AME 516: Thermal and Biological Transport Phenomena

Units: 4
Spring 2023 – MW 09:00-10:50 am

Location: OHE 100C

Instructor: Satwindar Singh Sadhal
Office: OHE 412A
Office Hours: MW 11:00am-12:00pm, 1:00-1:45pm
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Course Description

The main theme of the course is for the students to learn the analytical techniques for solving convective heat and mass transfer problems in a variety of practical situations. Problem-solving techniques in this course are applied to heat/mass transfer biological tissues. However, the transport phenomena in this course are also applicable to traditional industrial applications. Specifically, the following topics will be included (new topics are shown in blue):

1. **Fundamentals: Physics of heat and mass transfer.**
2. **Fourier law, Fick's law. Review of fluid dynamics, momentum conservation**
3. **Equations of energy conservation and mass transport.**
4. **Pennes equation for biotransport.**
5. **Darcy flow for bioporous media.**
6. **Laminar two-dimensional flow. Boundary layer theory for energy and mass transfer.**
7. **Flow through channels. Couette flow.**
8. **Flow through pipes with heat transfer. Graetz problems.**
9. **Mass transfer through tubes; application to blood flow**
10. **Darcy flow through bioporous media with mass transfer.**
11. **Flow past cylinders with heat transfer.**
12. **Laminar to turbulent flow transition.**
13. **Turbulent heat transfer in parallel flow**
14. **Turbulent heat transfer in ducts.**
15. **Mass transfer with fluid flow biochemical reactions.**
16. **Application to drug delivery.**

Catalogue Description: Analytical techniques for solving convective heat and mass transfer problems; applications include heat/mass transfer in biological systems as well as traditional industrial settings.

Learning Objectives

It is expected that when exiting AME 516, students will be able to:

- mathematically model thermal and solute transport in fluid systems and biporous media;
- set up relevant heat and mass conservation differential equations;
- obtain analytical solutions to many varieties of convective heat and mass transfer problems in a wide array of important applications, including biotransport and industrial systems;
- translate and quantify mathematical formulations to physically meaningful results;
- apply the skills acquired to real-life situations such as, e.g., cardiovascular flow, drug delivery, power-plant heat transfer, pollutant dispersion in water and the atmosphere.

Prerequisite: AME 525
Recommended Preparation: Undergraduate courses on differential equations, fluid dynamics, thermodynamics and heat transfer; AME 526

Other Details
Grading Type: Letter Grade.
The course will be available on DEN (Distance Education Network)

Technological Proficiency and Hardware/Software Required: MATLAB proficiency.

Textbook: "Transport Phenomena in Biological Systems," by Truskey, Yuan & Katz, Pearson Prentice Hall. ISBN-13: 978-0130422040, ISBN-10: 0130422045

Recommended Readings and Supplementary Materials
For further insights, the following additional materials are recommended:

1. "Convective Heat Transfer," by Louis C. Burmeister, Wiley Interscience, ISBN: 0-471-09141-3
2. "Transport Phenomena," by Bird, Stewart & Lightfoot, Wiley. ISBN-13: 978-0470115398, ISBN-10: 0470115394

Description and Assessment of Assignments
There will be thirteen homework problem assignments which will account for 20% of the final grade. These assignments will be provided by the instructor and due one week from the date they are assigned. Students should expect that the reading and homework assignments will require roughly eight hours/week outside class.

Grading Breakdown

Grading Scheme:	Homework ……..... Mid-Term Examination (7th week) …… Final Examination (as per schedule of classes) ……	20% 30% 50%
	TOTAL	100%

Assignment Submission Policy
Homework assignments will be due one week after assignment at the end of the of the Thursday lecture. Submit assignment online every week by the posted due date. All students will submit assignments through the DEN system.

Additional Policies

- Final grade will depend entirely on the performance on the above grading breakdown and will be independent of the financial support requirements (e.g., minimum grade requirement for tuition reimbursement).
- Work-related travel should be scheduled during time periods outside of the mid-term and final exams. Accommodation to take exams on different dates will be made only for family emergencies and documented illness or health-related emergencies. Other exceptions will be considered on a case-by-case basis.
- Homework will not be accepted after the due date. Exceptions due to documented medical or family emergencies will be considered on a case-by-case basis.

Course Schedule: Weekly Breakdown

Week/Dates	TOPICS	Homework
1	1. FUNDAMENTALS 1.1 Review of fluid mechanics. Conservation of mass and momentum 1.2 Scaling and nondimensionalization. 1.3 Boundary conditions	HW1
2	2. ENERGY CONSERVATION 2.1 The energy equation. Diffusion, convection, dissipation. 2.2 Energy from chemical, biochemical and nuclear reactions	HW2
3	3. MASS CONSERVATION (SOLUTES) 3.1 Convective and diffusive mass transfer	HW3
4	4. TWO-DIMENSIONAL PROBLEMS 4.1 Thermal and momentum boundary layers on flat plates 4.2 Karman-Pohlhausen boundary layer theory	HW4
5	4.3 Couette flow in channels. 4.2 Thermal entrance length in two-dimensional channels. Graetz Problem.	HW5
6	5. PROBLEMS IN CYLINDRICAL GEOMETRY 5.1 Heat transfer in pipes. Graetz problem for circular channels. 5.2 Pulsating flow in tubes. Application to blood flow.	HW6
7	5.3 Flow around tubes and tube bundles.	Prep for Mid-term
8	Mid-Term Examination (during class period): Wed, Feb 22, 2023 6. BUOYANCY-DRIVEN CONVECTION 6.1 Density variation as a driving force.	HW7
9	6.2 Dimensionless scaling, Grashof and Rayleigh numbers 6.3 Buoyant convection from a vertical flat plate	HW8
10	6.4 Buoyant convection between two parallel plates. Critical Rayleigh numbers for onset of convection. 6.5 Convective transport due to density stratification in isothermal systems.	HW9
11	7. TURBULENT HEAT AND MASS TRANFER 7.1 Laminar to turbulent transition 7.2 Turbulent boundary layers k-ε models 7.3 Application to flat plates and tubes	HW10
12	8. PROBLEMS IN SPHERICAL GEOMETRY 8.1 Classical problems with drops, bubbles and particles. 8.2 Evaporation of aerosols. Spherically symmetric problems. 8.3 Evaporation with translation of drops.	HW11
13	9. PENNES BIO-HEAT EQUATION 9.1 Blood perfusion as a heat-removal/addition mechanism. 9.2 Application to mammalian tissue. 9.3 Tumors, and radiation therapy. Thermal analysis.	HW12
14	10. POROUS AND BIOPOROUS MEDIA 10.1 Darcy equation for momentum conservation. 10.2 Convective heat and mass transfer in porous media 10.3 Application to targeted drug delivery.	HW13
15	11. SPECIAL TOPICS 11.1 Topics of current interest 11.2 Fluid dynamics and transport phenomena with aerosols	No HW
	FINAL EXAMINATION: Friday, May 5, 2022, 08:00-10:00 am	

Academic Conduct:
Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in SCampus in Part B, Section 11, "Behavior Violating University Standards" policy.usc.edu/scampus-part-b. Other forms of academic dishonesty are equally unacceptable. See additional information in SCampus and university policies on scientific misconduct, policy.usc.edu/scientific-misconduct.

Support Systems:
Counseling and Mental Health - (213) 740-9355 – 24/7 on call
studenthealth.usc.edu/counseling
Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention.
National Suicide Prevention Lifeline - 1 (800) 273-8255 – 24/7 on call
suicidepreventionlifeline.org
Free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week.
Relationship and Sexual Violence Prevention Services (RSVP) - (213) 740-9355(WELL), press "0" after hours – 24/7 on call
studenthealth.usc.edu/sexual-assault
Free and confidential therapy services, workshops, and training for situations related to gender-based harm.

Office of Equity and Diversity (OED) - (213) 740-5086 | Title IX – (213) 821-8298
equity.usc.edu, titleix.usc.edu
Information about how to get help or help someone affected by harassment or discrimination, rights of protected classes, reporting options, and additional resources for students, faculty, staff, visitors, and applicants.

Reporting Incidents of Bias or Harassment - (213) 740-5086 or (213) 821-8298
usc-advocate.symplicity.com/care_report
Avenue to report incidents of bias, hate crimes, and microaggressions to the Office of Equity and Diversity |Title IX for appropriate investigation, supportive measures, and response.

The Office of Disability Services and Programs - (213) 740-0776
dsp.usc.edu
Support and accommodations for students with disabilities. Services include assistance in providing readers/notetakers/interpreters, special accommodations for test taking needs, assistance with architectural barriers, assistive technology, and support for individual needs.

USC Campus Support and Intervention - (213) 821-4710
campussupport.usc.edu
Assists students and families in resolving complex personal, financial, and academic issues adversely affecting their success as a student.

Diversity at USC - (213) 740-2101
diversity.usc.edu
Information on events, programs and training, the Provost's Diversity and Inclusion Council, Diversity Liaisons for each academic school, chronology, participation, and various resources for students.

USC Emergency - UPC: (213) 740-4321, HSC: (323) 442-1000 – 24/7 on call
dps.usc.edu, emergency.usc.edu
Emergency assistance and avenue to report a crime. Latest updates regarding safety, including ways in which instruction will be continued if an officially declared emergency makes travel to campus infeasible.

USC Department of Public Safety - UPC: (213) 740-6000, HSC: (323) 442-120 – 24/7 on call
dps.usc.edu
Non-emergency assistance or information.