Simple, Low-Cost Demonstrations for UO II (Mass Transfer Operations)

Polly R. Piergiovanni
Lafayette College, Easton, PA

ABSTRACT

Hands-on activities were developed to demonstrate mass transfer principles to students unable to take the concurrent laboratory. The exercises were simple, could be performed during class time and cost less than $250 to purchase the materials for five or six groups. Most materials could be purchased at Home Depot or WalMart. The students enjoyed the activities, and referred to them on exams when asked to explain the principles of how the mass transfer operations worked. The exercises are summarized below.

INTRODUCTION

For learning to be meaningful, students should be actively engaged in identifying principles for themselves, rather than relying on an instructor's explanations[1]. Inductive reasoning (the process by which a general conclusion is reached from evaluating specific observations[2]) is a highly important aspect of learning. Studies have shown that when students learn by induction, the learning is deeper and the material is retained longer[3]. As an instructor, I strongly believe that this is a valuable method of teaching.

Often, the learning occurs during the laboratory sessions that usually accompany a Unit Operations course. However, due to major renovations to the engineering building, the seniors in the fall 2002 section of the course would not take the lab until the spring 2003 semester. Therefore, I developed a series of simple experiments for a unit operations course that would require the students to use inductive reasoning to identify some principles of mass transfer.

The course was taught during a two-hour time block, twice a week. About five class sessions were devoted to each mass transfer operation. The experiment or demonstration was done during the first class for the new separation method.

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EXPERIMENTS

Liquid-Liquid Extraction – The students were given jars with lids, water, and oil with red food coloring. A factorial experiment was designed (twice as much water as oil/red dye or half as much water as oil/red dye; mixing by gentle swirling or mixing by shaking for 3 seconds) and the groups chose their experiment. The jars were observed after 5 minutes and after an hour (see Figure 1). The students noted the trade-off between a lot of mixing (good removal) and separation time (the small bubbles take longer to separate). After we had collected the data, we began our discussion on LLE principles, equipment and scale up.

Figure 1: Separation of red dye from salad oil. (L-R) 1. Twice as much oil as water, shaken gently; 2. Twice as much water as oil, shaken gently; 3. Twice as much water as oil, shaken vigorously; 4. Twice as much oil as water, shaken vigorously.

Humidification Operations – A sample of the fill for a cooling tower was ordered, and shown to the students. The plan was to soak it with water, and hold it in front of a fan to let the students feel how the air was cooled as the water evaporated, but because it was pouring rain the day I planned it, the air only cooled slightly. This led to a discussion on how weather conditions affect cooling operations along with our discussion on cooling tower design. It also helped us in our review of reading psychrometric charts. We also described how a “swamp cooler” works in hot and less humid areas of the country, and a video at http://www.fathom.org/opalcat/swamp.html was used to demonstrate the process.

Chromatography – Large columns were made from PVC pipe (4” diameter, 12 or 24 inches long) with chicken wire covering one end (see Figure 2). The students filled the column with ping pong balls (the column packing), then dropped a mixture of marbles (14 mm diameter, density = 3.4 g/cm^3) and beads (2 mm to 10 mm diameter, density = 1 g / cm^3) into the column. The column was shaken gently or vigorously 5 times, and the number of each type of bead that exited the column was recorded and plotted (see Figure 3). The shaking was repeated until all of the beads had exited the column.

The retention time, t^*, was estimated for two different bead types as the number of shakes it took to reach the midpoint of the pulse, and the peak width, Δt, was estimated from the graph. The number of ideal stages of plates was estimated using $N=16(t^*/\Delta t)^2$, which was used as an estimate in the early studies of chromatography[4]. For a good separation of two components,

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their retention times should have a difference greater than or equal to ½ the sum of their peak widths, or $t^*_B - t^*_A > \frac{1}{2}(\Delta t_A + \Delta t_B)$. [4]

The students did the calculations, and verified the separations with calculations. After the students collected the data, we discussed how to measure how well the separation worked, and to note how column length and "velocity" affected the separation.

Simple models for scale up were developed, showing that the peak width is proportional to the square root of the column length, and the retention time is directly proportional to the length of the column. Their results for the two different length columns were compared to theory. The students found that they could not show that t^* was proportional to column length or that Δt was proportional to the square root of the column length due to differences in how students shook their columns. After some discussion, we decided that longer columns would also help to confirm this theory.

Figure 2: Ping pong ball chromatography columns.

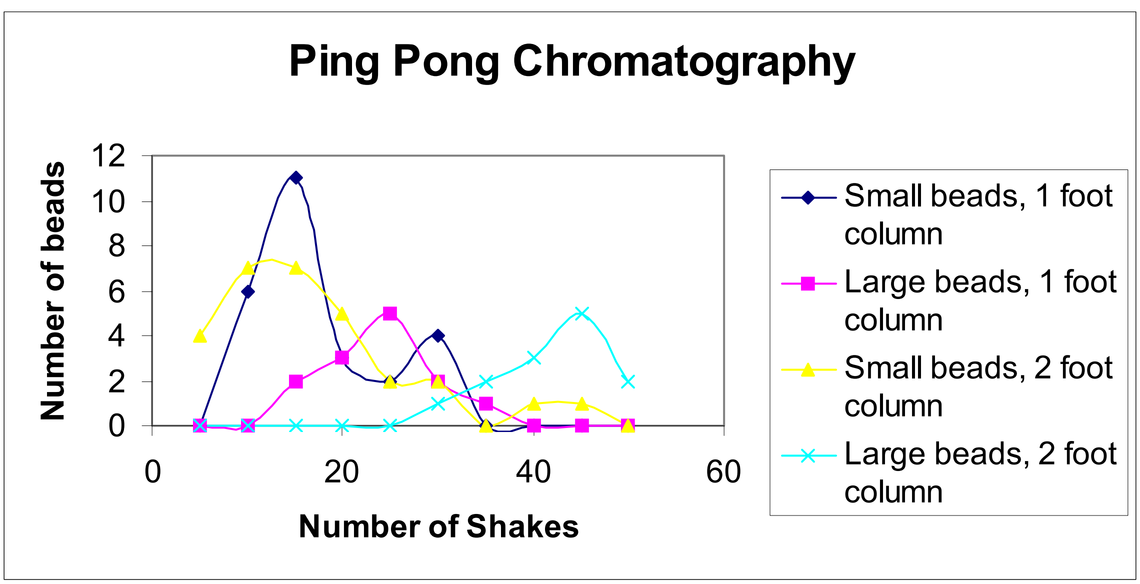

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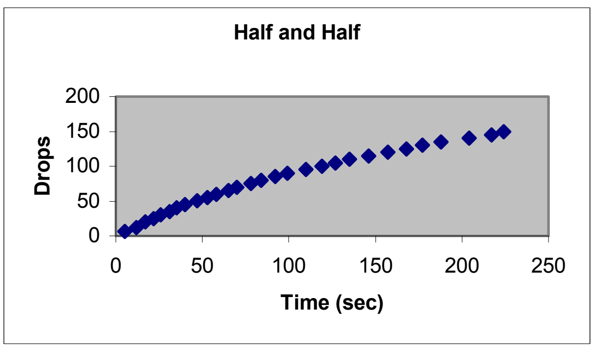
Figure 3: Separation of small beads using ping pong balls as the packing. The retention time, t^*, and the peak width, Δt, were estimated for each line.

Filtration –The students filtered a homemade cheese-whey mixture[5] through coffee filters to separate the cheese. Two filter sizes and two initial solid concentrations (either half and half or no-fat milk) were varied in a factorial design, so the students could observe how these variables affect the filtration time and other parameters. The best results were obtained when the time was recorded after every 5 drops of filtrate. The equations describing constant pressure filtration can be linearized[4] so the membrane resistance and the specific cake resistance can be calculated (see Figure 4). The students compared the specific cake resistance for the two different solid concentrations.



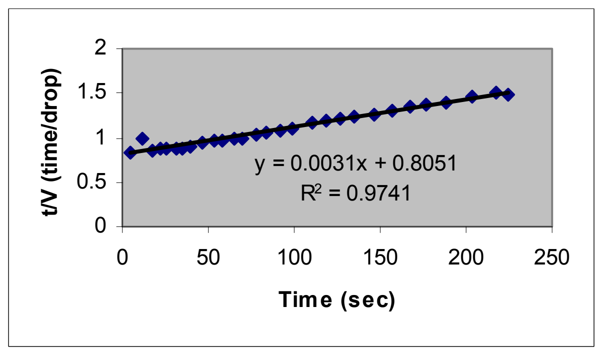


Figure 4 The rate of whey accumulation (left) and a linearized form of the plot (right). The slope and intercept are related to the membrane resistance and specific cake resistance.

Adsorption – The students filled a small diameter clear column with blue silica gel spheres (obtained from cleatpower.com, actually designed to adsorb moisture from soccer shoes). The spheres turn pink as water is adsorbed onto the silica. The water can be removed from the spheres by heating them in a microwave oven for 1 –3 minutes. A damp piece of cotton was placed at the top of the column, and a manual air pump was attached to the tube (see Figure 6). As moist air was forced through the column, the gel turned pink, starting at the top of the tube. The students varied the rate that they pumped the air and the amount of spheres that filled the column to see how the breakthrough curve was affected.

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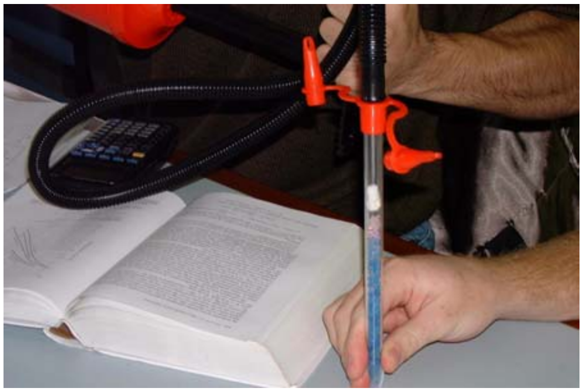

Figure 5. Students begin to pump moist air through the adsorption column. After a few minutes, the beads at the top of the column turns pink.

RESULTS AND FUTURE PLANS

Because the class began at 8:00 a.m., the students really enjoyed the days that began with an activity. All of the students participated willingly, and contributed to the discussions. Several students had suggestions to improve the experiments. Most exams had a closed book portion, where the students had to answer questions based on their understanding of how the separation method worked (rather than showing they could manipulate the mathematics). Many students used the experiments in explaining how a mass-transfer operation worked. A small group of students may take some of the units to a local elementary school to demonstrate separation methods. In addition, the units may be modified to use in the Introduction to Engineering course at Lafayette College.

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POLLY R. PIERGIOVANNI

Polly Piergiovanni is an Associate Professor of Chemical Engineering at Lafayette College. She received a B.S. from Kansas State University and a Ph.D. from the University of Houston, both in Chemical Engineering. Her research interests include cell culture and fermentation , and the LEGO project.

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