TO: The Engineering Faculty

FROM: The Faculty of the School of Mechanical Engineering

RE: New Course – ME 53500, Complex Fluids

The Faculty of the School of Mechanical Engineering has approved the following new course. This action is now submitted to the Engineering Faculty with a recommendation for approval.

ME 53500, Complex Fluids, Semester(s) Offered: Fall, Course Credits: 3 credits
Co-requisites: ME 50900 – Intermediate Fluid Mechanics,
AAE 51100 – Introduction to Fluid Mechanics, or an equivalent course.
Attributes: Upper Division (senior level status and above)

Course Description: The aim of the course is to provide a basic foundation in the fluid mechanics of viscous flows and complex fluids. Students completing this course are expected to understand the physics underlying the constitutive equations for these materials and be able to model them.

History: This course has previously been offered as a ME 59700 course titled "Complex Fluids" and "Low Reynolds Hydrodynamics" three times since 2015. The student enrolment in the course was as follows:

- Fall 2015: 10 students
- Fall 2017: 11 students
- Fall 2019: 11 students with 2 audits

Details of this course are outlined in the appended material below.

Eckhard A. Groll
William E. and Florence E. Perry Head of Mechanical Engineering,
and Reilly Professor of Mechanical Engineering

ME 53500
COMPLEX FLUIDS

Course Outcomes [Related ME Program Outcomes in brackets]

1. Develop a thorough understanding of complex fluids and relevant flow physics. [1,6]
2. Define and describe significant properties of complex fluids. [1,6]
3. Explain how properties of complex fluids are measured. [1,6]
4. Understand the physics underlying the constitutive equations for complex fluids. [1,6]
5. Enable continued study in advanced topics in fluid mechanics. [1,6,7]
6. Develop the ability to critically evaluate the scientific literature on complex fluids. [1,7]
7. Develop skills for scientific presentations. [1,3]

Fundamental properties of viscoelastic fluids (2 weeks)

1. Introduction and examples
2. Properties of viscoelastic fluids (e.g., relaxation time, normal stress differences, yield stress, shear-thinning properties)

Classical hydrodynamics (1 weeks)

1. Mass and momentum conservation
2. Examples of viscous flow problems

Non-Newtonian fluid mechanics (4 weeks)

1. Material functions
2. Generalized Newtonian fluids
3. Examples of non-Newtonian flow problems
4. Linear Viscoelasticity

Constitutive equations (4 weeks)

1. Admissible constitutive equations
2. Ordered fluid expansions
3. Differential constitutive equations
4. Integral constitutive equations

Suspensions and emulsions (4 weeks)

1. Suspensions of particles
2. Suspensions of microorganisms
3. Emulsions
4. Breakup of liquid jets

Representative Projects

1. Create a computational, experimental or web-based tool that demonstrates or implements concepts from the course.
2. Develop a computational, experimental or web-based tool to study a complex fluid (e.g., polymeric solution, suspension, emulsion).
3. Develop a mathematical description of properties of a complex fluid.
4. Develop a mathematical solution describing flow physics for a complex fluid.

COURSE NUMBER: ME 53500	**COURSE TITLE:** Complex Fluids (3 credits) **SHORT TITLE (max 30 char):** Complex Fluids
REQUIRED COURSE OR ELECTIVE COURSE: Elective	**PROPOSED EFFECTIVE TERM:** Fall 2021 **TERMS OFFERED:** Fall semester
JUSTIFICATION FOR THE COURSE: Complex fluids are often found in nature and industry. Examples are consumer products, biological fluids, polymeric solutions, etc. Despite their ubiquity, most engineering students have no exposure to complex fluids in their training program. This course is the only one at Purdue to describe the physical and mechanical properties of complex fluids and the methods used to measure these properties. The knowledge gained in this course helps students to effectively characterize and handle complex fluids.	**JUSTIFICATION OF THE NEED FOR THE COURSE:** Several faculty members at Purdue have research projects involving complex fluids. The research areas include pharmaceuticals, agricultural materials, chemicals, consumer products, food products, and biological fluids. This course prepares students who work in these areas for their research and future career. It is the only course at Purdue that focuses on this fundamental topic. The last offerings of the course attracted students from mechanical engineering, chemical engineering, and agricultural and biological engineering.
JUSTIFICATION THAT THE COURSE WILL BE TAUGHT AT GRADUATE LEVEL: The students taking the course benefit from prior trainings in courses on fluid mechanics that students take at the upper level.	**JUSTIFICATION FOR ONLINE/DISTANCE DELIVERY:** This course will be first taught as an edX course in fall 2021so that students from other universities and employees from industry and national laboratories can also take the course.
TEXTBOOK/REQUIRED MATERIAL: R.B. Bird, R.C. Armstrong, and O. Hassager, Dynamics of Polymeric Liquids, Vol. 1. Fluid Mechanics, Wiley, New York (1987), Second Edition. Guazzelli and Morris, A Physical Introduction to Suspension Dynamics, Cambridge University Press, 2012	**CO-REQUISITIES:** ME 50900 – Intermediate Fluid Mechanics, AAE 51100 – Introduction to Fluid Mechanics, or an equivalent course. **ATTRIBUTES**: Upper Division (senior status and above) **RESTRICTIONS:** NA **COURSE REPEATABLE?** Yes
COORDINATING FACULTY: A.M. Ardekani	
COURSE DESCRIPTION: The aim of the course is to provide a basic foundation in the fluid mechanics of viscous flows and complex fluids. Students completing this course are expected to understand the physics underlying the constitutive equations for these materials and be able to model them.	**COURSE OUTCOMES** [Related ME Program Outcomes in brackets]: 1. Develop a thorough understanding of complex fluids and relevant flow physics. [1,6] 2. Define and describe significant properties of complex fluids. [1,6]

ASSESSMENTS TOOLS:

1. Several homework assignments.
2. Midterm oral presentation.
3. Final project report and oral presentation

PROVIDE ADDT'L INFO ABOUT THE ASSESSMENT METHOD(s) THAT ADDRESS THE LEARNING OUTCOMES LISTED ABOVE (few sentences describing assignment, prj, etc and how they address learning objectives):

There will be about ten homework sets during the semester. The purpose of the homework is to help you learn how to use the course material. Additionally, each student in the course will be asked to give oral presentations by submitting recorded videos. An oral presentation and written report will be required for the final project.

3. Explain how properties of complex fluids are measured. [1,6]
4. Understand the physics underlying the constitutive equations for complex fluids. [1,6]
5. Enable continued study in advanced topics in fluid mechanics. [1,6,7]
6. Develop the ability to critically evaluate the scientific literature on complex fluids. [1,7]

Develop skills for scientific presentations. [1,3]

NATURE OF DESIGN CONTENT: The course project involves designing and creating a computational tool/experimental setup that demonstrates or implements concepts from the course.

PROFESSIONAL COMPONENT:

1. Engineering Topics: Engineering Science – 85%
   Engineering Design – 15%

COMPUTER USAGE: Basic knowledge of computer programming in MATLAB and/or Python will be required.

COURSE STRUCTURE/SCHEDULE:

a. Lectures – 2 days per week at 75 minutes

RELATED ME PROGRAM OUTCOMES:

1. Engineering fundamentals
2. Engineering design
3. Communication skills
4. Ethical/Prof. responsibilities
5. Teamwork skills
6. Experimental skills
7. Knowledge acquisition

GRADE MODE (Regular; Pass/No Pass; Audit; Satisfactory/Unsatisfactory: Regular, P/NP, Audit

FINAL GRADING CRITERIA (%):

Papers & Projects: 40%

Homework: 30%

Class Presentations: 30%

LIBRARY RESOURCES (describe any library resources that are currently available or the resources needed to support this proposed course. If none needed, explain how the students will complete their research for the course): R.B. Bird, R.C. Armstrong, and O. Hassager, Dynamics of Polymeric Liquids, Vol. 1. Fluid Mechanics, Wiley, New York (1987), Second Edition. Guazzelli and Morris, A Physical Introduction to Suspension Dynamics, Cambridge University Press, 2012 S. Kim and S.J. Karrila, Microhydrodynamics, Dover Publications Inc. 1991 M. O. Deville and T. B. Gatski, Mathematical Modeling for Complex Fluids and Flows, Springer, 2012	**ADDITIONAL FEES: No** **EXPLANATION OF COURSE FEES (Coop, Lab, Rate Request):**
ADDITIONAL COURSE INFORMATION:	**NA**
PREPARED BY: A.M. Ardekani	**REVISION DATE:** October 27, 2020

PURDUE UNIVERSITY

ME 53500 (CRN XXXXX)

Complex Fluids (3 credits)– Fall 2021

Course Syllabus

Class Meeting Time and Location

TuTh, 10.30 – 11:45 A.M., TBD

Course Instructor

Dr. Arezoo Ardekani

Office: ME2187 (765-496-0002)

Email: ardekani@purdue.edu

Office hours by appointment

Course goal: The aim of the course is to provide a basic foundation in the fluid mechanics of viscous flows and complex fluids. Students completing this course are expected to understand the physics underlying the constitutive equations for these materials and be able to model them.

Students successfully completing the course will be able to:
1. define and describe the significant properties of complex fluids,
2. explain how these properties are measured,
3. create a computational or a web-based tool that demonstrates or implements concepts from the course.

Textbook: The text for the course is R.B. Bird, R.C. Armstrong, and O. Hassager, *Dynamics of Polymeric Liquids, Vol. 1. Fluid Mechanics*, Wiley, New York (1987), Second Edition.

Other recommended references include:

S. Kim and S.J. Karrila, *Microhydrodynamics*, Dover Publications Inc. 1991

Guazzelli and Morris, *A Physical Introduction to Suspension Dynamics*, Cambridge University Press, 2012

M. O. Deville and T. B. Gatski, *Mathematical Modeling for Complex Fluids and Flows*, Springer, 2012

Corequisites: The following course or equivalents will be helpful for this course: ME50900

Homework: There will be about ten homework sets during the semester. The purpose of the homework is to help you learn how to use the course material. No

late homework will be accepted.

Each student in the course will be asked to give oral presentations by submitting recorded videos. An oral presentation and written report will be required for the final project.

Course grading: Your course grade is based on the following algorithm:

a.	Project	40%
b.	Presentations	30%
c.	Homework	30%

1. All final scores will be adjusted by adding a constant equal to or larger than (at the instructors' discretion) the difference between 100 and the highest score in the class. For example, if the highest score in the class is a 95, then all final scores will be increased by a value greater than or equal to 100 – 95 = 5 such that the new highest score in the class will now be ≥ 100. Continuing this example, if a different student has a score of 80, then that student's new final score will be ≥ 85.

2. The final grades will be determined using the following table, based on the adjusted final score.

$97 \leq$ score $\Rightarrow$ A+	$93 \leq$ score $< 97 \Rightarrow$ A	$90 \leq$ score $< 93 \Rightarrow$ A-
$87 \leq$ score $< 90 \Rightarrow$ B+	$83 \leq$ score $< 87 \Rightarrow$ B	$80 \leq$ score $< 83 \Rightarrow$ B-
$77 \leq$ score $< 80 \Rightarrow$ C+	$73 \leq$ score $< 77 \Rightarrow$ C	$70 \leq$ score $< 73 \Rightarrow$ C-
$67 \leq$ score $< 70 \Rightarrow$ D+	$63 \leq$ score $< 67 \Rightarrow$ D	$60 \leq$ score $< 63 \Rightarrow$ D
Score $< 60 \Rightarrow$ F		

Regrading requests must be submitted to your instructor within one week of the date the graded document was made available. Regraded items may result in a score that is higher, lower, or the same as compared to the original score.

Academic integrity: Academic integrity is one of the highest values that Purdue University holds. You are encouraged to alert university officials to potential breaches of this value either by emailing integrity@purdue.edu or by calling 765-494-8778. While information may be submitted anonymously, the more information that is submitted provides the greatest opportunity for the university to investigate the concern.

When submitting any exam, homework, and quiz you are adhering to the Purdue Honor Pledge: "As a boilermaker pursuing academic excellence, I pledge to be honest and true in all that I do. Accountable together – we are Purdue".

Any form of academic dishonesty on an exam, quiz, or homework (as defined at http://www.purdue.edu/studentregulations/student_conduct/regulations.html) results in a grade of zero for that exam or a semester long zero for all homework and all quizzes, and a letter will be sent to the Dean of Students.

Note that copying homework and exams directly from a friend, or from a file, or a solution manual (or any other resource such as Chegg, CourseHero, WeeklyJoys, or any other online resource) is cheating. If you are found to be posting and/or accessing exam, quiz, and/or homework questions and solutions on Chegg, CourseHero, etc., then you will receive a zero for that exam, for all quizzes, and/or for all homework without any exception.

Nondiscrimination statement: Purdue University is committed to maintaining a community which recognizes and values the inherent worth and dignity of every person; fosters tolerance, sensitivity,

understanding, and mutual respect among its members; and encourages each individual to strive to reach his or her own potential. In pursuit of its goal of academic excellence, the University seeks to develop and nurture diversity. The University believes that diversity among its many members strengthens the institution, stimulates creativity, promotes the exchange of ideas, and enriches campus life.

Students with disabilities: Purdue University strives to make learning experiences as accessible as possible. If you anticipate or experience physical or academic barriers based on disability, you are welcome to let your instructor know so that we can discuss options. You are also encouraged to contact the Disability Resource Center either by emailing drc@purdue.edu or by calling 765-494-1247.

Campus emergency policy: In the event of a campus emergency, campus emergency procedures (https://www.purdue.edu/ehps/emergency_preparedness/flipchart/index.html) will be followed. The course requirements, deadlines, and grading percentages are subject to changes that may be necessitated by a revised calendar. You will be informed of such changes by email from the instructor. You are expected to read your @purdue.edu email frequently on a daily basis.

Mental health statement: If you are struggling and need mental health services: Purdue University is committed to advancing the mental health and well-being of its students. If you or someone you know is feeling overwhelmed, depressed, and/or in need of mental health support, services are available. For help, such individuals should contact Counseling and Psychological Services (CAPS) at 765-494-6995 during and after hours, on weekends and holidays, or by going to the CAPS office of the second floor of the Purdue University Student Health Center (PUSH) during business hours.

Violent behavior policy: Purdue University is committed to providing a safe and secure campus environment for members of the university community. Purdue strives to create an educational environment for students and a work environment for employees that promote educational and career goals. Violent Behavior impedes such goals. Therefore, violent behavior is prohibited in or on any University Facility or while participating in any university activity.

Course Outline

PERIOD	DATE		SUBJECT	TEXT MATERIAL
1	T	8/20	Funny Flow Phenomena	Ch. 2
2	R	8/22	Classical hydrodynamics	Ch. 1
3	T	8/27	Classical hydrodynamics	Ch. 1
5	R	8/29	Classical hydrodynamics	Ch. 1
6	T	9/3	Material Functions I	Ch. 3
7	R	9/5	Material Functions II	Ch. 3
8	T	9/10	Material Functions II	Ch. 3
9	R	9/12	Generalized Newtonian Fluid	Ch. 4
10	T	9/17	Generalized Newtonian Fluid	Ch. 4

11	R	9/19	Generalized Newtonian Fluid	Ch. 4
12	T	9/24	Linear Viscoelasticity	Ch. 5
13	R	9/26	Linear Viscoelasticity	Ch. 5
14	T	10/1	Ordered Fluid Expansions	Ch. 6
15	R	10/3	Ordered Fluid Expansions	Ch. 6
	T	10/8	Fall break	
16	R	10/10	Ordered Fluid Expansions	Ch. 6
17	T	10/15	Differential Constitutive Equations	Ch. 7
18	R	10/17	Differential Constitutive Equations	Ch. 7
19	T	10/22	Differential Constitutive Equations	Ch. 7
20	R	10/24	Integral Constitutive Equations	Ch. 8
21	T	10/29	Continuum Mechanics	Ch. 9
22	R	10/31	Stokes equations	
23	T	11/5	Singularity solutions	
24	R	11/7	Multipole expansion	
25	T	11/12	Suspensions Viscosity	
26	R	11/14	Suspensions of particles	
27	T	11/19	Suspensions of particles	
28	R	11/21	Suspensions of microorganisms	
29	T	11/26	Emulsions	
	R	11/28	Thanksgiving break	
30	T	1/2	Breakup of liquid jets	