Chemical Engineering Laboratory Exercises with Design Problems for First Year Engineering Students

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Many students enter engineering programs with little idea of what engineering is or how a practicing engineer functions. Because the field is so diverse and ever-broadening, it is difficult to define. At Lafayette College, we have developed an Introduction to Engineering course (ES 101) to help students understand some of the aspects of each field. Through this course, we try to help students understand the profession, the available options and opportunities upon graduation, and what to expect in their education.

Introduction to Engineering is structured in four three-week blocks[1], and students spend three weeks learning about mechanical, civil and environmental, electrical and computer, and chemical engineering. Each instructor determines how to present their field within the three week block, which contains six 50-minute lecture periods and three 3-hour lab periods. The first and last weeks of the semester focus on AB engineering (a concentration of engineering policy and liberal arts), and students make final presentations during the last week of class.

The overriding course objective is to teach students the fundamental nature of engineering in the form of the engineering method and design/problem solving approach. This paper focuses on the implementation of the chemical engineering block.

The six lectures of the chemical engineering block are:

- Introduction to Chemical Engineering (a historical perspective)
- Processes in Chemical Engineering
- Material Balances
- Unit Operations – Fluidized Beds
- Unit Operations – Fermentation
- Unit Operations – Polymerization

A laboratory exercise accompanies each of the unit operations lectures. The fluidized beds are similar to the ones developed by Rowan[2]. In this laboratory, the students read a process flow diagram, learn to operate the fluidized beds, and perform simple calculations. They also learn to write an engineering summarizing memo.

The laboratory exercises for the fermentation and polymerization processes, along with their accompanying design problems are presented in this paper. The design problems use information obtained from the laboratory exercises and lead the students through the Ten Step Design Process[3]. Student comments on the course and initial assessment data is included.

I. Fermentation

In the lecture portion of the class, the students are shown an overview of how glucose is metabolized, the different phases of cell growth, the equations that describe exponential growth, and the operation of an airlift bioreactor. In the laboratory, each group of students is given a 600 ml airlift reactor, yeast, and a glucose-based growth medium. The students take samples from the bioreactor and measure cell concentration, glucose concentration and ethanol concentration. They use this data to calculate growth rate and yield factors.

Several aspects of this experiment make it a novel experience for the students. First, the airlift reactor (Kontes, Vineland, NJ), is a cost-effective reactor for cell culture (see Figure 1). The airlift reactor is glass, and can therefore be reused after an easy cleaning and autoclaving. While we use it for fermentation of yeast, it can be used for any standard airlift application (suspension of tissue culture, insect cell cultures, microcarrier culture, and culture of plant cells and blue-green algae). The airlift bioreactor has a working volume of 580 ml and is surrounded by a glass jacket, which students fill with warm water for temperature control. Compressed air flows through a flowmeter at about 1.2 scfh, into a valve in the base of the airlift (to increase yield of ethanol, nitrogen could be used). Students use syringes to take culture samples from a sample port. We attached the reactor to 1 ft^2 acrylic squares, to prevent the reactors from tipping. Operating the reactor gives first year students hands on experience with realistic equipment.

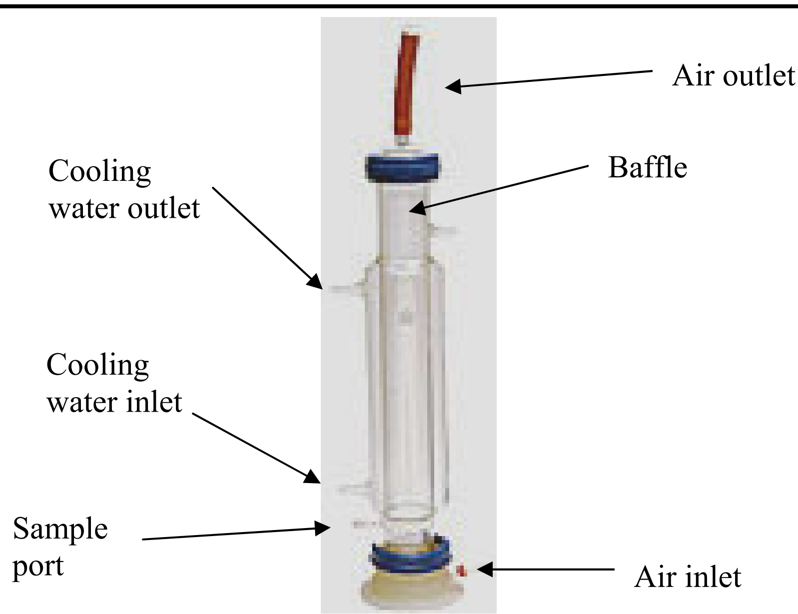

Figure 1. The Kontes CYTOLIFT® Glass Airlift Bioreactor

The yeast fermentation process lasts for several hours, after a lag of about two hours. Because the lab period is only three hours long, the students are given a plastic container with sugars and salts (6 g/l glucose, 5 g/liter sodium monophosphate, 2 g/liter ammonium sulfate and 0.4 g/liter magnesium sulfate) and told to add warm water to it about two hours before lab begins (only a problem for those students with the 8 am lab!). Once the solids are dissolved, they add the yeast (0.8 g/l, in a second container).

When the students arrive in lab, they pour the contents from their plastic container into the airlift fermenter, turn on the air, fill the outer jacket with warm water, and collect their first sample. The amount of yeast in the sample is estimated using a turbidimeter

(VWR) and a calibration equation. Students measure the turbidity every 30 minutes, and at the end of the lab use the data to estimate the specific growth rate and doubling time of the yeast. Figure 2 shows one student group's results.

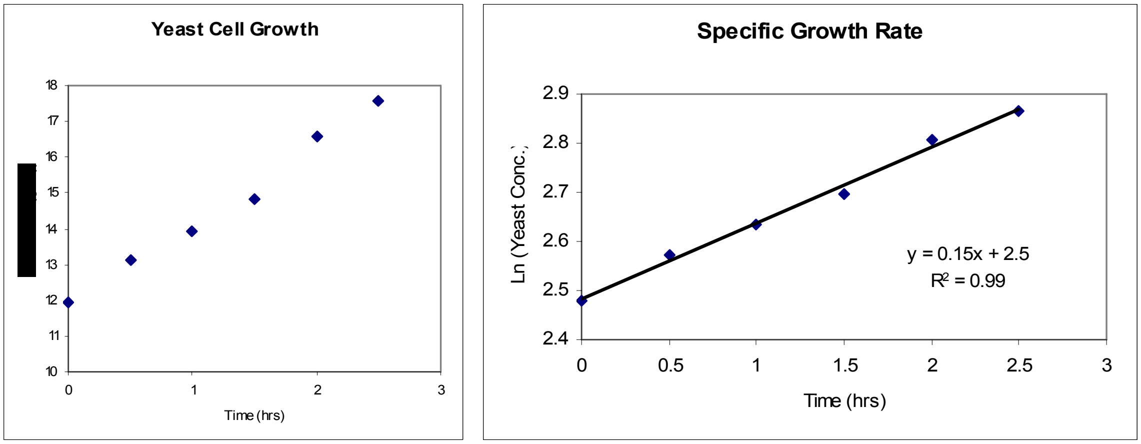

Figure 2. Student data. The graph on the left shows the yeast cell concentration increasing with time. On the left, the data has been fit with a trendline, to estimate the specific growth rate.

It is also interesting for students to know that, as the yeast have been growing, they have been consuming the glucose (as had been outlined in the lecture portion of the course). Chemical assays are the most accurate method of measuring glucose concentration, however, this is not easily done with a large group of first year students who are trying to complete a lab in three hours. Instead, we use the OneTouch® Ultra® Glucose test meter, normally used for diabetics (among meters tested, the OneTouch® gave the most reproducible results). The students place a drop of the culture medium on the end of the test strip, and within five seconds get a measure of the amount of glucose left in the medium. Figure 3 shows one student group's results. The glucose consumption and increase in cell concentration are used to calculate yield factors.

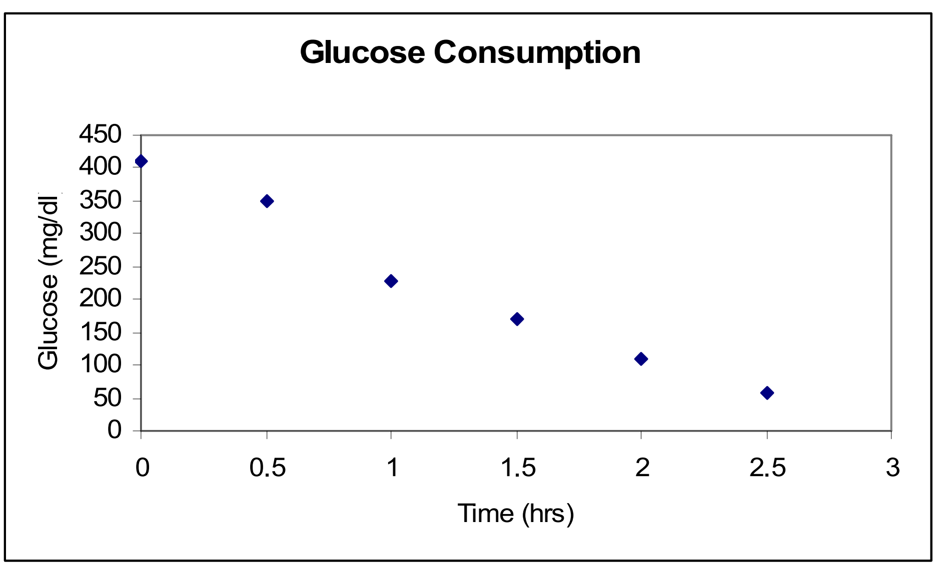

Figure 3. Consumption of glucose by yeast grown in the airlift fermenter.

Last, it would be interesting for the students to be able to measure the amount of ethanol produced by the fermentation, since the overall goal of the experiment is to produce ethanol. Normally, ethanol is quantified by gas chromatography, but this is not practical for the first year students. Instead, we use ALCO-SCREEN™ test strips (Chematics, North Webster, IN), which are strips used to measure the amount of ethanol in saliva. The colorimetric strips give a reasonable amount of ethanol present in the fermentation broth in two minutes. For students who are interested, we can discuss the colorimetric enzyme reaction that occurs on the test pad. The students note that only a small amount of ethanol was produced (0.02 – 0.04 BAC (blood alcohol concentration), which corresponds to 0.12 – 0.48 g ethanol in the 600 ml of fermentation broth[4]), and we discuss how the yield could be improved.

During the time between samples, the students work on the design problem. In this instance, they are provided with algebraic equations which approximate the amount of cell mass produced and ethanol synthesized based on glucose and sucrose consumption rates. While the equations have been simplified, they provide students with the trends observed during the fermentation. Costs for glucose and sucrose are also provided. The students use this data to determine which sugar provides more economical ethanol production. Next, they are given costs for various sizes of airlift bioreactors, the associated operator and energy costs, and they are to determine what combination of reactors would be most economical for large scale ethanol production.

This innovative project allows first year students to try a beginning process design, and realize some of the factors that are important. While the design is much simplified (the students do not supply pumps, pipes, heat exchangers, etc.), they get a taste of the procedure, and make some engineering decisions.

II. Polymerization

In the lecture portion of the course, the students receive a short history of polymer development, learn the three steps of the polymerization reaction, and a little about two types of polymers (thermosets and thermoplastics). In the lab, the students perform the polymerization of vinyl acetate to produce polyvinylacetate. As they are preparing the solutions, we review the concepts of catalyst and monomer, and discuss the use of water as a heat sink for the exothermic reaction. They measure the temperature in the reaction vessel as a function of time to follow the polymerization. When it is nearly finished, each group receives their polymer to test for waterproofing ability.

For the last three years, the overall theme of ES 101 has been developing a temporary shelter. A chemical engineering contribution to the project has been to waterproof the fabric of the tent. After the students produce their polymer, they test its waterproofing ability against an “aged” polymer (the same polymer with much of the excess water evaporated), and determine the mass / area of each polymer needed to waterproof cotton and polyester fabrics satisfactorily.

For the design portion, the students design a tent, and calculate its surface area. They are provided with costs for the “fresh” polymer, the “aged” polymer, cotton and polyester fabrics, and seamstresses and other laborers. They are encouraged to use the data to develop the least expensive tent.

Student Comments

The chemical engineering block was offered in this form for the fall semesters of 2004, 2005 as well as being taught this semester (Fall 2006). Student comments about the laboratory and design portion of the block have been generally positive with 29% of those who commented calling the labs "interesting and good" and 25% of the commenters writing that they were "fun and enjoyable". After the first offering, 13% of the students who commented considered that there was "too much standing around time", especially during the fermentation lab. The design problem for that lab was modified, so that the calculations took the students most of the time between sample collections to complete. There were no similar comments from the students in fall 2005. A small number of students commented that the lab / design projects were "instructional", "hands on" or "gave real world experience". While student retention is not the aim of the lab exercise / design problem combination, from the students who took the class in Fall 2005, no students who had declared chemical engineering as their likely major changed out of it, and seven students who were undecided engineering majors chose chemical engineering as their major.

References:

1. Nesbit, S., Hummel, S., Piergiovanni, P.R. and Schaffer, J., "A Design and Assessment-based Introductory Engineering Course", International Journal of Engineering Education, 21:434 (2005).
2. Hesketh, R. P., Slater, C. S., Carney, M., "A Fluidized Bed Polymer Coating Experiment", ASEE 2000 Annual Conference, Session 3413, St. Louis, MO.
3. Oakes, William C., Leone, Les L., and Gunn, Craig J., Engineering Your Future: An Introduction to Engineering, Great Lakes Press, Inc., Okemos, MI, 2004.
4. http://www.officeofroadsafety.wa.gov.au/Facts/dd_brochure/what_is_bac.htm, accessed September 14, 2006.