# DEVELOPMENT OF A POWDER TECHNOLOGY OPTION AT CCNY

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Powder technology defines the field of dry powder processing, including such operations as characterization, storage, transport, mixing, classification, grinding, and agglomeration. Taken more broadly, powder technology includes all operations where fine solid particles are involved either by themselves or in combination with a fluid, therefore encompassing a wide range of subjects in materials synthesis and processing, rheology, and colloid and aerosol science.

Funded by NSF, the project at CCNY aims to develop undergraduate courses in the more restricted area of powder science and technology and to integrate them into a chemical engineering curriculum. The purpose of this paper is to present the program at CCNY, the courses developed, the books used, and the teaching methodology of the subject as it is combined with an undergraduate laboratory. The core of the program is a basic course, "Powder Technology," that is described in some detail in this paper. Other courses which form the group of electives (option) associated with the above course are "Fluidization and Fluidization Technology" and a "Unit Operation Laboratory II" that has most experiments associated with powders. These courses are also described in this paper.

## BACKGROUND

Dry powders are assemblages of large numbers of small, irregularly shaped, solid particles resting on each other.[1] Their sizes range from several microns up to 200 μm, and in some cases up to 1 millimeter. The space between particles is filled by a fluid (usually called void space) so that the overall density of the medium is much smaller than the true material density of the solid. Since particles touch at well defined points of contact, short range interactive forces combine with surface friction to give the so-called *bulk* powder many interesting properties which neither the solid nor the interstitial fluid possess. Some of these properties include "liquid-like" behavior in that powders exhibit a "free surface" and also "flow" when poured from a container. Due to internal friction, however, they exhibit (unlike liquids) an angle of repose when poured into heaps.

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Another interesting property is the high chemical reactivity that is due to their large, exposed surface to the fluid. A typical example is the explosive behavior of coal dust dispersed in air, while large chunks of coal can be ignited only with great difficulty. Good examples of bulk powders are beach sand, cement, sugar, wheat flour, salt, and ground coffee. Some authors even go so far as to suggest that powders are a fourth state of matter, but this view does not hold water since it can be shown that all thermodynamic properties are linear superpositions of the properties inherent in the component phases.

Powder technology is a relatively new branch of engineering that has experienced rapid development in the last thirty years or so. In a restricted sense, it defines the field of dry powder processing, including the operations of characterization and measurement, storage, transport, mixing, classification or separation, comminution or grinding, and agglomeration or size increase. Taken more broadly, powder science and technology includes all operations where fine solid particles are involved either by themselves or in combination with a fluid, thereby encompassing a wide range of subjects in materials synthesis and processing, rheology, and colloid and aerosol science. In the present program, powder technology is used in the restricted sense, although such subjects as pneumatic conveying, slurry flow, fluidization and fluid-particle systems in general are also presented.

The introduction of powder technology as an academic discipline was first achieved in Germany in the 1960s;[2] today, more than a dozen universities teach the subject throughout Germany. Teaching powder technology was later developed in other countries such as Japan, the United Kingdom, the Netherlands, Australia, and New Zealand. The emphasis in these countries was more on the study of powder processing than on the initial effort in design and development of special machinery, as was the case in the German schools.

The urgent, large-scale need for powder technologists and scientists was recognized in England as early as 1981, and a serious effort was funded by the British Government to develop teaching and research centers in the field.[3] Eighty-six grants were awarded to about twenty institutions on the following subjects: particle (powder) formation and synthesis, handling and processing, and solid-liquid phenomena. At least four Schools of Powder Technology exist in the United Kingdom today, with many other departments, mostly in chemical engineering, teaching the subject on both the graduate and undergraduate levels.

The effort in Japan is even more elaborate since it enjoys funding by both private companies and the government. The Powder Technology Society of Japan coordinates the more than six hundred researchers and teachers in the field. There are twenty-eight active research centers in Japan, and the Association of Powder Process Industry has over three hundred companies supporting the effort.

**Powder technology is a relatively new branch of engineering that has experienced rapid development in the last thirty years or so. . . . Funded by NSF, the project at CCNY aims to develop undergraduate courses in the more restricted area of powder science and technology and to integrate them into a chemical engineering curriculum.**

## POWDER TECHNOLOGY IN THE U.S.

In a recent paper published in *Chemical Engineering Progress,*[4] a group from DuPont describes the sad state of affairs of research and teaching of powder science and technology in the U.S. They write, "...while other nations have long recognized the importance of powder technology, the U.S. lags seriously behind. Industry, government, and academia all must play key roles if we are to improve our mastery of powders . . . and our competitiveness."

In another article,[5] a senior engineer at DuPont stated that 60% of the company's 3000 products are *in particulate form.* Another 20% of DuPont products use particles to improve the required properties of the products. He further indicated that plants using finely divided solid feed (*e.g.,* powders), may operate at as little as 50% of design capacity. Summarizing his concern about university education, he writes that a young engineering graduate joining his company has an 80% probability of having an assignment involving particulate processing for which he is totally unprepared and that typical fluid mechanics and other courses being taught "inadequately prepare graduates to solve, or even recognize, these . . . problems."

Even though major discoveries in the theory of powders, such as the direct application of soil mechanics principles to storage hopper (bin) design, were made in the U.S. in the mid-fifties, and although powder engineering is practiced on an enormous scale in the U.S., no center for teaching the subject in American universities has developed. The area is scattered through many fields, such as civil engineering, materials science, metallurgy, and chemical engineering, and there is no concerted effort to teach the subject at the undergraduate level. It must be mentioned, however, that while the subject is not taught at the undergraduate level, several consulting companies teach short courses at chemical engineering (and other) meetings as well as at corporate centers for postgraduate learning. The need for powder technologists is enormous, and companies that need engineers in these specialties must train them on the job or hire them from overseas.

A survey of about forty chemical engineering departments[6] showed that only West Virginia University offered a course in powder technology, and that at the graduate level only (see Table 1, next page). Other universities offer other courses that cover the broader area of powder technology, but no undergraduate degree is offered in the field. (It should be noted that the survey was not exhaustive of the chemical engineering departments nor of material science and/or mining engineering departments where subjects in powder technology are sometimes covered.)

The lack of focus on powder and particle technology in the U.S. has begun to be recognized in the last three to four years, and there is a recent movement (initiated mainly by the DuPont Company and the Fluid/Particle Separations Society) to develop particle technology curricula. During the same time period, NSF initiated start-up of Centers of Excellence in the field at the Pennsylvania State University and the University of Florida and also supported various other initiatives to strengthen powder technology in the U.S. (It should also be mentioned that AIChE formed a "Particle Technology Area" in 1990 and a "Powder Technology Forum" in 1992.) The present effort to develop powder technology curricula at CCNY, along with programs started at the Universities of Pittsburgh and Minnesota (albeit with a somewhat different focus) are all part of the same process.

## POWDER TECHNOLOGY COURSES AT CCNY

The powder science related courses that have been taught in the Department of Chemical Engineering at CCNY since 1963 are described in some detail in Table 2. The course in fludization is a comprehensive study of fluidized beds and their application as industrial heat exchangers, reactors, filters, granulators, etc. The students are first introduced to the hydrodynamics of a particle moving in an infinite medium, followed by the study of flow in packed beds and the minimum fluidization conditions. Various measurements in the fluid bed and the characterization of the particles involved are also described. Bubbling and fast (circulating) fluidized beds, their interesting properties and behavior, are presented in detail, both theoretically and practically, in the associated laboratory (see Table 3).

The last part of the course is dedicated to the study of heat transfer and chemical reactions in fluidized beds with such applications as the Fluid Bed CAT cracker and the Fluid Bed Granulator. We anticipate that this course will be offered at both the graduate and the undergraduate levels and will be integrated into the undergraduate group of electives.

The course in "Fluid Particle Systems" is an advanced, graduate-level study of special topics on the flow, heat, and mass transfer of solid particles, bubbles, and drops in low and high concentration systems with such applications as pneumatic conveying, slurry flow, filtration, etc., and is not offered at the undergraduate level. Additional graduate courses in interfacial phenomena and non-Newtonian fluid flow are offered at least once a year, and with these courses the Chemical Engineering Department is at the forefront of teaching these subjects. In fact, the overall strength of the department is concentrated in the "broad" area of powder technology and related fields.

### TABLE 1
**Results of Survey of Courses on Powder Technology and Materials Processing (after Chase, 1993[6])**

(Legend: G=Graduate, U=Undergraduate; B=Both graduate and undergraduate)

| STATE/SCHOOL | LEVEL | COURSE TITLE |
|---|---|---|
| **FLORIDA** | | |
| FAMU/FSU | G | Mechanics and Rheology of Composite Fluids |
| **GEORGIA** | | |
| Georgia Institute of Tech. | B | Technology of Fine Particles |
| **ILLINOIS** | | |
| Illinois Institute of Tech. | U | Fluidization |
| | B | Applied Particle Technology |
| | G | Fluidization and Gas-Solid Flow Systems |
| **IOWA** | | |
| University of Iowa | G | Microstructural Processes in Materials |
| **MASSACHUSETTS** | | |
| Worcester Polytech. Inst. | U | Dynamics of Particulate Systems |
| **MISSOURI** | | |
| U. of Missouri-Columbia | B | Particulate Systems Engineering |
| **NEW YORK** | | |
| City University | G | Fluidization |
| | G | Fluid-Particle Systems |
| Clarkson University | U | Fine Particle Technology |
| | G | Bubbles, Drops, and Particles |
| Cornell University | G | Fluid Mechanics of Suspensions |
| **PENNSYLVANIA** | | |
| University of Pittsburgh | G | Fluidization and Pneumatic Transport |
| **TEXAS** | | |
| Texas A&M, Kingsville | B | Problems in Particle Mechanics |
| Texas A&M | U | Processing of High Technology Materials |
| **WEST VIRGINIA** | | |
| West Virginia University | G | Fluidization Engineering |
| | G | Powder Technology |

### TABLE 2
**Graduate Courses in Powder Technology and Related Fields at CCNY**

■ ***Fluidization: The Theory and Practice of Fluidization*** *(3 class hours, 3 credits)*
General behavior of fluidized beds both static and flowing; mass transfer and heat transfer; modeling of chemical reactions in fluidized beds.

***Textbooks***

- ► Kunii, D., and O. Levenspiel, *Fluidization Engineering,* John Wiley and Sons, NY (1990)
- ► Geldart, D., *Gas Fluidization Technology*, Wiley-Interscience (1986)

***Topics***

- Hydrodynamics of single particles
- Characterization of fluidized beds
- Bubbling fluidized beds
- High velocity fluid beds
- Fluid bed heat transfer
- Applications

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■ ***Fluid Particle Systems*** *(3 class hours, 3 credits)*
Basic equations of multiphase systems; transport processes of rigid and deformable particles; drag coefficients; heat and mass transfer rates; turbulence effects; transport properties of clouds of particle; pipe flow of a suspension; filtration of aerosols and industrial filters.

***Textbooks***

- ► Clift, R., J.R. Grace, and M.E. Weber, *Bubbles, Drops, and Particles,* Academic Press, NY (1978)
- ► Dullien, F.A.L., *Porous Media-Fluid Transport and Pore Structure,* Academic Press, NY (1979)

***Topics***

- Introduction
- Flow, heat, and mass transfer to a particle in an infinite fluid
- Flow, heat, and mass transfer in a porous media
- Applications

***The Powder Technology Group of Electives*** • The undergraduate chemical engineering curriculum at CCNY contains a group of technical electives that bear 5-6 credits. The powder science and technology group of courses (option) was designed to fit these requirements and is composed of the "Powder Technology" course (see Table 4) and the undergraduate version of the "Fluidization" course (see Table 2). In addition, seniors are required to take "Unit Operations Laboratory II," which was transformed and reorganized to include mostly powder-related experiments (see Table 3).

***Books in Powder Technology*** • The first book dedicated exclusively to the study of fine particles and powders was compiled by Dallavelle[7] in the early 1940s. It is a comprehensive presentation of methods to measure particulate properties and to manufacture powders, and it describes unit operations containing such processes as mixing, transport, segregation, etc., It was subsequently translated into Japanese and became the starting point of that country's strong development of the field after World War II.

The contribution of Dallavelle was not widely used in the U.S. and only gained some recognition after C. Orr published a book on *Particulate Technology* in 1966 that expanded the material, introducing other unit operations such as grinding, storage, granulation, etc. Then, in 1981, a major development was achieved through the publication of *Particulate Science and Technology*[9] which, in addition to describing unit operations associated with powders, gave detailed descriptions of microlevel phenomena in surface science and physical chemistry that helped explain overall bulk properties. This author drew attention for the first time to the simplistic "black box" approach to the study of powders and to the U.S. need to study the field at both graduate and undergraduate levels. The book has been used extensively to teach the subject during the last ten or so years.

Table 5 gives a partial list of books published in the field. Two groups are presented: textbooks and topical books. They are not presented in any preferred order, nor is the list exhaustive. It reflects, rather, the availability of the books to the author and the ease with which undergraduate students who took the course over the last two years related to the individual works. The list of topical books is also incomplete, and the table gives information on the chapters used for the preparation of the undergraduate course under the heading "Advantages." Of the textbooks mentioned in the

**TABLE 3**

**Unit Operations Laboratory II** ***(2 credits)***

*The laboratory contains eight stations on the following topics:*

1. ***Particle size and size distribution measurement***
   a) Standard set of sieves*
   b) Malvern laser scattering particle size analyzer

   Sand and CAT cracking catalyst are used with sieves; zeolite is used with the Malvern; data from both sets of measurements are fitted to standard two-parameter models (such as the Rosin-Rammler distribution)
2. ***Electron* and Optical Microscopy***
   Experiments are performed and pictures taken to study the surface of powders and granules; powders used are glass beads, CAT cracking catalyst, and an agglomerate granule from experiment #6.
3. ***Characterization of a powder using BET pycnometry** and mercury porosimetry*****
   Materials from experiment #2 are characterized.
4. ***Determination of a Material Yield Locus using a Jenike Cell****
   Noncohesive (fine sand) and cohesive (zeolite) powders are used with different degrees of precompression.
5. ***Fluidization experiment***
   A bubbling bed of fine glass particles is used to demonstrate bed defluidization due to the presence of a sticky liquid. The bed is also used for heat transfer studies.
6. ***Granulation of a fine powder in a high shear mixer***
   A mixture of fine glass powder and zeolite is granulated in an Eirich mixer. Granule size and size distribution is correlated with binder properties and operating conditions.
7. ***Production of a ceramic powder***
   The dilatometer*/chemical reactor** system is used to produce aluminum nitride from a carbon and aluminum oxide polymeric precursor by carbothermal nitridation at 1500 °C
8. ***Extrusion of a suspension in a Brabender Rheometer***
   Suspension viscosities are measured in the rheometer as a function of solid concentration.

* *Experiment being upgraded*
** *Experiment in the process of development*

**TABLE 4**

**Undergraduate Powder Technology Course**

■ ***Powder Technology*** *(3 credits)*

Metrology: characterization of particles and particle assemblies. Packing of granular solids; powder mechanics and the design of hoppers; interparticle forces and tribology in particulate systems. Bulk powder processing: mixing and separation, agglomeration, and communition, conveying, and storing.

***Textbooks***

- ▶ Rhodes, M.J., *Principles of Powder Technology,* John Wiley and Sons, NY (1990)
- ▶ Rumpf, Hans, *Particle Technology,* translated from German by F.A. Bull, Chapman and Hall, London and NY (1990)
- ▶ Beddow, J.K., *Particulate Science and Technology,* Chemical Publishing Co., NY (1980)
- ▶ Shamlou, P.A., *Handling of Bulk Solids: Theory and Practice,* Butterworth & Co., Ltd. (1988)

***Topics***

- Characteristics of particle assemblies; particle size and distribution; particle metrology
- Packing of granular solids
- Powder mechanics; design of hoppers
- Interarticle forces, adhesion and friction; prediction of bulk behavior from single particle properties
- Bulk powder processing: separation, mixing, agglomeration, conveying, and feeding

***Prerequisites***

- Transport Phenomena I
- Unit Operations I

table, all except the second entry (*Principles of Powder Technology,* edited by Rhodes) are out of print.

Since no particular book fits the needs of the undergraduate course by itself, three books were chosen to be used together: *Particle Technology*, by Rumpf, and *Principles of Particle Technology,* edited by Rhodes, were used to cover all topics in particle characterization and metrology, powder mechanics, and hopper design, etc. (see Table 4), while *Handling of Bulk Solids,* by Shamlou, was used for the study of powder transport and pneumatic conveying and feeding. In addition, materials from other books listed in Table 5 were used.

***Powder Technology Course*** • The syllabus, textbooks used, and the main topics covered in the course are given in detail in Table 4. The course starts with such basic principles as characterization and particle measurement, the theory of packings and powder mechanics, and interparticle forces of interaction. Unit Operations such as powder mixing and separation, agglomeration and comminution, and feeding and transport are subsequently presented. The material is structured such that chemical engineering principles in thermodynamics, fluid flow, heat and mass transfer, and strength of materials *are extended* to the study of particles and their assemblies. It is also shown that bulk behavior can be explained from first principles and from basic properties of the particles and fluids which form them. Whenever possible, bulk properties are correlated to individual particle properties while the special measuring techniques used to assess these properties are both described theoretically and demonstrated practically in the "Unit Operations" laboratory attached to the course (see Table 3).

As an example of how teaching powder technology lends itself to a useful application of first principles to technically important problems, computation of the strength of a powder from the knowledge of interparticle forces is given. This concept and the need for studies to accomplish this and similar generalizations from first principles to industrial problems is eloquently described by Ennis, *et al.*[4] One starts by describing in detail the short-range interactions between two powder particles at their contact point, which can be due to a multitude of phenomena, the simplest of which is the presence of a liquid. Other interactions can result from simple deformation and/or the presence of adhesion, electrical, and other short-range forces. Statistical consideration of the distribution of these contacts over one particle and within the entire powder mass, first suggested by Rumph and later improved by Kendall[10] and others,[11] leads to the prediction of the overall yield strength of the bulk powder. This characteristic can, in turn, be measured experimentally using a shear cell, invented in the early 1960s by Jenike. Students are shown methods to measure both the interparticle force and the bulk shear strength and at the same time they are given the theoretical procedure detailed above, allowing them to assess the validity of the assumptions used. The same approach is followed for prediction of the resistance to flow of a gas or liquid in a powder mass. The concepts of flow in a pipe and around a free particle are generalized with appropriate assumptions and complications to arrive at the generalized form of the Ergun correlation (see Ref. 12).

***Powder Technology Laboratory*** • The Unit Operations

**TABLE 5**
**Partial List of Books in Powder Technology**

| *Title, Author; Publisher (Year)* | *Advantages* | *Remarks* |
|---|---|---|
| ***TEXTBOOKS*** | | |
| • *Particle Technology,* Rumpf (translator, Bull); Chapman and Hall (1990) | Intended as an undergrad textbook | Originally published by Carl Hansen (1975) in German (out of print) |
| • *Principles of Particle Technology,* Rhodes (ed.); Wiley & Sons (1990;1993) | Postgraduate textbook | Contains solved problems (very expensive) |
| • *Particulate Science and Technology,* Beddow; Chemical Pub. Co. (1980) | Detailed presentation of underlying physico-chemical principles | Out of print |
| • *Particulate Technology,* Orr; Macmillan Co. (1966) | Treats P.T. as unit operations | Out of print |
| ***TOPICAL BOOKS*** | | |
| • *Particle Size Measurement,* Allen; Chapman and Hall (1968;1990) | The most authoratative in this field | Fourth edition |
| • *Powder Surface Porosity,* Lowell, Shields; Chapman and Hall (1979,1984) | Engineering oriented | Useful technical information for students |
| • *Theory of Particulate Processes,* Randolph, Larson; Academic Press (1988) | Chaps. 1-3 only | Size distribution and population balances |
| • *Handling of Bulk Solids: Theory and Practice,* Shamlou; Butterworth (1988) | Useful text for students | Used for bulk flow of powders |
| • *Bulk Solids Handling,* Woodcock, Mason; Chapman and Hall (1987) | Text for student; unit operations for bulk transport | Powder transport equipment presented |
| • *Mixing in the Process Industries,* Hornby, *et al.;* Butterworth (1985) | Detailed text for engineers (Chaps.1-3) | Used only for characterization of mixtures |
| • *Size Enlargement by Agglomeration,* Pietsch; John Wiley & Sons (1991) | Chaps. 2,3; interparticle forces | Monograph on agglomeration |
| • *Slurry Flow: Principles and Practice,* Shook, Roco; Butterworth (1991) | Chaps. 1-4; particle-fluid interaction | Monograph |
| • *Pneumatic Conveying of Solids,* Marcus, *et al.;* Chapman and Hall (1990) | Chaps. 2-4; gas-particle conveying | Monograph |
| • *Gas Fluidization Technology,* Geldart (ed); John Wiley & Sons (1986) | Chaps.2,4; basics of fluidization | Contains solved problems |
| • *Tribology in Particulate Technology,* Brisco, Adams (eds); Adam Hilger (1987) | Part 2: Adhesive forces & powder flow<br>Part 4: Attrition and agglomeration | Interesting new topics in particle technology |

Laboratory II course is taken by seniors during the seventh semester of study. The laboratory has been reorganized to contain experiments related to powder technology and is offered as an elective to support the two theoretical courses within the option. The lab is composed of eight stations that are covered within fourteen weeks (five hours each) of study. The eight stations are briefly described in Table 3; four experiments are in the process of being upgraded, while two (#3, Characterization of Powders, and #7, Production of a Ceramic Powder) are in the process of development from scratch, *e.g.,* new equipment is being purchased, installed, and incorporated into the lab.

The students are first introduced to powder characterization such as particle size and size distribution (#1), surface structure and composition using optical and electron microscopy (#2), and surface area and pore volume using gas adsorption (BET gas pycnometry) and mercury intrusion (#3). A major improvement in these experiments will be achieved by the purchase of new instruments to measure surface area and granular pore size. Further characterization of bulk powders is achieved in the Jenike Shear Cell, where material and wall yield loci are obtained for different powders at different initial compression levels. This is a special instrument, characteristic of powder engineering, used to determine powder flowability characteristics as well as for the design of powder storage vessels such as hoppers and bins. Two powders, one cohesive or nonflowing such as zeolite (used extensively in the chemical industry as a catalyst) and another noncohesive or free flowing, such as fine dry sand, are used to show the great difference in behavior due to cohesion. The results are also used to design a hopper for a powder tested during this experiment (zeolite).

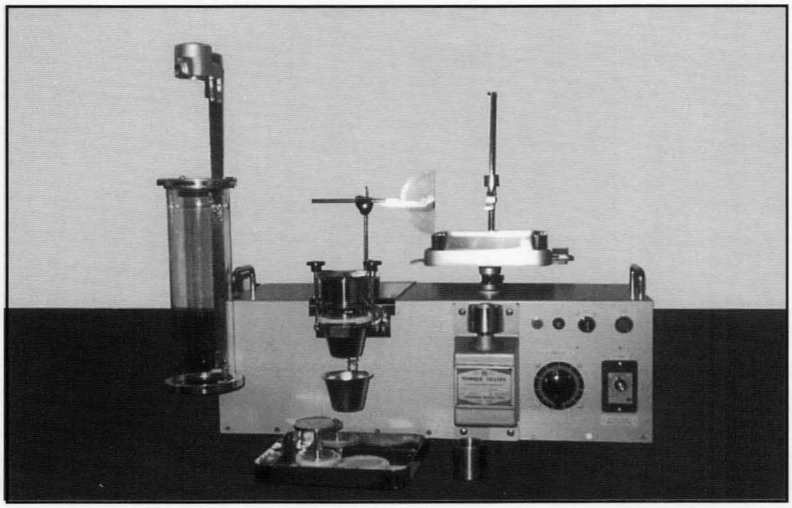
The next set of three experiments demonstrates different unit operations with powders such as fluidization (#5), granulation or size increase (#6), extrusion or flow through a small orifice at high pressure (#8), and a chemical reaction to produce a powder (#7). These are all well-developed experiments used in the past and taken over from previous research projects. The chemical reactor is in the process of being retrofitted with a newly acquired mass spectrometer that will be installed at the gas exit port. This will enable the study of reaction kinetics of the gas-solid reactions taking place in the reactor.

With this hands-on experience, the students taking the powder technology option will be in a position not only to recognize processes in which powders are used, but also to address and solve practical problems relating to such powder operations as characterization, storage, fluidization, agglomeration, etc. The practical experience will also reinforce the theoretical concepts assimilated in class.

## MODULE DEVELOPMENT

The behavior of liquids and gases is taught and demonstrated in most physics courses and in mechanical and chemical engineering curricula. Students, especially freshmen and sophomores, are rarely if at all exposed to the study of dry powders: their production, use, and very peculiar behavior. A demonstration module was developed to provide freshman students with hands-on experience with powder handling, the measurements of some of the most important bulk properties, and the use of the measurements to characterize a powder. The main objective of this effort was to develop a package and purchase an instrument to demonstrate to students at the freshman level the substantial difference between the behavior of fluids and dry bulk powders during storage, emptying of a vessel, flow in a pipe, and dispersion in air.

Continued on page 181.



The MikroPul Hosokawa Micron Powder Characteristics Tester provides seven mechanical measurements with one easy-to-use instrument, including **1)** angle of repose, **2)** compressibility, **3)** angle of spatula, **4)** cohesiveness, **5)** angle of fall, **6)** dispersibility, and **7)** angle of difference.

Measuring such properties has great importance in the design of storage hoppers, feeders, conveyors and other powder processing equipment. The analyzing of such characteristics is also a daily routine for quality control of powdered products. Conventionally, these properties were each determined manually, using several different instruments. Now the Powder Characteristics Tester offers quick and reliable measurements with a single unit. With controlled mechanical means, far more consistent and accurate data can be obtained than by manual methods.

Measurements obtained from the Powder Characteristics Tester can be directly converted into the flowability or floodability index with the use of "Flowability Index Tables" prepared by R.L. Carr, Jr., of BIF and published in McGraw-Hill's *Chemical Engineering* (Vol. 28, January 28, 1965). The index thus obtained is a reliable guide for the trouble-free handling of the powder.

***Figure 1.*** *The Powder Characteristics Tester apparatus*

options considered, and present the solution chosen, with supporting calculations. Good writing skills are required not only in the formal report, but also throughout the course. The design problem counts for twenty-five percent of the grade in that quarter.

This course is exciting and dynamic With the interaction between coursework and current events, there is always an abundance of material for consideration. For example, a June 1992 railroad accident in Superior, Wisconsin, resulted in a mixture of chemicals, including benzene, being spilled both on land and in the Nemadji River. The resulting cloud caused the evacuation of thousands of residents, the largest evacuation to date in the U.S. due to a spill of hazardous materials. Resources from the regulatory agencies in Wisconsin and Minnesota are available to present this local case study in class, and discussion touches on the areas of spill response, hazard assessment, reporting, cleanup, and panic.

## SUMMARY

Hazardous waste management is a relevant area for chemical engineering skills that are not in the realm of civil engineering, and it is vital that chemical engineers have a firm foundation in pollution prevention. The capability to develop and change process structure places responsibility for waste management firmly in the chemical engineer's domain. It is an area vital to the long-term health and growth of the chemical engineering profession, both from an industrial and personal viewpoint. Chemical engineers are best equipped with the knowledge for designing and operating equipment or systems for the proper disposal and recycling of waste water and solid wastes, for proper pollution control, and for process modifications to avoid production of hazardous materials. This educational program will meet future needs for maintaining and improving the environment.

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# POWDER TECHNOLOGY COURSE

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The Mikro-Pul Hosokawa Company's Micron Powder-Characteristics-Tester is a measuring instrument that is commercially available and is used for demonstration. A schematic representation of the apparatus and a list of all measurements that can be performed with it are given in Figure 1. The students can measure the angle of repose (the angle which a heap of powder makes with the horizontal), flowability (capacity of a powder to flow out from a vertical cylindrical vessel with a hole in the bottom), and dispersability of a powder in air (talc and sand in this case) and compare it to the behavior of a liquid. The demonstration module is being introduced into a general engineering course given to all engineering students in the first semester of study.

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