Experiments, Demonstrations, Software Packages, and Videos for PNEUMATIC TRANSPORT AND SOLID PROCESSING STUDIES

GEORGE KLINZING
University of Pittsburgh • Pittsburgh, PA 15261

George Klinzing *is Professor of Chemical Engineering at the University of Pittsburgh, where he has been conducting research and teaching solids processing for a number of years. His research has shown a concentration in pneumatic conveying. He is a fellow of AIChE and a lecturer in their continuing-education program. His publications include three books on pneumatic conveying.*

Experiments

Pickup and Saltation Velocities • In order to design a pneumatic conveying system, a knowledge of the proper conveying velocity is essential to transport the material efficiently. The pickup velocity from the bottom of a transfer line and the saltation velocity at which the particles salt out of the flow are essential. These velocities can be determined experimentally with the basic flow system shown in Figure 1. Several of different parameters influence these velocities: particle size, particle density, particle shape, cohesiveness, pipe diameter, and gas density. Work in our laboratory has developed a correlation for the particle pickup velocity.[1] Videos can be easily prepared of the pickup and saltation phenomena and can be shown in the classroom. Further details are given at the end of this article.

Avalanching • The release of particles onto a self-forming pile of particles (avalanching) presents some interesting observations that possibly can be used to characterize the particles themselves. This characterization can have a bearing on the way the particles behave in pneumatic conveying and other solids processing operations. A simple device to deliver particles to a pile and for observing the behavior of particle avalanching can provide students with a unique experiment to further their knowledge of particles. Figure 2 shows this experiment, and Figure 3 shows a method of classifying the avalanching with particle size.[2] Here, the weight of each avalanche that occurs is plotted against the percentage of avalanches having a weight greater than this value. Each material shown has a particular characteristic curve. Again, video taping can be carried out to provide an additional classroom resource.

Pneumatic Conveying Flow Loop • A simple flow loop is shown in Figure 4. Every loop must have an air supply, a feeder from a bin or a hopper, a transport line, and a collector. House air can supply the transport gas for a 1- or 2-inch

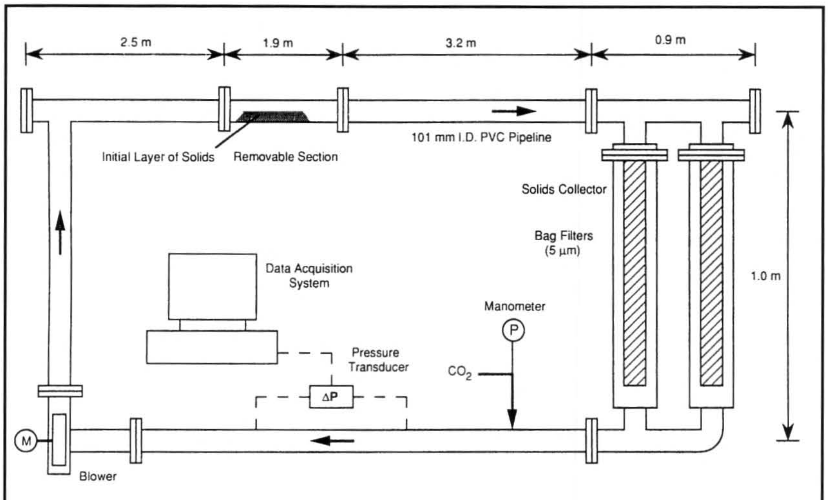

Figure 1. *Pickup and saltation flow system.*

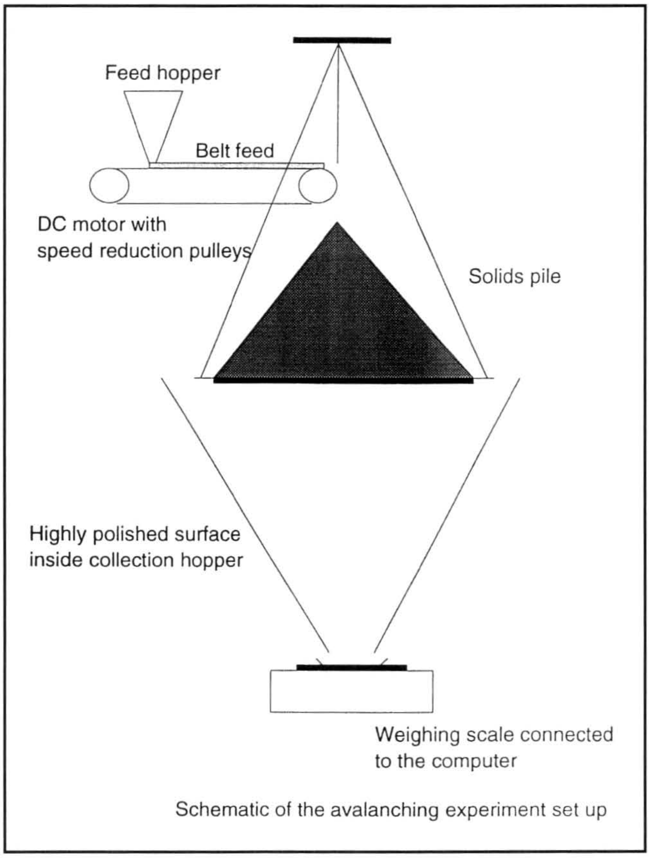

Figure 2. *Avalanching experimental setup.*

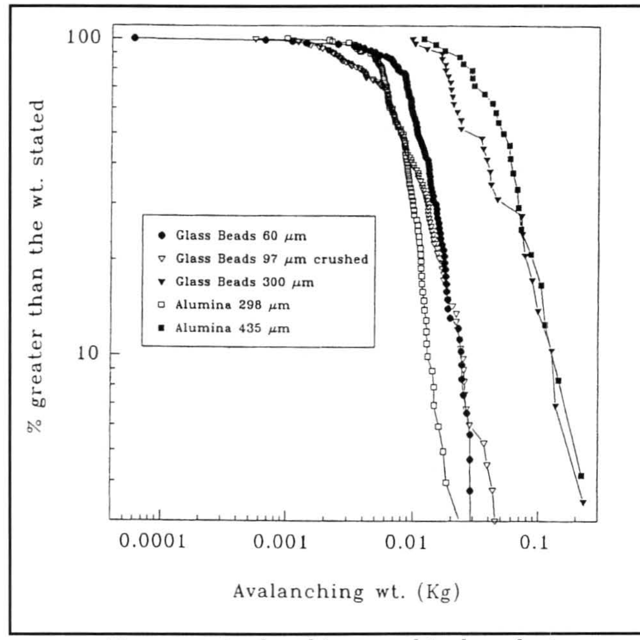

Figure 3. *Avalanching graphical analysis.*

line. The most common type of feeder is a rotary valve, which can be the most expensive component of the system. The collector can be a cyclone, especially when collecting millimeter-or-larger size particles. These units can be easily constructed using the standard design equations for cyclones. The loop can be instrumented with relatively inexpensive pressure transducers coupled with a computer measuring scheme, which can provide a wealth of information about entrance effect, horizontal and vertical conveying differences, and bend pressure losses. Further details can be found in the Appendix to this article.

Bins and Hopper Flows • Delivery of the solids from a bin or hopper through a feeder to a conveying line is essential to all solids transport operations. If the material will not leave the bin or hopper, nothing will be conveyed. A simple two-dimensional experiment to measure the effect of the wall angle of the bin or hopper on the type of flow can be easily constructed. By using different colored particles, one can follow the flow patterns and velocities. Using a video or Polaroid camera can provide a good record of the experiment. The detailed dimensions of this wedge unit are given in the Appendix to this article.

Bend Erosion • Demonstration of the process of erosion in conveying can be carried out by using a marking pen and a glass bend. A grid can be drawn on the inside of the bend, be it a short radius or a tee. This marked bend can then be subjected to the flow conditions with particle flow. As time goes on, it can be seen that the marking will erode in certain regions of the bend. The time of operation is short, and video taping of the process can provide a clearer understanding of the flow patterns in such operations.

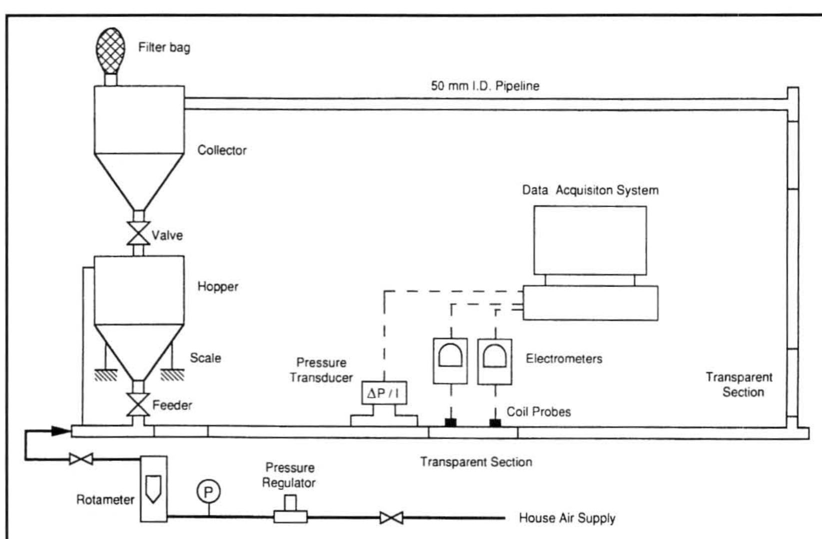

Figure 4. *Pneumatic conveying flow loop.*

Demonstrations

In order to impress on the students the basic principles described by mathematical analysis, one should search for appropriate demonstrations for classroom use. We have developed a few of these demonstrations that can give the instructor a small tool box to help in teaching solids-handling principles.

Plug Flow • Following a demonstration first employed by Peter Arnold (Wollongong University), we constructed a Plexiglas column with an aluminum disk connection to a cable that threaded through the column over a pulley and attached to a pull-spring scale. A plug of bird seed approximately 6 inches long provided the plug for study. Measuring the force needed to move the plug can be recorded at different plug lengths, indicating the nonlinear force relationship with the plug length. Adding a small amount of air at the bottom of the column will slightly fluidize the plug and permit significant reduction of the force required to move the plug. The details of this device are seen in Figure 5.

Wall Pressure • Likewise, Peter Arnold has shown that a paper tissue placed at the end of a tube and tied with a rubber band can support a column of solids because the walls support a significant portion of the weight of the particles. This unit is also shown in Figure 5.

Fluidization • A simple fluidization pipe can show gas fluidization by simply blowing through a tube connected to an air distributor leading to a fluidizing chamber containing particles. Figure 6 shows this device.

Bin and Hopper • John Carson (Jenike and Johanson, 1 Technology Park Drive, Westford, MA 01886) has provided small-bin demonstration devices in an hourglass-type unit made of Plexiglas that show mass flow with a steep bin angle and funnel flow with a shallow bin angle. He has educated a large number of students with this excellent demonstration (see Figure 7).

Segregation • This process can be shown easily through the movement of a mixture of large and small particles in a Plexiglas chamber having internals similar to a bin or hopper. The larger particles are seen to migrate to the outside of the forming pile, while the small particles stay in the center. G. Enstad (Telemark Institute, Norway) first constructed this device to observe the segregation phenomenon. Figure 8 shows the details of this device, which has four chambers arranged in an internal X-geometry.

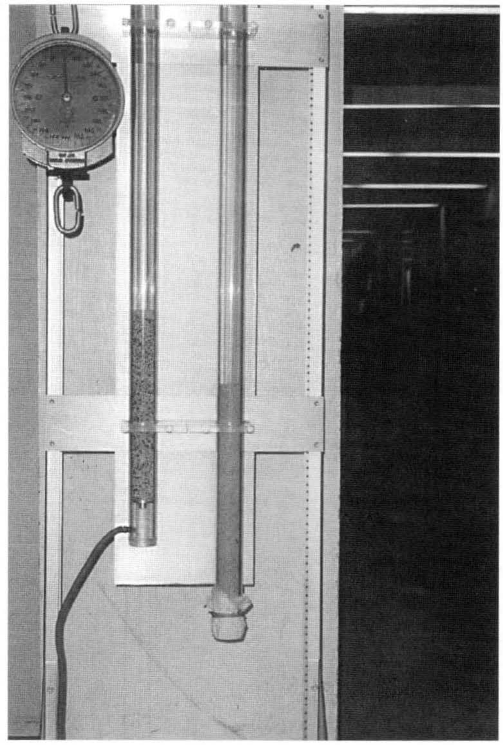

Figure 5.

Plug flow and lateral pressure demonstration unit.

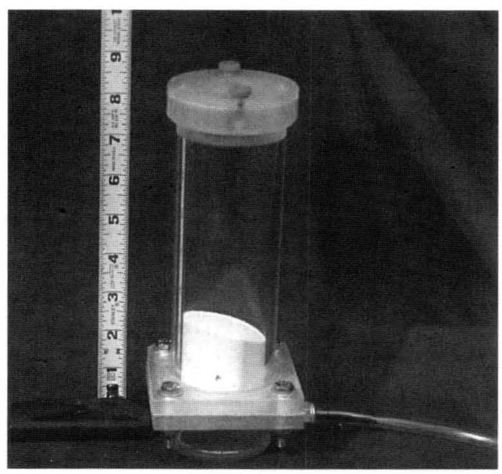

Figure 6.

Fluidization demonstration.

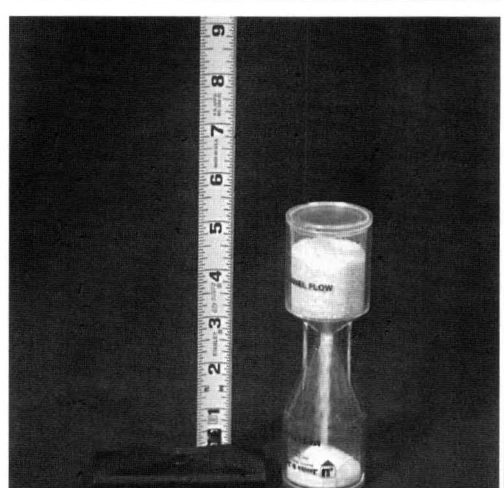

Figure 7.

Funnel and mass bin flow demonstration.

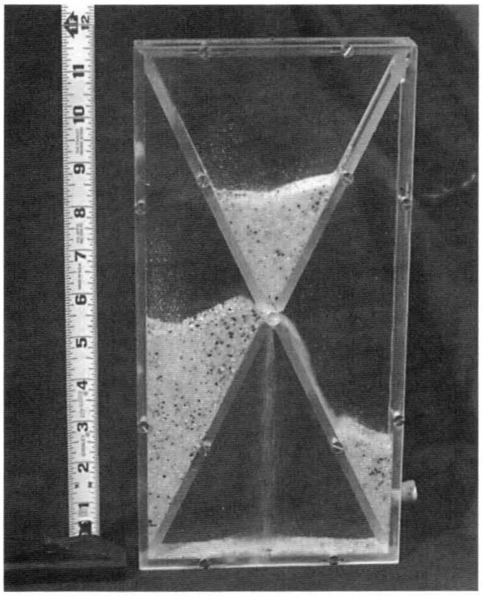

Figure 8.

Segregation flow demonstration.

Troubleshooting Pneumatic Conveying System

Troubles in your system may be due to any of the following possible reasons:

Loss of conveying air was found to be a possible cause.

Filled receiver vessel is a possible cause.

Explore further whether material coating inside the pipe may be a possible cause.

Change in solids throughput demands more careful analysis.

It appears that there is a physical obstruction in the conveying line.

** End - press ENTER to continue.

Troubleshooting Pneumatic Conveying System

Choose one or more of the following listed causes:

Yes
" Loss of conveying air
" Filled receiver vessel
" Material coating inside conveying line
" Change in material being conveyed
" Increased feed rate
" Physical obstruction in conveying line

1. Use arrow key or first letter of item to position the cursor.
2. Select all applicable responses

Figure 9. *Artificial intelligence troubleshooting example.*

Computer Packages

A number of computer packages have been developed in our laboratory that provide the student with a wide cadre of tools to help design a pneumatic conveying system.[3]

OPSD • This program is designed to predict the energy losses in a dilute phase-conveying system using the basic energy equations for two-phase flow. The calculations account for a wide range of geometries, including long-distance pipe stepping calculations.

Nuselect • This is an artificial intelligence package to help the design choose the best conveying system offering both dilute and dense phase systems with different types of air movers.

Feeder • Another artificial intelligence package, crafted with the help of experts, to choose the most appropriate feeder for an application.

Panacea • Once a system is in operation, it will invariably develop operational difficulties. This artificial intelligence package provides a first-aid approach to remedying a system, providing recuperation of the operation or moving the system to a more optimum point (see Figure 9).

Cyclone • Using a series of common design strategies for cyclones, this program helps the designer select the approach cyclone by estimating the operating characteristics and dimensions.

Videos

A convenient way to record an experiment is to video tape the phenomenon. In our laboratory we have video taped a wide variety of our experimental endeavors. In some cases, this record could be analyzed quantitatively to develop predictive models. In other cases, further understanding of the process was gained by viewing the video record.

REFERENCES

1. Cabrejos, F.J., and G.E. Klinzing, *Powder Tech.,* **79,** 173 (1994)
2. Rastogi, S., and G.E. Klinzing, *Part. Part. Syst. Charact.,* **11,** 453 (1994)
3. Pneumatic Conveying Consultants, 529 S. Berks St., Allentown, PA 18104-6647
4. Pelczarski, E., PhD dissertation, University of Pittsburgh (1964)

APPENDIX

Pickup and Saltation Velocities

The pickup-velocity experimental rig consists of a trans-

Continued on page 155.

nies that included these characteristics. As a result, I found a match with Andersen Consulting and wound up accepting an offer from them.

The internships also helped reinforce my desire to pursue an engineering degree. When I began college, I chose to go into chemical engineering because I had enjoyed chemistry in high school and my father was an engineer. I did not have much else to go on, but as each summer passed, I was more and more certain that this was a field I could succeed in.

I would not be in the position that I am in today without the benefits of INROADS and my experiences at Apache and 3M. Although I realize that not all students find themselves in a position to intern every summer, they should be encouraged by their chemical engineering departments to seek out internship opportunities. It is surprising to see just how many industries are looking for chemical engineers today. The versatile knowledge base that a chemical engineer offers is unique and in demand. Faculty and advisors should make every effort possible to help expose chemical engineering undergraduates to this wide world of opportunity.

REFERENCES

1. Information relating to INROADS obtained from *1996 INROADS Annual Report* and "Train to be a Leader." Headquarters are in St. Louis, Missouri; phone 314-241-7488. ❒

Pneumatic Transport Studies

Continued from page 117.

parent 7-m long, 52-mm I.D. pipeline with a removable section, a regulated air supply, and a solid particle collector. The test section is made up of a 1.2-m long removable section in the middle of the 7-m long tube. At the end of the horizontal pipeline, a transparent T-bend is inserted so visualization of the bend behavior can take place. The solids collector was constructed from a 0.093-m^3 cardboard drum with an inlet of 100-mm I.D. The particles are separated from the air as the flow passes through a paper filter bag. Fine-particle collection was achieved with a double-paper filter bag assembly. For the saltation velocity of a single particle, a small slide valve was installed in the top section of the pipeline to feed the individual particles, allowing the behavior to be observed. In the three devices described, in-house construction was required, but a number of the items were purchased and incorporated into the overall design.

Pneumatic Conveying Loop

The pneumatic conveying system consists of a 14.5-m long, 50-mm I.D. horizontal copper pipeline with a 2.2-m long vertical section, a return line, T-bends, and several transparent sections placed along the pipeline. A regulated compressed-air supply provides the gas at the pressure necessary to convey the solids. A hopper placed on a scale and connected through flexible connections to the collector and feeder is used to continuously weigh the solids inventory. A solids collector consists of a paper filter bag placed at the top of the hopper. A gate valve is used to deliver the solids from the hopper, and different settings can provide various flow rates of the solids. The transparent sections allow visual observation of the flow patterns. Morris couplings are used to seal the connections and to keep the pipeline aligned (see Figure 4).

Wedge Construction

The wedge-shaped container was constructed of two pieces of clear Plexiglas (76-cm high, 74-cm wide, 0.4-cm thick). These were bolted to two steel supporting legs. Four bolts (1.27-cm diameter, 0.96-cm long), two to each leg, were used to attach each plastic sheet to the supporting legs. The front plastic piece was scribed so that it had a 1-by-1-cm grid network across the entire area. The grid network formed a convenient transparent graph for readily obtaining the position of the black marker beads in the bed. The width of the wedge, *i.e.,* the distance between the Plexiglas faces, was 1.61 cm. Two brass rectangular bars (83.0-cm long, 1.61-cm wide, 2.54-cm thick) were used to form the inclined surfaces of the wedge. The surface of the brass bar adjacent to the glass beads was machined to be flat, with a tolerance of ± 0.05 mm. The brass bars were taped to take eight brass screws (0.63-cm diameter, 0.96-cm long) on each side of the bar. These screws were used to fasten the bars to the Plexiglas at any desired inclination. A thin Plexiglas strip (76-cm long, 1.61-cm wide, 0.64-cm thick) was then placed on each machined brass bar surface to form the slide surface for the beads.

A vertical plastic disengaging section (6.35-cm high, 15.3-cm wide, 1.61-cm deep) was located at the bottom of the sloping sides of the wedge. The disengaging section was included to even out velocity gradients that could have been generated by the flow of beads through the slot located at the bottom of this section. The slot was adjustable and was made of two pieces of steel (17.0-cm long, 2-cm wide, 0.16-cm thick) that were attached by means of screws to the vertical front and back Plexiglas walls. The edges of the steel pieces that formed the slot were machined within ±0.05 mm to ensure perfect mating when the edges met. The slot opening was set with feeler gauges so that the opening was uniform to within ±0.05 mm across the width of the slot. The gate was closed with a piece of tape simply by attaching the tape to the front plastic wall. To start the flow of beads, the tape was removed and the gate fell open, permitting the solids to flow. The legs supporting the wedge had adjustable leveling screws mounted underneath them. These leveling screws were used to align the equipment vertically and horizontally. It had been shown that unless this equipment was perfectly aligned, it was impossible to obtain symmetrical velocity profiles.[4] ❒