

BAE 590-008: AEROSOL MECHANICS - LECTURE SESSION

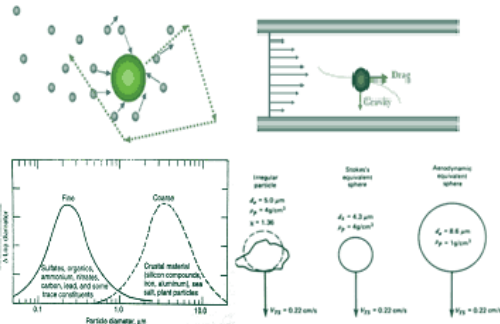
M.W. 10:15am – 11:05am, 142 Weaver Labs

BAE 590-208: AEROSOL MECHANICS - LAB SESSION

F. 1:30pm – 3:20pm, 143 Weaver Labs

SYLLABUS – FALL 2009

Department of Biological and Agricultural Engineering, NCSU



Instructor Information:

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Prerequisite:

Senior / graduate status or approval of instructor

Instructional Objectives:

This course is designed for graduate and senior undergraduate students who have a desire to work in the area of air quality. Upon completion of this course, students will be able to (1) identify the governing mechanism(s) for aerosol behavior under different circumstances; (2) evaluate various aerosol measurement techniques and analyze their limitations; (3) design particulate matter (aerosol) sampling systems for source emission determination; ambient air monitoring; workplace air quality monitoring; and laboratory experiments; and (4) apply aerosol fundamentals in control of particulate matter emission.

Course Text:

Hinds, W.C. *Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles*, 2nd edition. John Wiley & Sons, New York, 1999. ISBN0471194107.

References:

1. Zhang, Y. *Indoor Air Quality Engineering*. CRC press, Florida, 2005. ISBN1566706742.
2. Baron, P.A. and K. Willeke. *Aerosol Measurement: Principles, Techniques, and Applications*, 2nd edition. John Wiley & Sons, New York, 2001. ISBN0471356360.
3. Cooper, C.D. and F.C. Alley. *Air Pollution Control – A Design Approach*, 3rd edition. Waveland Press, Inc. prospect heights, Illinois, 2002. ISBN1577662180.
4. Seinfeld J.H. and S.N. Pandis. *Atmospheric Chemistry and Physics: from Air Pollution to Climate Change*. Wiley Interscience, 1997. ISBN 0-471-17816-0.
5. Copies of relevant technical papers will be handed out to update materials given in text.

Course Description:

The lecture session of course covers the fundamental principles of mechanical, fluid dynamical, electrical, optical and molecular effects for understanding aerosol properties and modeling aerosol behavior. Subjects to be discussed include:

- Aerosol fundamentals: particle size statistics; fluid resistance to aerosol particle motion; diffusion and coagulation of particles; optical characteristics of aerosol; electrical behavior of aerosol; condensation / evaporation; aerosol dispersion; bioaerosol; and health effects

- Aerosol measurements: aerosol mass concentration measurements (including source sampling, ambient PM sampling techniques such as TSP, PM₁₀, PM_{2.5}, TEOM, and samplers for work place); particle size distribution (PSD) measurements (including cascade impactor, electrical sensing zone, laser diffraction, microscopy, etc.); aerosol speciation (including organic and inorganic composition analysis)
- Aerosol controls: case studies for different control technologies in application of particulate matter emission control

General Description of Labs:

In the lab, students will work in teams of two people to complete the lab project. Each team will be responsible for completing the lab as assigned. Tentative hands-on lab experiments include:

- Application of psychometrics for air density determination
- Air flow rate and pressure drop measurements
- Ambient aerosol (PM₁₀, PM_{2.5}, TSP) sampling using gravimetric samplers and TEOM
- Particle density measurement using AccuPyc 1330 Pycnometer
- PSD measurement using LS13 320 multi-wavelength PSD analyzer
- PSD measurement using inertial impactor (cascade impactor)
- Particle inorganic compound analysis using PILS/IC, etc.

The Lab Teams:

Students will be working in teams for hand-on lab experiments. Two teams have been randomly assigned

Team #1	Team #2
Michael Burr	Xinyi Dong
Xiaozhen Liu	Joshua Hemperly
Frank Gronwald	Qianfeng Li

Lab Reports:

The reports, as scientific papers, should have a fairly consistent format that contains the following major sections to help organize information clearly:

- Title
- Abstract – executive summary of the work accomplished
- Introduction – literature review
- Objective(s)
- Material and method
 - Experimental setup
 - Experimental design
 - Experimental procedure
 - Data analysis
- Results and discussions
- Conclusions
- Recommendations for the future work
- References

Lab Grade Determination:

Labs count as 20% of your final grade for this course. You will be graded based on your individual written reports. Each team member will write his or her OWN report for each lab topic. The report will be submitted after the completion of a particular lab project. The exact due date will be determined at least a week before the report is due.

Homework:

Homework will be assigned periodically. It will be collected at the beginning of the class on the due date. Late homework will be accepted up to 5:00pm on the due day, but it will receive a maximum grade of 80%.

Examinations:

There will be two exams and the final. The exams will be closed book, closed notes; however, students are allowed to bring a formula sheet to the exam. Missed exams will be a ZERO, except for University Excused Absences. In order to take a makeup exam, students have to inform instructor about the absence BEFORE the exam unless there is an unexpected accident.

Term Project:

There will be a term project representing 15% of the grade for this course. The project topic is of the student's choosing. Each student should have a topic selected upon instructor's approval by October 2. Each student is expected to give a 15 – 20 minutes oral presentation on their term project research on December 5. The final paper is also due on December 4, and should be written in the style of a paper to be submitted to a major journal for publication.

Grade Determination:

The final grade will not be graded on a curve, and will be determined based upon the following components:

Components	Homework	Lab reports	Exam 1	Exam 2	Final	Term Project
BAE590-008-208	20%	20%	15%	15%	---	15%

- ❖ Your final grade = [homework grade*0.2 + lab report grade*0.2 + exam1*0.15+exam2*0.15+term project grade *0.15]/0.85
- ❖ Final will be optional. You may use your final to replace either exam 1 or exam 2

Grading: border-line grades may be upgraded based upon attendance, class participation, and evidence of improvements.

A ⁺	98-100	B ⁺	87-89	C ⁺	77-79	D ⁺	67-69	F	<60
A	95-97	B	84-86	C	74-76	D	64-66		
A ⁻	90-94	B ⁻	80-83	C ⁻	70-73	D ⁻	60-63		

Lab Safety Regulations:

- Do not use any equipment until the instructor or TA has approved of you doing so. If you are ever uncomfortable using equipment or not 100% confident that you know what you are doing, please ask for help from the instructor or TA. There are going to be instances when you will probably be teased or placed under peer pressure to use tools or equipment that you are not sure how to use. Please ignore this and ask the TA or instructor for help. It is better to be an embarrassed 10-fingered person than an accepted nine-fingered person. Keep in mind that some of the tools we will use to construct prototypes may carry unanticipated dangers including electrical shock, poisoning, burns, as well as loss of hearing, eyesight, skin, blood, and other body parts.
- Never work in the lab on physical construction or modification of your prototype alone. Someone else must be in the lab if you are building / testing. This other person can be from another team. You are not permitted to work in the lab on your project except for normal working hours (8-5 weekdays) with permission from the instructor.
- Wear appropriate clothing. Never wear loose fitting clothes when using power equipment as they may become entangles in the machine and cause serious injury. Wear closed toe shoes (no sandals or flip-

flops). Wear clothes that you don't mind getting stained or dirty. Tie-up long hair so it cannot get tangled in equipment.

- Safety in the lab is everyone's responsibility. You must watch out for your classmates and alert them when they may be doing something unsafely. This is especially true for those of you with experience using equipment. If you see someone doing something unsafe, please try and correct them and if they refuse to change their behavior, report them to the TA or instructor.

Academic Integrity:

The Code of Student Conduct at North Carolina State University sets out a code of ethics and personal dignity. Students should refer to this code and value honesty and integrity. The code could be found at www.ncsu.edu/policies/student_services/student_discipline/POL11.35.1.php.

It is permissible in this course to discuss the interpretation of the problem statement, share ideas or approaches for solving the problem, and explain the concepts involved in the problem. Any other aid is not permissible and considered as a violation of the academic integrity policy. No academic misconduct will be tolerated in this course.

Attendance:

Students are expected to attend class on time. In case of absence, the student must provide documentation substantiating the reason for the absence that is satisfactory to the instructor, within one week of the last date of the absence. For illness, documentation should include a note from a doctor or clinic. For further information, students should refer to the University attendance policy at www.ncsu.edu/provost/academic_regulations/attend/reg.htm.

Students with University Excused Absences will be allowed to makeup missing exam and late homework without any penalty. However, it is the student's responsibility to identify the materials covered during the absence and to contact instructor for scheduling makeup exam.

Incomplete Grades:

The university policy form incomplete grades can be found at <http://www.fis.ncsu.edu/ncsulegal/41.03-codeof.htm>. An IN is not an alternative to an "F".

Students with Disabilities:

Reasonable accommodations will be made for students with verifiable disabilities. In order to take advantage of available accommodations, students must register with Disability Services for Students at 1900 Student Health Center, Campus Box 7509, 515-7653.

http://www.ncsu.edu/provost/offices/affirm_action/dss/

Tentative Course Outline:

Part I: Aerosol Fundamentals

1. Introduction: overview and definitions (*Hinds, Ch.1*)
 - a. Overview and definitions
2. Properties of gases (*Hinds, Ch.2; Zhang, Ch.5; Cooper & Alley, Ch.10*)
3. Particle size statistics (*Hinds, Ch.4; Zhang, Ch.3*)
 - a. Properties of size distribution
 - b. Number distribution
 - c. Mass distribution
 - d. The log-normal distribution
4. Particle mechanics – 1 (*Hinds, Ch.3; Zhang, Ch.4*)
 - a. Uniform particle motion
5. Particle mechanics – 2 (*Hinds, Ch.5*)
 - a. Straight-line acceleration and curvilinear particle motion
6. Adhesion of particle (*Hinds, Ch.6*)
7. Diffusion (*Hinds, Ch.7, Ch.12; Zhang, Ch.6*)
 - a. Brownian motion
 - b. Diffusion coefficient
 - c. Diffusive deposition
8. Thermal and Radiometric forces (*Hinds, Ch.8*)
9. Coagulations of aerosols (*Hinds, Ch.12*)
 - a. Monodisperse coagulation
 - b. Polydisperse coagulation
 - c. Kinematical coagulation
10. Condensation and evaporation (*Hinds, Ch.13*)
 - a. Thermodynamics
 - b. The Kelvin-Helmholz equation
 - c. Growth by condensation
 - d. Evaporation
11. Filtration of aerosols (*Hinds, Ch.9; Zhang, Ch.10*)
 - a. Properties of filters
 - b. Filtration mechanisms
 - c. Filter efficiency
 - d. Pressure drop
12. Electrical behavior of aerosols (*Hinds, Ch.15; Zhang, Ch.12*)
 - a. Basic considerations
 - b. Charging mechanisms
 - c. Electrical measurement of aerosols
13. Optical characteristics of aerosols (*Hinds, Ch.16*)
 - a. Scattering of light
 - b. Extinction
 - c. Optical measurement
14. Spray and atomization (*Hinds, Ch.21, handout*)
15. Atmospheric aerosols (*Seinfeld, Ch.7; Hinds, Ch.14; Handout*)
 - a. Introduction and background
16. Bioaerosols (*Hinds, Ch.19; Baron & Willeke, Ch.24*)
 - a. Definition and classification
 - b. Characteristics
 - c. Collection and sampling
17. Health effect of aerosols – aerosols in air quality (*Hinds, Ch.11, handout*)

Part II: Aerosol Measurement

18. Uncertainty analysis in aerosol measurement (*Handout*)
 - a. Basic concepts
 - b. Uncertainty analysis
19. Air flow rate control and PM concentration determination (*handouts*)
20. Stationary PM source sampling
21. Impaction and gravitational settling in aerosol measurements
22. Low Reynolds sampling cyclone
23. PSD measurement method
24. Open path technology
25. Diffusion denuders
26. FRM PM sampler performance
27. Interaction of PSD and sampler performance characteristics
28. Dispersion modeling of PM emissions
29. Aerosol measurement in the workplace (*Baron, Ch.25 and handout*)
 - a. ACGIH sampling criteria for inhalable, thoracic and respirable fractions
 - b. Occupational exposure limits
 - c. Industrial hygiene aerosol samplers
30. Indoor aerosols (*Baron, Ch.29*)
 - a. Measurement strategies
 - b. Sampling and analysis methods
 - c. Sampling of PM emission from building
31. Air quality regulatory process and ambient air monitoring (*Handout*)
32. National air emission monitoring study (NAEMS)

Part III: Aerosol Emission Control

33. Industrial cyclones for PM emission control (*handout*)
 - a. Theory and design considerations
34. PM scrubbers (*handout*)
 - a. Theory and design considerations
35. Electrostatic precipitators (ESP) - (*Zhang, Ch.12; Cooper & Alley, Ch.5*)
 - a. Theory and design considerations
36. Fabric filters –PM bag house design (*handout*)
 - a. Theory and design considerations
37. Case studies (*handout*)

Tentative Lecture Schedule & Topics:

Week	Class	Date	Topics	Assignments	Reading
1	1	08-19-09	Introduction: overview & definitions		Hinds, Ch.1
	2	08-21-09	Lab: psychometrics and air density determination	Lab report#1	Handouts
2	3	08-24-09	Properties of gases		Hinds, Ch.2; Zhang, Ch.5
	4	08-26-09	Particle size statistics		Hinds, Ch.4
	5	08-28-09	Lab: sampling flow rate control and PM concentration determination		Handouts
3	6	08-31-09	Uniform particle motion	HW #1	Hinds, Ch.3
	7	09-02-09	Straight-line acceleration and curvilinear particle motion		Hinds, Ch.5
	8	09-04-09	Lab: ambient PM monitors and PM samplers		
4		09-07-09	No class, Holiday		
	9	09-09-09	Adhesion of particle		Hinds, Ch.6
	10	09-11-09	No class, time used for field trip on 9/16/2009		
5	11	09-14-09	In-class practice on psychometrics		
	12	09-16-09	Lab: field trip – observation of PM monitoring systems at a research	Lab report#2	
	13	09-18-09	Thermal force; time used for field trip on 9/16/2009		
6	14	09-21-09	Brownian motion and diffusion		Hinds, Ch.7
	15	09-23-09	Diffusive deposition		Hinds, Ch.7
	16	09-25-09	Coagulation, Condensation and evaporation	HW#2	Hinds, Ch.12, Ch.13
7	17	09-28-09	Electrical behavior of aerosol		Hinds, Ch.15
		09-30-09	Optical characteristics of aerosol		Hinds, Ch.16
	18	10-02-09	Lab: particle density measurement	Lab report#3	
8	19	10-05-09	Filtration	HW#3	Hinds, Ch.9, Zhang, Ch.12
		10-07-09	No class, Fall Break		
		10-09-09	No class, Fall Break		
	20	10-12-09	Review for exam 1		
9	21	10-14-09	Exam 1: in-class (closed book, closed notes)		
	22	10-16-09	Lab: TSP/PM ₁₀ sampling practice	Lab report#4	
10	23	10-19-09	Impaction and gravitational settling in aerosol measurements		Hinds, Ch.5, Zhang, Ch7., Baron, Ch.10
	24	10-21-09	Stationary PM source sampling		Hind, Ch.10, Zhang, Ch8,
	25	10-23-09	Lab: PSD measurement method and practices	Lab report#5	
11	26	10-26-09	FRM ambient sampler performance		Handouts
	27	10-28-09	Dispersion modeling of PM emissions	HW #4	Handouts
	28	10-30-09	Lab: PM chemical speciation – Dr. Jayanty, RTI		
12	29	11-02-09	Ambient PM monitoring network		Handouts
	30	11-04-09	Review of HW 4		
	31	11-06-09	Bioaerosol (HW#4 due)		Hinds Ch19, Baron, Ch24
13	32	11-09-09	Review for exam #2		
	33	11-11-09	Exam 2: in-class (closed book, closed notes)		
	34	11-13-09	Guest lecture: BAM vs. TEOM monitors by Jim McGaughey, NCDENR (term paper abstract due)		
14	35	11-16-09	Review exam #2		Handouts
	36	11-18-09	Review exam #1		Handouts
	37	11-20-09	Lab: field trip – NCDENR PM monitoring site at Millbrook High (Lab report#5 due)		
15	38	11-23-09	Open path technology/diffusive denuder		Handouts
		11-25-09	No class, thanksgiving holiday		
		11-27-09	No class, thanksgiving holiday		
16	39	11-30-09	Review for final		
	40	12-02-09	Term paper presentations	Term paper due	
	41	12-04-09	Guest lecture (1) Measurement methods for ammonium nitrate/ammonium sulfate and its precursors (2) Measurement and modeling of particle air-surface exchange by Dr. John Walker, EPA		
12-16-2009 at 8:00 – 10:00am:			Final Exam	Closed book, closed notes	