ME 537 FLUID MECHANICS OF AEROSOLS
FALL 2020

INSTRUCTOR: Goodarz Ahmadi, Room 267 CAMP (325-268-2322)
gahmadi@clarkson.edu
Office Hours: Monday and Wednesday 12:30 - 3:30 pm
(Due to COVID-19, all meetings will be by appointment on Zoom)
TEXT: None. Lectures notes are available on the web.
TA: Athukorala Chethani (CAMP 292) Office hours: Friday 3:00-5:00pm

Course Description
Review of viscous flow theory. Creeping flows around a sphere. Drag and lift forces acting on particles. Introduction to aerosols. Diffusion of aerosols in laminar flows. Brownian motion and Langevin equation. Mass diffusion in pipe and boundary layer flows. Effects of electrostatics, van der Waals and other surface forces. Computational aspects of aerosol dispersion in laminar flows. Particle adhesion and particle removal from surfaces. Coagulation of aerosols due to Brownian movements. Experimental techniques for particle adhesion measurements. Cleanroom equipment. Applications to micro-contamination control, xerography, surface cleaning in microelectronic and imaging industries. Aerosol transport and deposition in environmental and biomedical applications.

Delivery Method
The course is offered in blended mode, both in-person in the class, as well as online (asynchronous). The lectures will be captured Echo 360 and will be made available to students on Moodle.

COURSE WEB SITE:
https://webspace.clarkson.edu/projects/crcd/public_html/me537/index.php
https://sites.clarkson.edu/gahmadi/courses/me537/

Course Objectives

1. To provide a fundamental understanding of aerosol transport and removal in laminar flows.
2. To provide a fundamental understanding of particles adhesion and removal from surfaces
3. To provide a fundamental understanding of computational modeling of particle resuspension in laminar flows.
4. To provide a fundamental understanding of the industrial, environmental, and biomedical applications of aerosols.

Course Learning Outcomes

Objective 1:
- Students will be able to formulate and solve aerosol transport and deposition in laminar flows.

Objective 2:
- Students will be able to analyze adhesion and removal of micro- and nano-particles to surfaces.

Objective 3:
- Students will demonstrate a fundamental understanding of computational fluid mechanics and particle trajectory analysis procedures.
- Students will demonstrate using the ANSYS-Fluent Code for solving aerosol transport in

laminar flows.

- Students will become familiar with the experimental procedure for particle adhesion and removal analysis.

Objective 4:

- Students will understand the micro-contamination problems in microelectronic and imaging industries.
- Students will understand the basics of surface cleaning, including ultrasonic cleaning.
- Students will demonstrate the application of aerosol transport and dispersion in at least one industrial, environmental, or biomedical applications.

COURSE OUTLINE

Course Schedule & Graded Activities

Dates	Module Title	Learning Materials (readings, videos, etc.)	Activities
Week 1	**I. REVIEW OF VISCOUS FLOWS**	− Navier-Stokes Equation − Simple Flows − Creeping Flows − Drag on Spherical Particles	Homework
Weeks 2-4	**II. AEROSOLS**	− Introduction to Aerosols − Hydrodynamic Forces (Drag, Lift) − Brownian Motions − Convective Diffusion − Aerosol Kinetics − Particle Deposition Mechanisms − Gravitational Sedimentation − Aerosol Coagulation	Homework
Weeks 5-6	**III. PARTICLE ADHESION**	− JKR and other Adhesion Models − Particle Removal − Effects of Charge and Humidity	Homework
Weeks 7-9	**IV. COMPUTATIONAL FLUID MECHANICS**	− Finite Difference and Finite Volume Methods − Introduction to CFD − Introduction to ANSYS-Fluent Code	Computer Projects Exam-1
Weeks 10-12	**V. SIMULATION METHODS**	− Laminar Flow Simulation − Spherical Particles in Laminar Flows − Brownian Motion of Nano-particles − Spherical Particles Resuspension	Computer Projects
Weeks 13	**VI. EXPERIMENTAL TECHNIQUES**	− Particle Adhesion Measurement − Particle Removal − Surface Cleaning − Laser Surface Scanner	Homework
Weeks 14-16	**VII. APPLICATIONS**	− Micro-contamination Control − Surface Cleaning − Clean Room and Process Equipment − Ultrasonic and Megasonic Cleaning − Aerosol Transport and Deposition in Environment	Homework

COURSE TOPICS

I. REVIEW OF VISCOUS FLOWS

- Navier-Stokes Equation
- Simple Flows
- Creeping Flows
- Drag on Spherical Particles

II. AEROSOLS

- Introduction to Aerosols
- Hydrodynamic Forces (Drag, Lift)
- Brownian Motions
- Convective Diffusion
- Aerosol Kinetics
- Particle Deposition Mechanisms
- Gravitational Sedimentation
- Aerosol Coagulation

III. PARTICLE ADHESION

- JKR and other Adhesion Models
- Particle Removal
- Effects of Charge and Humidity

IV. REVIEW OF COMPUTATIONAL FLUID MECHANICS

- Finite Difference and Finite Volume Methods
- Introduction to Fluent Code

V. SIMULATION METHODS

- Laminar Flow Simulation
- Spherical Particles in Laminar Flows
- Brownian Motion of Nanoparticles
- Spherical Particles Resuspension

VI. EXPERIMENTAL TECHNIQUES

- Particle Adhesion Measurement
- Particle Removal
- Surface Cleaning
- Laser Surface Scanner

VII. APPLICATIONS

- Micro-contamination Control
- Surface Cleaning
- Clean Room and Process Equipment
- Ultrasonic and Megasonic Cleaning

– Aerosol Transport and Deposition in Environment

EVALUATION METHOD

Exam 1 (October 9, 2020, CAMP 178, 6:00-7:15 pm) 25%
Final Exam (Final Exam week) 35%
Computational Projects 30%
Homework 10%

Grading

Grade Ranges

Graduate Letter Grades

Course Average	Grade	Quality Points
97+	A+	4.0
93-96	A	4.0
90-92	A-	3.667
87-89	B+	3.334
84-86	B	3.0
80-83	B-	2.667
76-79	C+	2.334
70-75	C	2.0
<70	F	0

Course Policies

Etiquette Expectations & Learner Interaction

Educational institutions promote the advancement of knowledge through positive and constructive debate--both inside and outside the classroom. Please visit and follow: Netiquette and Electronic Learner Interaction Guidelines.

Institutional Policies

Institutional Policies & Regulations

Academic Integrity

Students are expected to abide by the standards of academic honesty, as described in the Clarkson Regulations. The work or words of others must be properly cited. Please refer to Clarkson Library's Guide to Plagiarism and Citing Sources.

Students with Disabilities Policy

Clarkson University welcomes inquiries and applications from individuals who have disabilities. Information relating to disabling conditions is not a determining factor in admission decisions. The University strives to make all facilities and programs accessible to students with disabilities by providing appropriate academic adjustments and other appropriate modifications (accommodations), as necessary. Timely notification of any need for accommodations due to a disability is encouraged so that the Office of Accommodative Services (OAS) may provide for students in an efficient manner.

For more information or other appropriate campus referrals, contact:

Director of Accommodative Services
Clarkson University
P.O. Box 5645
Potsdam, NY 13699-5635
Phone: 315-268-7643
Fax: 315-268-2400
Email: oas@clarkson.edu
Office of Accessibility Services Website

Instructor Participation

During this course, as your instructor, you can expect me to

- Respond to emails and voicemails within 1 day
- Grade activities and assessments within 3 days
- Be an active participant on the discussion board

REFERENCES

1. J. Y. Tu, K. Inthavong, and G. Ahmadi, "Computational Fluid and Particle Dynamics in the Human Respiratory System," Springer, New York (2013). https://www.springer.com/gp/book/9789400744875
2. W.C. Hinds, Aerosol Science and Technology, Wiley (1983, 1999).
3. J. Happel and H. Brenner, Low Reynolds Number Hydrodynamics, Martinus Nijhoff (1983).
4. N.A. Fuchs, The Mechanics of Aerosols, Dover (1989).
5. V.G. Levich, Physicochemicals Hydrodynamics, Prentice-Hall (1962).
6. F. White, Viscous Flow, McGraw Hill (1974).
7. R.L. Panton, Incompressible Flow, John Wiley (1984).
8. H. Schlichting, Boundary Layer Theory, McGraw Hill (1979).
9. J.O. Hinze, Turbulence, McGraw Hill (1975).
10. H. Tennekes and J.L. Lumley, A First Course in Turbulence, MIT Press (1981).
11. G.M. Hidy, Aerosols, Academic Press (1984).
12. G.M. Hidy and J.R. Brook, The Dynamics of Aerocolloididal Systems Pergamon Press (1970).
13. Papavergos and Hedley, Chem. Eng. Rs. Des., Vol. 62, September 1984, pp. 275-295.
14. S.K. Friedlander, Smoke, Dust and Haze, Wiley (1977).
15. J. H. Vincent, Aerosol Science for Industrial Hygienists, Pergamon Press (1995).