

Academic Year: (2018 / 2019)

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Department assigned to the subject: Bioengineering and Aerospace Engineering Department

Coordinating teacher: RIPOLL LORENZO, JORGE

Type: Compulsory ECTS Credits : 6.0

Year : 3 Semester : 1

REQUIREMENTS (SUBJECTS THAT ARE ASSUMED TO BE KNOWN)

It is strongly advised to have completed Calculus I and II, Physics I and II. It is also very beneficial, but not compulsory, if Differential equations, Biomechanics of Continuum Media II (fluids) and Numerical Methods in Biomedicine have been completed.

OBJECTIVES

Within this course students will be provided with a foundation in understanding and solving problems related to biomedical engineering applications of momentum, heat, and mass transport phenomena. At the end of the course, each student will be able to:

- Formulate differential equations that represent the physical situation of biomedical problems involving mass, momentum, or heat transfer (or combinations of these) and determine appropriate boundary conditions.
- Apply conservation laws of fluid flow to describe the system for various geometries, particularly for flow through a conduit.
- Distinguish between modes of heat transfer or mass transfer, explain analogies between heat and mass transfer and apply the correct equations to describe each mode.
- Determine convective mass transfer coefficients using appropriate analogies for the geometric situation.
- Use modeling software (Matlab) to model mass transport problems and analyze experimental data.

DESCRIPTION OF CONTENTS: PROGRAMME

Intro. Introduction to Transport in Biological Systems:

1. Introduction,
 - 1.1. The Role of Transport Processes in Biological Systems,
 - 1.2. Definition of Transport Processes (Diffusion, Convection, Transport by Binding Interactions)
 - 1.3. Relative Importance of Convection and Diffusion,
 - 1.4. Transport Within Cells (Transport Across the Cell Membrane, Transport Within the Cell,
 - 1.5. Transcellular Transport (Junctions Between Cells, Epithelial Cells, Endothelial Cells)
 - 1.6. Physiological Transport Systems (Cardiovascular System, Respiratory System, Gastrointestinal Tract, Liver, Kidneys, Integrated Organ Function)
 - 1.7. Application of Transport Processes in Disease Pathology, Treatment, and Device Development (Transport Processes and Atherosclerosis, Transport Processes and Cancer Treatment, Transport Processes, Artificial Organs, and Tissue Engineering)
 - 1.8. Relative Importance of Transport and Reaction Processes

Part I. Introduction to Physiological Fluid Mechanics:

2. Conservation Relations and Momentum Balances:

- 2.1. Introduction,
- 2.2. Fluid Kinematics (Control Volumes, Velocity Field, Flow Rate, Acceleration, Fluid Streamlines,
- 2.3. Conservation Relations and Boundary Conditions (Conservation of Mass, Momentum Balances, Forces, Boundary Conditions)

- 2.4. Fluid Statics (Static Equilibrium, Surface Tension, Membrane and Cortical Tension)
- 2.5. Constitutive Relations (Newton's Law of Viscosity, Non-Newtonian Rheology, Time-Dependent Viscoelastic Behavior)
- 2.6. Laminar and Turbulent Flow
- 2.7. Application of Momentum Balances (Flow Induced by a Sliding Plate, Pressure-Driven Flow Through a Narrow Rectangular Channel, Pressure-Driven Flow Through a Cylindrical Tube, Pressure-Driven Flow of a Power Law Fluid in a Cylindrical Tube, Flow Between Rotating Cylinders)
- 2.8 Rheology and Flow of Blood

3. Conservation Relations for Fluid Transport, Dimensional Analysis, and Scaling:

- 3.1. Introduction,
- 3.2. Differential Form of the Equation of Conservation of Mass in Three Dimensions (General Form of the Equation of Conservation of Mass, Conservation of Mass for Incompressible Fluids)
- 3.3. Differential Form of the Conservation of Linear Momentum and the Navier-Stokes Equations in Three Dimensions (General Form of the Equation of Conservation of Linear Momentum, The Navier-Stokes Equation)

4. Approximate Methods for the Analysis of Complex Physiological Flow:

- 4.1. Introduction,
- 4.2. Integral Form of the Equation of Conservation of Mass,
- 4.3. Integral Form of the Equation of Conservation of Linear Momentum

Part II. Fundamentals and Applications of Mass Transport in Biological Systems:

5. Mass Transport in Biological Systems:

- 5.1. Introduction
- 5.2. Solute Fluxes in Mixtures (The Dilute-Solution Assumption)
- 5.3. Conservation Relations (Equation of Conservation of Mass for a Mixture, Boundary Conditions)
- 5.4. Constitutive Relations (Fick's Law of Diffusion for Dilute Solutions, Diffusion in Concentrated Solutions)
- 5.5. Diffusion as a Random Walk
- 5.6. Estimation of Diffusion Coefficients in Solution (Transport Properties of Proteins, The Stokes-Einstein Equation, Estimation of Frictional Drag Coefficients, The Effects of Actual Surface Shape and Hydration, Correlations)
- 5.7. Steady-State Diffusion in One Dimension (Diffusion in Rectangular Coordinates, Radial Diffusion in Cylindrical Coordinates, Radial Diffusion in Spherical Coordinates)
- 5.8. Unsteady Diffusion in One Dimension (One-Dimensional Diffusion in a Semi-Infinite Medium, One-Dimensional Unsteady Diffusion in a Finite Medium, Model of Diffusion of a Solute into a Sphere from a Well-Stirred Bath)

6. Diffusion with Convection or Electrical Potentials:

- 6.1. Introduction
- 6.2. Fick's Law of Diffusion and Solute Flux,
- 6.3. Conservation of Mass for Dilute Solutions (Transport in Multicomponent Mixtures)
- 6.4. Dimensional Analysis
- 6.5. Diffusion and Convection (Release from the Walls of a Channel: A Short-Contact-Time Solution)
- 6.6. Macroscopic Form of Conservation Relations for Dilute Solutions
- 6.7. Mass Transfer Coefficients
- 6.8. Mass Transfer Across Membranes: Application to Hemodialysis

7. Energy and Bioheat Transfer

- 7.1. Introduction
- 7.2. First Law of Thermodynamics and Metabolism
- 7.3. Steady and Unsteady Heat Conduction
- 7.4. Convective Heat Transfer
- 7.5. Energy Transfer Due to Evaporation
- 7.6. Metabolism and Regulation of Body Temperature

LECTURES:

Due to the large amount of topics covered and their multidisciplinary nature, it is important that the student does some research on the topic before the class.

- 1) Lectures: During the lectures the proposed topic will be presented, always encouraging discussion.
- 2) Discussion Sessions: When the topic allows it, groups of 3-5 will be formed for discussion sessions to solve particular problems related to the current topic with the main idea of understanding the system and developing different strategies to solve it, underlining the fact that there are almost always different approaches to the same problem.
- 3) Oral Presentations: At least once during the course each student will have the chance to do a short oral presentation on a topic related to the course within their "Team". These oral presentations will be prepared in groups of between 4 and 6 students ("Teams") and have a duration of approx. 10 minutes per student.

TEAM PRESENTATIONS:

When divided in the reduced groups, there will be several days dedicated to group research, being the class divided into 5 teams:

TEAM Cardio
TEAM Vascular
TEAM Hemoglobin
TEAM Gastro
TEAM Glomerulus
TEAM Joints

Each team will have a maximum of 7 members, ensuring that each team is balanced. The role of these teams is to prepare a 50 minute class that will be presented at the end of the course on their particular topic, covering: Biology, Physics, and Artificial Organs related to their particular organ or system, One Problem to be solved by the class, and Two multiple Choice questions

HOMEWORK:

Homework will be assigned frequently during the course. Homework is intended to help each student practice setting up and solving momentum, heat, and mass transfer problems. For each assignment, all homework problems are required to be solved. All problems will be checked for effort. Credit will be given only for problems for which the student has made a clear attempt to solve the problem correctly. All assignments are due at the beginning of class on the due date. No late assignments will be accepted.

LABORATORY SESSIONS:

For these sessions the class will be divided into its reduced groups, and each experiment will be performed in groups of no more than 3 students. During these sessions simple experiments will be done to understand the basics of transport and flow. The main goal during these sessions is to understand the physics behind the experiment and how it relates to the theory we presented during the lectures, to obtain rigorous experimental data, to analyze this data, and finally to present this data as a scientific report. Different software for data analysis will be used, mainly Matlab and ImageJ. **IMPORTANT:** laboratory sessions will take place during the first weeks of the course. Attendance is mandatory.

ASSESSMENT SYSTEM

% end-of-term-examination/test:	60
% of continuous assessment (assignments, laboratory, practicals...):	40

The final grade will be a combination of Laboratory Sessions (10%), continuous assessment (50%) (note that $10\%+50\%=60\%$) and Final Exam (40%), in particular:

1) **LABORATORY SESSIONS (10%):** Effort, methodology and ingenuity, not for how accurate the final result is, will be the relevant points in the report. What is important is to present the results, even if they were negative, in a scientific manner, explaining in detail why the experiment failed (in case it did) or analyzing the results thoroughly in case it was successful. The grade will be shared in case the experiment was done by more than one student. Attendance to all sessions is compulsory. 50% of the grade will be the document handed in with the lab results and 50% from the group research document prepared during the lab classes.

2) **CONTINUOUS ASSESSMENT (50%):** Within this category we will have grades for the Oral Presentation each student will make together with their respective TEAM (20%), one written mid-term exam (20%) and homework assignments (10%).

% end-of-term-examination/test:	60
% of continuous assessment (assignments, laboratory, practicals...):	40

3) FINAL EXAM (40%): The final exam will be a written exam and take place at the end of the course, being common for all students. It will include problems and multiple choice questions to be solved covering the main topics of the course. The MINIMUM SCORE in order for the result to count in the overall grade of the course is 4.0 over 10, irrespective of the grades obtained in the continuous assessment.

EXTRAORDINARY EXAM

The continuous evaluation grade is maintained for the extraordinary exam. The final grade for the extraordinary exam will be the maximum between a 100% of the extraordinary exam and 60% continuous evaluation + 40% exam.

EXCHANGE STUDENTS ABROAD

Students following the course from abroad will thus miss all activities which require physical presence (experiments, research group work and oral presentation). In this case they will only have access to 70% of the grade after the final exam (40% final exam, 20% mid term done via internet, and 10% homework). In order to access 100% of the grade they will have to take the extraordinary exam at the end of the school year.

DISHONEST CONDUCT

Copying and otherwise dishonest conduct is not allowed in any the activities of this course and will be punished with severities which may range between a zero in that particular activity and a disciplinary hearing by the council of the university.

BASIC BIBLIOGRAPHY

- Mark Johnson and C. Ross Ethier Problems for Biomedical Fluid Mechanics and Transport Phenomena, Cambridge University Press; 1 edition, 2013
- G.A. Truskey, F. Yuan, and D.F. Katz Transport Phenomena in Biological Systems, 2nd edition, Pearson Prentice Hall, 2009

ADDITIONAL BIBLIOGRAPHY

- F.P. Incropera, D.P. DeWitt, T.L. Bergman, and A.S. Lavine Fundamentals of Heat and Mass Transfer, 6th edition, John Wiley & Sons, 2007