Transport phenomena in biomedical engineering

Academic Year: (2021 / 2022) **Review date: 04-06-2021**

Department assigned to the subject: Bioengineering and Aeroespace 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, 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

LEARNING ACTIVITIES AND METHODOLOGY

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, discussion sessions will take place 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 online by groups of between 4 and 6 students ("Teams") and have a duration of approx. 10 minutes per student. The students will prepare a video with their material which will be projected to the rest of the class during the last days of the course.

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 approximately 7 members, ensuring that each team is balanced. The role of these teams is to prepare a 50 minute class, to be presented in video format, that will be presented in VIDEO format 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.

MULTIPLE CHOICE QUIZ:
During the classes multiple choice questions will be shown that are to be answered by each student individually using their mobile phone or an iPad/tablet.

LABORATORY SESSIONS:
These sessions are individual, and the class will be divided into its reduced groups. Each experiment will be performed individually groups. 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. Matlab will be used to analyze the data. Students may form groups of up to 3 students to upload the report.

IMPORTANT: laboratory sessions will take place during the first two weeks of the course. Attendance is mandatory.

ASSESSMENT SYSTEM

The final grade will be a combination of Laboratory Sessions (10%), continuous assessment (60%) and the 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. Attendance to all sessions is compulsory. 50% of the grade will be the document handed in with the lab results, 40% from being present during the actual lab classes and 10% for taking the Video Quiz for each Lab Session.

2) CONTINUOUS ASSESSMENT (60%): 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%), homework assignments (10%), and Quiz Results (10%).

3) FINAL EXAM (30%): 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 on fluids (20% of the total) and diffusion (70% of the total). 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 70% continuous evaluation + 30% exam. Those students that are interested on improving their overall mark may do so, but only this final exam would count for the above mentioned averages.

EXCHANGE STUDENTS ABROAD
Students following the course from abroad will thus miss all activities which require physical presence (experiments - 10%, research group work and oral presentation - 20%). In this case they will only have access to 70% of the grade after the final exam (40% final exam, 20% mid term donde 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 MISCONDUCT
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.

% end-of-term-examination:	30
% of continuous assessment (assigments, laboratory, practicals…):	70

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
- G. K. Batchelor An Introduction to Fluid Dynamics , Cambridge University Press, 2000
- Olivier Darrigol Worlds of Flow, Oxford University Press, 2005