A SURVEY COURSE IN PARTICLE TECHNOLOGY

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In the spring semester of 1998, an overview course in particle technology was launched in the School of Chemical Engineering at Purdue University. The student enrollment in the initial offering of this course was relatively high (25 students) for an elective course; hence, the course is now being offered yearly in Purdue's spring semester. It will also be taught starting in the spring semester of 2000 via videoconferencing as a part of Purdue's continuing education program for practicing engineers, some of whom are working part-time towards their Masters of Engineering degree at Purdue.

The objective of the course is to provide a broad overview of the field, with emphasis on concepts and practical applications. Specific topics include particle characterization, sedimentation, gas fluidization, pneumatic conveying, gas-solid separation, particle storage, mixing, size reduction and enlargement, and dust hazards and explosions. About one week of coverage is given to each of the above topics; the emphasis is clearly toward breadth rather than depth.

At Purdue, as well as at most other universities in the U.S., the current educational treatment of particle technology is limited to a one-semester course. This constraint dictates that the time available in a single-semester course is best spent in an overview fashion. Hence, emphasis is on relating to the students an appreciation for the many aspects of this complex field and on developing an awareness of the resources available to them if they find themselves working in industies involved with the processing of particulate solids.

The overview course in particle technology is offered as a 500-level course available to junior and senior undergraduates as well as to graduate students. Enrollment in the two offerings of the course to date has been an even mix of undergraduate and graduate students from a range of disciplines that includes chemical engineering, mechanical engineering, food science, agricultural and biological engineering, civil engineering, and pharmacy. The textbook used in the course is *Introduction to Particle Technology* by Martin Rhodes (Wiley, 1998).

The course includes guest speakers from several industrial companies such as Dow and DuPont. At least one field trip to an industrial company involved in solids handling is included each semester so that students can see first-hand the many unit operations discussed in the lectures. The course schedule for the spring 1999 offering of the course can be found in Table 1.

Slurry flow is the only subject covered in the course that is not treated in the Rhodes text. Reading for this material is given as handouts and is based on the text *Bulk Solids Handling* by Woodcock and Mason (Blackie Academic, 1987). Supplementary material for other lectures is taken from the following texts:

- *Principles of Powder Technology,* Rhodes; Wiley, 1990
- *Processing of Particulate Solids,* Seville, Tuzun, and Clift; Blackie Academic, 1997
- *Principles of Gas-Solid Flows,* Fan and Zhu; Cambridge University Press, 1997
- *Particle Size Measurement,* Allen; Chapman & Hall, 1997
- *Fluidization Engineering,* Kunii and Levenspiel; Butterworth-Heinemann, 1991
- *Pneumatic Conveying of Solids,* Marcus, Leung, Klinzing, and Rizk; Chapman & Hall, 1990

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INTRODUCTORY LECTURE

The aim of this lecture is to convince students of the critical importance of particle technology and also to clearly show them that the concepts they learned in a typical engineering fluids course may not necessarily translate to the flow and storage of particles. This lecture sets the stage and motivation for the course. If done well with lots of visuals, it is highly effective in imparting to students the importance of knowledge in this technical area.

This same lecture works well as a recruiting tool to attract students to the course. At Purdue, chemical engineering undergraduates must take a chemical engineering seminar course every semester. During part of one class period in the seminar course, I present some key concepts from this introductory particle technology lecture to all of the chemical engineering students. Many of the students end up registering for the particle technology course because of the material contained in this presentation. I have also given the lecture to industrial visitors to our university; they are usually "sold" on particle technology after hearing it.

The basic components of this lecture are a definition of particle technology, a presentation of the importance of particle technology in industry, and a presentation of examples in which particles behave in a unique way, often very differently than fluids. In most of these examples, I give a visual picture to the audience either by illustrating with a real particulate material or through the use of a graph, photograph, etc.

An outline of the introductory lecture can be found in Table 2 (next page).

TABLE 1
Course Schedule

		Reading in Rhodes
January 12	Introduction	Chapter 3
14	Particle characterization	Chapter 3
19	Particle characterization	Chapter 3
21	Particle size measurement	Chapter 3
26	Sedimentation	Chapter 1
28	Sedimentation	Chapter 2
February 2	Packed beds	Chapter 4
4	Fluidization	Chapter 5
9	Fluidization	Chapter 5
11	**Exam #1**	
16	Pneumatic conveying	Chapter 6
18	Pneumatic conveying	Chapter 6
23	Gas-solid separation	Chapter 7
25	FIELD TRIP: National Starch	
March 2	FIELD TRIP: Cargill	
4	Slurry flow	Notes
9	Particle mixing	Chapter 9
11	**Exam #2**	
23	Guest Lecturer: Rachel Anderson, Dow "Design of Particle Storage Devices"	Chapter 8
25	Guest Lecturer Rachel Anderson, Dow "Design of Particle Storage Devices"	Chapter 8
30	Guest Lecturer: Mohsen Khalili, DuPont "Case Studies in Particle Technology"	
April 1	Guest Lecturer: Mohsen Khalili, DuPont "Case Studies in Particle Technology"	
6	Particle size reduction	Chapter 10
8	Particle size enlargement	Chapter 11
13	Guest Lecturer: Professor Wassgren, MechE, Purdue "Simulation of Particle Flow"	
15	Dust hazards/explosions	Chapter 12
20	Oral presentations - Project	
22	**Exam #3**	
27	Oral presentations - Project	
29	Oral presentations - Project	

COURSE PROJECT

One of the key components of the overview course in particle technology, in addition to the traditional lecture, homework, and exam format, is the course project. In the project, students work in teams to investigate one specific topic in particle technology in detail. The team project comprises one-third of the course grade, and the last lectures of the course each semester are devoted to presentations of the group projects. The project brings depth in one particle technology topic to a course that emphasizes breadth. The project also provides additional experience for the students in the teamwork and communication skills that are essential on the job.

A course project is very attractive to the students because they can work in an open-ended fashion on a particle technology subject of their choosing. Most undergraduates enjoy the team aspect of the course project since they are accustomed to working in teams in their senior engineering design courses and, for some, in their co-op positions. The graduate students like the course project because they are given the opportunity to probe topics discussed in lecture in more detail. Many of the graduate students who enroll in the course want specific topics along the lines of their graduate research developed in greater detail than the treatment given in the lectures. Since this is not possible in the lectures, given the time constraints, the course project offers another format for meeting these students' expectations for the course.

In the course project, the students are engaged in both background research and in making a forward step, that is, moving beyond what is currently known and putting forth something new. The "something new" can take the form of a research proposal, new theory, new insight, new calculations, new data (some students have access to appropriate experimental facilities in their research group), etc. In the course at Purdue, the weighting on the background research versus the "something new" portion of the project is approximately 75/25%.

Students work in teams of three to four people. The teams and their presentation dates are chosen randomly by picking numbers out of a hat during the first class meeting. At least fifteen minutes is allocated during the first lecture period for the group members to exchange contact information and class schedules, briefly get to know one another, and to decide on a group leader. Other opportunities are given during the semester towards the end of class periods for group discussions.

The teams are given three weeks to decide on a project topic. Students are instructed to peruse the titles of articles in the journals of *Powder Technology* and *Particle Science & Technology* to stimulate ideas for projects. Often when a graduate student is one of the team members, he or she takes on the leadership role and guides the course project to a topic related to his or her graduate research. This pattern of the graduate student taking charge of the team has not yet created any group conflicts; rather, many of the undergraduate students seem to be relieved when a project direction is decided on quickly and easily. The only group conflict that has arisen to date has been when two graduate students were on the same team and they had areas of graduate research specialization in particle technology that involved little overlap. For that team, coming to an agreement on a project topic required a lot of compromising among the group members.

Focus areas for project topics have spanned the spectrum of particle sizes and particle science and technology applications. Representative topics have included

- *Use of Electrokinetic Sonic Amplitude in the Characterization of Colloidal Suspensions*
- *Particle Size Distribution Effects in Pneumatic Conveying*
- *Novel Designs for FCC Reactors*
- *Use of Simulation Techniques to Improve Cyclone Design*

TABLE 2
Outline of Introductory Lecture

Particle Technology
- Particle technology refers to the science and technology related to the handling and processing of particles and powders
- Also known as "powder technology" (sometimes when the particle size is less than 100 microns)
- Powders or particles also referred to as particulate solids, bulk solids, and granular solids
- Particle technology includes solid particles as well as liquid droplets, emulsions, and bubbles
- Wet/dry particulate systems—with and without liquid

Importance of Particle Technology
- 62% of DuPont's 3000 products involve particles (*ChE Progress,* 1994)
- 50% of Dow Chemical's products
- Rand Corporation Study (*ChE Progress,* 1985)
  - 37 solids processing plants studied
    - 2/3 operated at less than 80% design capacity
    - 1/4 operated at less than 40% design capacity
    - (95% is average for the CPI as a whole)
- Ignorance of particle technology often results in loss of production, poor product quality, health risks, dust explosions, and storage silo collapse. Typically, 20-25 deaths occur each year due to failures in particle technology operations.
- Particle technology impacts fields of chemical engineering, mechanical engineering, agricultural engineering, food engineering and food science, electrical engineering, civil engineering, pharmaceuticals, metallurgy, and minerals engineering. In each of these fields I give examples of processes involving particle technology. I also ask the students for input here because the students in the course come from a diverse set of science and engineering backgrounds.

Particles Do Not Necessarily Behave Like Fluids
- Particles expand in a dry bulk assembly when sheared. Walking on sand at the beach is a good example of particle expansion during shear.
- The ability of particles to form a heap. **Visual**—two different types of particulate material and a discussion of the angle of repose and how particle cohesivity influences flow behavior.
- Differences in pressure drop behavior in pipelines in a single-phase gas versus a gas-particle mixture. **Visual**—Show and discuss a graph of how it is possible in dense-phase conveying of particulates to have a reduction in pressure drop with an increase in gas velocity at a constant solids flowrate. Also discuss how the addition of a small fraction of very fine particles to a turbulent fluid may cause a reduction in the pressure drop.
- Particle flow behavior in bends can be very problematic. **Visual**—An illustration of the roping phenomena; an actual pipe bend ruined by erosion.
- Particle storage in hoppers can also be problematic. **Visual**—Mass flow versus funnel flow—stagnation regions do not occur in fluid storage in a similar vessel; plugging of the outlet of a hopper.
- Particle flowrate out of hopper as the head decreases. **Visual**—Clear hopper and observation of outlet flowrate as a function of head—contrast with fluid flow out of a tank as head decreases.
- Particle bulk density varies with "tapping." **Visual**—Tapping of a fine particulate material in a vial and observation of volume occupied by particulate material—contrast with a single-phase fluid in a vial.
- Large particle placed at the bottom of a container of a dry granular material will rise to the surface if the container is vibrated in a vertical plane. **Visual**—Shaking of a particulate material in a vial containing one larger particle and observation of the large particle movement.
- Fill volume of two types of particles can depend on the order of filling of the container. **Visual**—Filling a jar with two sizes of nuts and observation of volume occupied—contrast with combining two fluids and the resulting volume.
- Stirring a mixture of two types of particles of different sizes may result in segregation rather than improved mixing quality. **Visual**—Photographs of segregation patterns before and after a blending operation—contrast with mixing of two fluids.

- *Probing the Mechanisms of Particle Charging*
- *Ultra-High Performance Electrostatic Precipitators*
- *Moisture Content and Caking in Foodstuffs*

There are four aspects to be graded in the overall course project:

1. The first is a written report of at least ten pages prepared by the group that summarizes the background information on the topic and the novel aspects of the investigation.
2. The second is an oral presentation of the topic, thirty to forty-five minutes in length. All of the group members are required to participate in the oral presentation. Typically, one student outlines the discussion points in the beginning of the presentation, and then the team members take turns speaking on each of the presentation bullets. Often the presentations are supplemented with visual aids or a short demonstration to introduce the topic and capture the attention of the audience. The oral presentation is followed by a questioning period. During the questioning period, each of the project teams in the audience is required to ask at least two questions of the presenting team. This requirement is highly successful in keeping the class engaged in the presentations; the students also often generate outstanding questions. This peer questioning is one aspect of peer review (see task #3 below) that is incorporated into the course project to help develop the communications skills of the students. After the questioning period is over, the instructor gives the presenting team immediate feedback, both positive and negative, in front of the entire class. This helps to improve the quality of the subsequent presentations since students get a better understanding of what is successful, what are some of the pitfalls, and what are the standards expected for the presentations.
3. Every team performs a peer evaluation of each of the other teams. The peer evaluation is on both the written and oral presentations of the course project. In the written report, each team serves as a reviewer of the other team reports, marking grammatical and typographical errors directly on the manuscript. They write a short summary of the manuscript that includes an overall evaluation, specific positive aspects, constructive criticisms, and suggestions. For the oral presentations, a structured evaluation form is used that is provided by the instructor. Therefore, at the end of the peer evaluation process, each team has a large amount of anonymous feedback—a written and oral report from each of the other teams. Although these peer evaluations do not influence the grade of the team being evaluated, they are very instructive; the students tend to listen and readily accept the comments from their peers. The peer evaluations prepared by each team are graded for thoroughness and level of insight by the instructor.

   The value of peer review has been documented in the literature,[1-5] and its benefits are abundantly evident in the particle technology course. Perhaps this is due to the fact that the course is an elective course. Presumably, students already have some interest in the topic when they enroll in the course and the peer review merely enhances their involvement in it. Students take the reviewing task seriously. They do an excellent job in identifying the strengths and weaknesses in the work of their fellow students. The peer review also aids the students in recognizing the strengths and weaknesses of their own oral and written reports.
4. Finally, each team member submits to the instructor a summary report of the relative contributions of each of their own group members, including an assessment of their own contribution to the team effort. This helps the instructor assign appropriate individual grades to the group project.

Aside from the technical benefits a particle technology project brings to the course, there is the additional, more general benefit of improving team skills. Team skills are a requirement for a successful workforce; about 80% of U.S. organizations use teams to accomplish tasks.[6] In technical fields, teamwork is particularly crucial as engineers and scientists become more specialized. Students, through the course project, gain more experience in how to capitalize on the unique skills of others, and, in turn, they often learn more about their own capabilities. In addition, they learn better how to motivate others, how to organize a group effort, and how to manage in difficult teams since team members are not reassigned even if a team is having problems working together. In fact, student feedback indicates that while being a member of a "problem team" is certainly not a pleasant experience, those team members are the ones that make the strongest comments about their huge learning experiences in team skills.

SUMMARY

A survey course in particle technology is a highly effective way to introduce the basics in this field to a diverse group of students. A "gee-whiz"-type introductory lecture helps sell the importance of particle technology to different audiences. Visuals enhance presentation of the unique features of particulate systems. Incorporation of a team project into the course allows for students to focus on one particular topic in particle technology and adds depth to the breadth of material covered in this survey course. Also, the course project brings many positive factors to the learning experience of the students.

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