# Lahore University of Management Sciences

## ChE`273 - PHY 362 – Fluid Mechanics

Spring 2024

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| **Instructor** | Qasim Imtiaz |
| **Room No.** | SBASSE 4th Floor, Bird Wing, 9-443A |
| **Office Hours** | TBA |
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| **Secretary/TA** | TBA |
| **TA Office Hours** | TBA |
| **Course URL (if any)** | |

| **Course Teaching Methodology** |
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| • Teaching Methodology: All lectures and tutorials will be in-person on campus.<br>• Lecture details: The lectures will be delivered by the instructor, whereas the TA/instructor will conduct the tutorials. |

| **Course Basics** | | | | |
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| Credit Hours | 03 | | | |
| Lecture(s) | Nbr of Lec(s) Per Week | 02 | Duration | 75 min |
| Recitation/Lab (per week) | Nbr of Lec(s) Per Week | | Duration | |
| Tutorial (per week) | Nbr of Lec(s) Per Week | 01 | Duration | 60 min (TBA) |

| **Course Distribution** | |
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| Core | BS Chemical Engineering |
| Elective | |
| Open for Student Category | Sophomore and Junior Year SSE Undergraduate Students |
| Close for Student Category | |

| **Course Description** |
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| Transport phenomena comprise fluid dynamics, mass transfer, and heat transfer. Fluid dynamics involves the transport of momentum; mass transfer is concerned with the transport of mass of various chemical species, and heat transfer deals with the transport of energy. This course is designed to study and analyze the transport of momentum and intends to provide learners with a basic understanding of fluid behavior at rest and in motion. Some of the topics include the description of fluid flow in terms of Lagrangian and Eulerian coordinates; the derivation of the continuity equation, Bernoulli's equation, and the Navier-Stokes equations from the fundamental principles of mass, energy, and momentum conservation; use of dimensional analysis to identify important non-dimensional parameters that describe a given flow problem; and analytic solutions of the Navier-Stokes equation for simple fluid flow problems. The knowledge of fluid dynamics gained in this course is a foundation for many other courses in the chemical engineering program and other disciplines, such as renewable energy, atmospheric and oceanic circulation, and biological processes, such as blood flow. |

| **Course Prerequisite(s)** | |
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| • | ChE 260 (Principles of Chemical Engineering) |
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| **Course Objectives** | |
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| • | Give students an understanding of conservation laws and constitutive equations as they apply to convective and viscous transport of momentum. |
| • | Train students to solve simple one-dimensional fluid flow problems using transport equations. |
| • | Develop the technique of dimensional analysis of problems and illustrate its importance. |

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| Learning Outcomes | |
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| | On successful completion of this course, the student should be able to: |
| • | **Calculate** the key fluid properties used in the analysis of fluid behavior. |
| • | **Calculate** the forces and moments exerted by a fluid at rest on submerged surfaces. |
| • | **Apply** the laws of conservation of mass, momentum, and energy to the contents of a finite control volume. |
| • | **Analyze** simple one-dimensional fluid flow problems using the Navier-Stokes equations. |
| • | **Identify** a set of dimensionless parameters important for a given flow situation. |
| • | **Calculate** energy losses and flow rates associated with different pipe flow situations. |

**Grading Breakup and Policy**

Attendance*: 0 %
Class Participation: 5 %
Homework: 20 % (10 in total, 2.5 % each, N-2 will be applied)
Midterm Examination: 35 %
Final Examination: 40 %
*You are required to attend a minimum of 75% of all classes. It is possible to fail the course if your total absences equal more than 25% of the required attendance.
#Grading will be on an absolute scale, and the instructor has the liberty of varying the grading breakup by 10%.

**Relation to Program Outcomes**

| CLOs | Related PLOs | Levels of Learning | Teaching Methods | CLO Attainment checked in |
|---|---|---|---|---|
| CLO1 | PLO01 | C3 – Applying | Lectures/Tutorials | Homework, Exams |
| CLO2 | PLO02 | C3 – Applying | Lectures/Tutorials | Homework, Exams |
| CLO3 | PLO02 | C3 – Applying | Lectures/Tutorials | Homework, Exams |
| CLO4 | PLO02 | C4 – Analyzing | Lectures/Tutorials | Homework, Exams |
| CLO5 | PLO02 | C4 – Analyzing | Lectures/Tutorials | Homework, Exams |
| CLO6 | PLO02 | C3 – Applying | Lectures/Tutorials | Homework, Exams |

**Examination Detail**

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| Midterm Exam | Yes/No: Yes<br>Combine/Separate: Combined<br>Duration: 3 h<br>Preferred Date:<br>Exam Specifications: 20 % closed book, 80 % open book |
| Final Exam | Yes/No: Yes<br>Combine/Separate: Combined<br>Duration: 3 h<br>Date:<br>Exam Specifications: 20 % closed book, 80 % open book |

**Course Overview**

| Week/ Lecture/ Module | Topics | Recommended Readings | Objectives/ Application |
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| **Week # 01** | a. Course overview, fluids and the continuum, properties at a point<br>b. Point-to-point variation of properties in a fluid, compressibility, surface tension | Welty, Rorrer, and Foster, Chapter 01 | Introduction of basic definitions and concepts to provide a basis for communication. |
| **Week # 02** | a. Pressure variation in a static fluid<br>b. Forces on submerged surfaces, buoyancy | Welty, Rorrer, and Foster, Chapter 02 | Study of point-to-point variation of pressure in a fluid at rest. |
| **Week # 03** | a. Fluid-flow fields, steady and unsteady flows, streamlines, systems, and control volumes<br>b. Integral relation for the conservation of mass | Welty, Rorrer, and Foster, Chapter 03<br>Welty, Rorrer, and Foster, Chapter 04 | The basic concept used in the description of a flowing fluid.<br>Derivation of the law of conservation of mass in integral form. |

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| **Week # 04** | a. *Worked examples*<br>b. Integral relation for linear momentum | Welty, Rorrer, and Foster, Chapter 04<br>Welty, Rorrer, and Foster, Chapter 05 | Derivation of Newton's second law of motion in integral form. |
| **Week # 05** | a. *Worked examples*<br>b. Integral relation for the conservation of energy | Welty, Rorrer, and Foster, Chapter 05<br>Welty, Rorrer, and Foster, Chapter 06 | Development of an integral expression for the conservation of energy. |
| **Week # 06** | a. The Bernoulli equation and its applications<br>b. *Worked examples* | Welty, Rorrer, and Foster, Chapter 06 | |
| **Week # 07** | a. Newton's viscosity relation, non-Newtonian fluids, viscosity<br>b. Shear stress in multidimensional laminar flows of a Newtonian fluid | Welty, Rorrer, and Foster, Chapter 07 | Study of shear stress in laminar flow and its dependence upon viscosity. |
| **Week # 08** | a. **Midterm exam**<br>b. Analysis of a differential fluid element in laminar flow | Welty, Rorrer, and Foster, Chapter 08 | Estimation of fluid behavior from a differential point of view. |
| **Week # 09** | a. The differential continuity equation<br>b. Derivation of the Navier-Stokes equations | Welty, Rorrer, and Foster, Chapter 09 | Derivation of a set of differential equations describing the detailed motion of the fluid. |
| **Week # 10** | a. Derivation of the Navier-Stokes equations, cont'd…<br>b. *Worked examples* | Welty, Rorrer, and Foster, Chapter 09 | |
| **Week # 11** | a. Dimensional analysis of governing differential equations, the Buckingham method<br>b. Geometric, kinematic, and dynamic similarity, model theory | Welty, Rorrer, and Foster, Chapter 11 | Identification of important non-dimensional parameters that describe any given flow problem. |
| **Week # 12** | a. Reynolds's experiment, friction drag, pressure drag, drag coefficient data*<br>b. The boundary layer concept, the boundary layer equations | Welty, Rorrer, and Foster, Chapter 12<br>*Munson, Okiishi, Huebsch and Rothmayer, Chapter 09 | Study of viscous fluids and the role of viscosity as it affects the flow. |
| **Week # 13** | a. Description of turbulence, turbulent shearing stresses, turbulent velocity profile<br>b. *Worked examples* | Welty, Rorrer, and Foster, Chapter 12 | |
| **Week # 14** | a. Dimensional analysis of conduit flow, friction factors for fully developed flow in circular conduits<br>b. Friction factor and head-loss determination for pipe flow, friction factors for flow in the entrance to a circular conduit | Welty, Rorrer, and Foster, Chapter 13 | Analysis of fluid flow, both laminar and turbulent, through closed conduits. |
| **Week # 15** | a. *Pipe-flow analysis* | Welty, Rorrer, and Foster, Chapter 13 | |
| **Week # 16** | **Final Exam** | | |

**Textbook(s)/Supplementary Readings**

**Textbook**

James Welty, Gregory L. Rorrer, David G. Foster. *Fundamentals of Momentum, Heat and Mass Transfer*, 7th edition, John Wiley & Sons, 2019.

**Additional reading**

R. Byron Bird, Warren E. Stewart, Edwin N. Lightfoot, Daniel J. Klingenberg. *Introductory Transport Phenomena*, 1st edition, John Wiley & Sons, 2014.

Andrew L. Gerhart, John I. Hochstein, Philip M. Gerhart. *Munson, Young, and Okiishi's Fundamentals of Fluid Mechanics*, 9th edition, John Wiley & Sons, 2021.

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| Course Expectations |
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This is a fundamental course in the chemical engineering curriculum, and many of you will learn a new way to think about describing physical phenomena. However, y**ou will only get out of this course what you put into it**. For success in this course, you are strongly advised to

1. **Review/work** on the material from the previous lecture before the next class.
2. **Read** the relevant sections of the textbook before each lecture.
3. **Take** notes during the lectures. You will frequently need to consult your notes over the semester.
4. **Work out** all derivations and examples in the textbook on your own after each lecture.
5. **In case of questions**, please see the instructor during office hours or raise questions in the class. Please do not delay this to the exam week.

Solving transport problems is a skill that is refined over time. Professional athletes, musicians, and physicians all spend time practicing their skills to master their craft; engineers must do the same. To hone your analytical and critical thinking skills, I will post ten problem sets during the semester, all due within **seven days**. Problem solutions must be uploaded on LMS before the deadline to receive credit. After each problem set is graded, a detailed solution will be provided. You may work together with your classmates on homework, but don't deny yourself the opportunity to "struggle" with difficult concepts and problems (by having friends "spoon-feed" you). You cannot consult solution manuals/online resources for these problem sets.

| Grading Policy |
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I will grade all problem sets and exams fairly. Since you will have the problem set in your possession for a week or longer and the assistance of me/the TA, for troublesome problems, I expect nearly perfect work. I will grade the problem sets with this in mind, *i.e.,* if it is clear that you are clueless about how to work a problem, you will receive zero credit. Additionally, there are a few items for which you will be penalized: (i) serious conceptual algebra, calculus, and differential equations errors, (ii) conceptual transport errors (*i.e.*, wrong coordinate system, etc.), and (iii) errors in units. Finally, the following scale will be used to determine your final letter grade.

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| A+ | > 89 % | A | 79 - 89 % | A- | 70 – 79 % |
| B+ | 62 – 70 % | B | 55 – 62 % | B- | 49 – 55 % |
| C+ | 44 – 49 % | C | 40 – 44 % | C- | 37 – 40 % |
| D | 35 – 37 % | | | | |
| F | < 35 % | | | | |

I reserve the right to adjust the cut-off points or curve the final score.

| Academic Honesty |
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I encourage open discussion and problem-solving with your peers, which is helpful and often efficient. However, seeking credit for any work products you did not prepare is dishonest and ultimately self-limiting. Therefore, the work you submit for individual homework assignments and exams should represent your analysis, synthesis, and execution. Any instances of academic dishonesty in this course (intentional or unintentional) will be dealt with swiftly and severely. Potential penalties include receiving a failing grade on the assignment in question or the course overall. For further information, students should make themselves familiar with the relevant section of the LUMS student handbook.

| Harassment Policy |
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There is zero tolerance for any behavior that is intended or has the expected result of making anyone uncomfortable and negatively impacts the class environment or any individual's ability to work to the best of his/her potential. If you think you may be a victim of harassment, or if you have observed any harassment occurring in the purview of this class, please reach out and speak to me. If you are a victim, I strongly encourage you to contact the Office of Accessibility and Inclusion at oai@lums.edu.pk or the sexual harassment inquiry committee at harassment@lums.edu.pk for any queries, clarifications, or advice. You may choose to file an informal or formal complaint to put an end to the offending behavior. You can find more details regarding the LUMS sexual harassment policy here: https://mgshss.lums.edu.pk/lums-harassment-policy. To file a complaint, please write to harassment@lums.edu.pk. In addition to LUMS resources, SSE's Council on Belonging and Equity is committed to devising ways to provide a safe, inclusive, and respectful learning environment for students, faculty, and staff. To seek counsel related to any issues, please feel free to approach either a member of the council or email at cbe.sse@lums.edu.pk.