture 34 **HW#6 – 7/25** **Quiz#11 7/29**	Module 5: *Radiation* Section 1 - Fundamentals of radiation: properties of real surfaces Section 1 - Fundamentals of radiation: Kirchhoff's law and gray surfaces. Section 2: Radiation exchange between surfaces: view factors and blackbody radiation exchange	Ch. 12.5 - 12.8 Ch. 13.1	Ch. 33, 39, 45, 49a-b, 51
12 8/1 – 8/5	 Lecture 35 Lecture 36 Lecture 37 **HW#7 – 8/1** **Quiz#12 8/5**	Module 5: *Radiation* Section 2: Radiation exchange between surfaces: radiation exchange in enclosures Section 2: Radiation exchange between surfaces: radiation shields and re-radiating surfaces Section 2: Radiation exchange between surfaces: multimode heat transfer	Ch. 13.2 - 13.4	Ch. 13: 2, 3, 11, 14, 20, 26, 48, 52, 61, 68, 72, 73
13	8/8 8/9 8/10 **8/12**	**Exam #3 Module 3 – Section 4 to Module 5, to be taken on 8/8 any time.** Review session for students NOT opting out the final exam Review session for students NOT opting out the final exam **Final exam (Cumulative)**		

Policies and Resources

Disability Statement. Penn State welcomes students with disabilities into the University's educational programs. Every Penn State campus has an office for students with disabilities. Student Disability Resources (SDR) Web site provides contact information for every Penn State campus: http://equity.psu.edu/sdr/disability-coordinator. For further information, please visit Student Disability Resources Web site: http://equity.psu.edu/sdr. In order to receive consideration for reasonable accommodations, you must contact the appropriate disability services office at the campus where you are officially enrolled, participate in an intake interview, and provide documentation: http://equity.psu.edu/sdr/guidelines. If the documentation supports your request for reasonable accommodations, your campus's disability services office will provide you with an accommodation letter. Please share this letter with your instructors and discuss the accommodations with them as early in your courses as possible. You must follow this process for every semester that you request accommodations.

Counseling & Psychological Services (CAPS) Statement. Students with academic concerns related to this course should contact the instructor in person or via email. Students also may occasionally have personal issues that arise in the course of pursuing higher education or that may interfere with their academic performance. If you find yourself facing problems affecting your coursework, you are encouraged to talk with an instructor and to seek confidential assistance at the Penn State Counseling and Psychological Services (CAPS) Center at (814) 863-0395. Visit their website for more information http://studentaffairs.psu.edu/counseling/. In addition, crisis intervention is always available 24/7 from Centre County CAN HELP (1-800-643-5432), or contact University Police at (814) 863-1111.

Academic Integrity Statement. This course adheres to University Senate Policy 49-20: "Academic integrity is the pursuit of scholarly activity in an open, honest, and responsible manner, serving as a basic guiding principle for all academic activity. Academic integrity includes a commitment not to engage in or tolerate acts of falsification, misrepresentation or deception. Such acts of dishonesty violate the fundamental ethical principles of the University community and compromise the worth of work completed by others." Unless explicitly directed otherwise by the instructor, all assignments are expected to be the student's own original work completed individually without collaboration. Violations of this code of conduct will result in reduced grades and can be reported to the College or University for further action.

Statement of Nondiscrimination. The Pennsylvania State University is committed to the policy that all persons shall have equal access to programs, facilities, admission, and employment without regard to personal characteristics not related to ability, performance, or qualifications as determined by University policy or by state of federal authorities. The Pennsylvania State University does not discriminate against any person because of age, ancestry, color, disability or handicap, national origin, race, religious creed, sex, sexual orientation, or veteran status.

Direct all inquiries regarding the nondiscrimination policy to:
Affirmative Action Director
The Pennsylvania State University
201 Willard Building
University Park, PA 16802-2801
Telephone: (814) 863-0471 U.Ed.OVP98-4