Cost Effective Experiments in Chemical Engineering Core Courses

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Abstract

Through funding of National Science Foundation we have developed some novel experiments that present process science principles suitable for a variety of chemical engineering core courses. These experiments are cost effective and represent some of the emerging areas: polymer processing, food processing, environmental reactor design, fluidization, membrane separation. These experiments have been utilized by chemical engineering faculty at a unique hands-on industrially integrated NSF workshop on Novel Process Science and Engineering conducted at Rowan University. We have integrated these experiments into our curriculum so that students can see chemical engineering principles in action and therefore improve the quality of education.

Introduction

Hands-on laboratory experience is a critical element in undergraduate chemical engineering education [Par94, Gri97]. Chemical engineering programs are often confronted with how to more effectively integrate the experimental experience more widely across the curriculum in a cost-effective manor. Some departments are also challenged with bringing laboratory experience into the Freshman year. Others are interested in presenting advanced technology or emerging fields through laboratory experiments.

Typically chemical engineering laboratory experiments are presented in a Senior-level unit operations laboratory. In this setting students gain experience with many of the processes that are presented in various previous courses in the curriculum, e.g. heat exchanger, distillation column, extraction column, filter press, reverse osmosis system. In the majority of cases these are pilot-scale process units that are quite expensive and complex. A pilot scale distillation system for student costs nominally more than $100K. These experiments serve the role to give students a more realistic depiction of actual processing equipment.

At Rowan we believe that it is important to integrate laboratory experience throughout our curriculum in courses that make sense pedagogically [Hes97a,b, Hes98]. These "course labs" occurs in several places and typically use a bench-scale experiment that can be performed within 2 hours. We also have multiple laboratory set-ups [Sla96] to facilitate an experimental period being conducted with a multiple groups of students running the same experiment.

To facilitate a laboratory program of this nature the time, scale, complexity and cost must all be optimized and matched to the appropriate experimental setting. What we are describing in this paper is the first step in our laboratory development efforts. We will present overviews of some of the experiments we have developed and have utilized in chemical engineering courses and those successfully employed in a recent National Science Foundation Undergraduate Faculty Enhancement Workshop on Novel Process Science and Engineering. More thorough papers on each of the lab experiments described will be presented at ASEE Regional and Annual Conferences in addition to being published in appropriate journals.

This paper does not attempt to review the literature on the subject of small-scale cost-effective experiments. Many papers have been presented at ASEE and AIChE Annual conference and published in Chemical Engineering Education. Our developments from our NSF Workshop and through our coursework will be described.

Before we present the experimental descriptions we will briefly describe the NSF project that funded some of our laboratory development efforts. NSF project DUE-9752789 supports two hands-on, industry integrated workshops that will have a major impact on upper and lower level engineering, technology and science instruction. One workshop was held July 1998 and another one is scheduled for July 1999. Participants gain experience in novel process engineering through hands-on laboratories, industry experts, and interactive demonstrations [Sla99a,b].

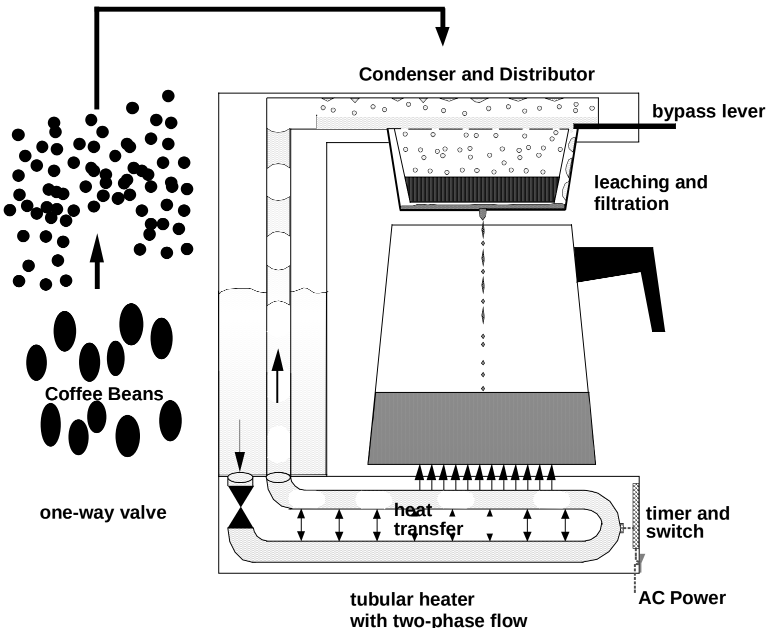
The overall philosophy of each one week workshop is to give the faculty participants hands-on experiences in state-of-the-art process engineering [Ame96]. Each day contains laboratory experiments, computer simulations, cooperative learning exercises and essential lectures. The central portion of the workshop integrates industrial experts from new and emerging fields into the laboratories, teamwork exercises, and lectures. The final day of the workshop is devoted to incorporating the participants' experience with leading-edge process engineering gained from this workshop into their home institution's curriculum.

Through industry involvement from 10 process engineering companies, faculty were given an initial networking base. Companies contributing industrial speakers include Sony Music, Inductotherm, DuPont Engineering, Chemical Industry Council of New Jersey, Cochrane, Tasty Baking Co., DuPont Pharmaceuticals, DuPont Nylon, Hyprotech, and Mobil Technology Co.

Over half of the workshop was devoted to integrated lecture-laboratory sessions designed in consultation with experts from industry. Through these activities the participants learn about processes and how they can in turn use the laboratory experiments with their students at their home institutions. These cost effective experiments are suitable for integration into lower level introductory courses or more advanced laboratories. Some can even be used as recruitment tools for pre-college students. Therefore, this project will have an additional impact on pre-college students and teachers since faculty participants will use these experiments in outreach activities.

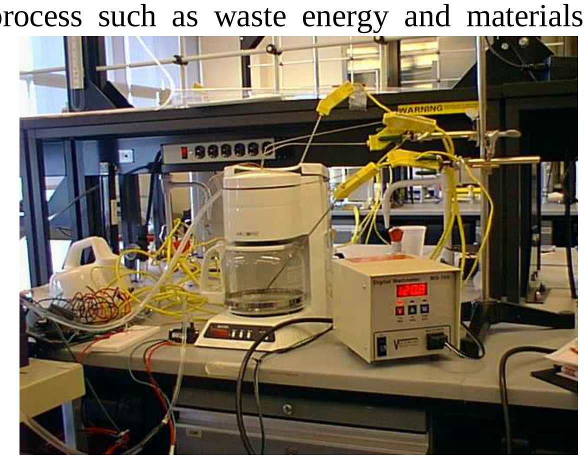
The bench-scale experiments used at the workshop were a coffee maker, reverse osmosis system, catalytic reactor, breadmaker, fluidized bed polymer coating process. These experiments present a cost-effective and time efficient approach to engineering experimentation. Advanced instrumentation and data acquisition will be employed in these experiments where appropriate. These experiments are summarized below.

Coffee Maker Experiments



Most traditional experiments and demonstrations of a complete engineering process are very complex and require an investment of time by students to familiarize themselves with each component of the process. Hesketh has shown how the novel use of an automatic coffeemaker [Hes96] dramatically reduces the time required for a student to assimilate the fundamentals of engineering processes. Since nearly every household owns a coffeemaker, the initial unfamiliarity associated with most industrial processes is absent in using the coffeemaker. Through hands-on experiments, students see how this familiar device is an excellent vehicle for introducing a complete engineering process to lower division students. The professor can immediately discuss and demonstrate process variables that effect the quality and quantity of the final product. As an added benefit the students can give immediate sensory feedback on the process operation!

The coffee machine has examples from at least 8 engineering processes. These process operations are shown in above as; particle size reduction (grinding); tank efflux through a one-way valve; liquid heating in a tubular heater; upward two-phase flow in pipes; vapor condensation; liquid flow distribution and bypass; flow through a no-drip valve; leaching and filtration. Underlying these unit operations, there are fundamental principles of process engineering and engineering science such as: fluid flow - both single and 2-phase; heat transfer; thermodynamics ("engineering science" and equilibrium); mass transfer; particle technology; and general and organic chemistry. Detailed design topics such as materials of construction, engineering economics, process control, electronics and circuits are also shown using the coffee machine. Novel environmental aspects of this process such as waste energy and materials minimization can be analyzed.



A unique series of cost effective experiments used successfully at the Freshman level at Rowan University [Hes97a,b] is based on the Coffee maker. In the spring semester, a section of freshman students devote an entire semester reverse engineering a coffee maker. These laboratories reinforce the concept of process engineering and unit operations. The participants take apart a coffee maker to see how it works, identify the major components and speculate on the engineering principles.

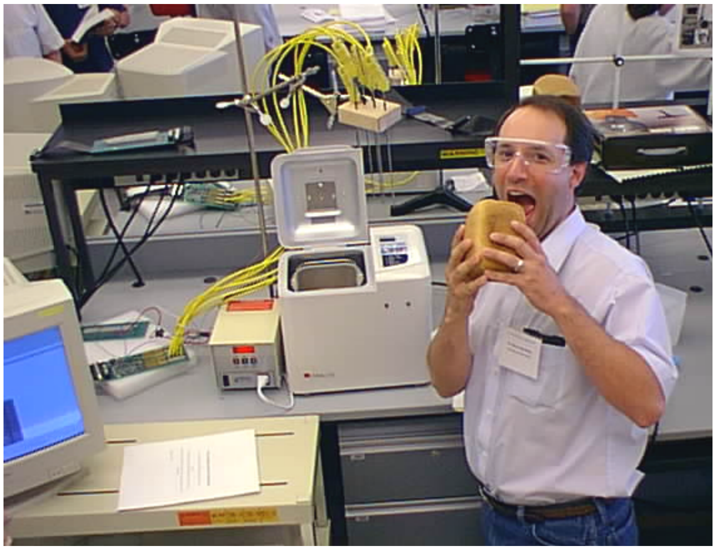
This Freshman Spring semester contains faculty led experiments and student designed experiments. The faculty led experiments consist of a series of non-intrusive experiments. In the non-intrusive experiment students measure the electrical power delivered to the coffee maker; the temperature of the liquid in the feed tank, exit of the leaching unit and the coffee carafe; and the flowrate from timed volume readings on the side of the reservoir. The second series of faculty driven experiments examine the rate of leaching of coffee. The effect of water temperature, particle size and concentration driving force was examined. Concentrations were determined from absorption measurements from a spectrometer and a data acquisition system. In a third set of experiments students examine the fluid mechanics by observing the two phase flow within a clear plastic riser tube; the function of the one-way valve; and measure the flowrate indirectly from pressure measurements in the reservoir. These experiments are relatively inexpensive and only require a $20 coffee machine and typical laboratory equipment.

The student driven and designed experiments start with dissection experiments and culminates in a completely instrumented coffee maker. The destructive experiments start by having the students take apart a coffee machine. A basic requirement for this activity is to obtain a screw driver set with security bits! Students examine the operation of thermal and electric switches, one-way valves, bypass valves, and no-drip valves. They measure the resistance of the tubular electric heater and cut them open to examine the coiled Nichrome wire. This experience ends with students placing thermocouples throughout the coffee machine, using a pressure transducer to measure pressure in the feed tank and a wattmeter to measure power to the coffee machine. All of these devices are connected to a computer controlled data acquisition system. The instrumented coffee machine experiment requires data acquisition boards, thermocouples, pressure transducers, wattmeter and a computer. The estimated cost of the setup shown in the photograph is $2,500 excluding the computer.

Reverse Osmosis

A cost-effective membrane experiment that has been developed by Stewart Slater is a small-scale reverse osmosis unit. Several versions of this experiment have been developed that use a variety of bench-scale units [Hes97b, Sla94a]. The experiment is suitable for an introductory chemical engineering material balance course and in a mass transfer / separation processes course [Sla94b]. We have successfully utilized this experiment in our NSF Novel Process Workshop and in our Separation Processes course.

This experiment shows the use of membrane technology in water purification and provides a way to easily introduce an advanced concept into the laboratory. The experiment uses a bench-scale reverse osmosis system, PUR Power Survivor-80E (Recovery Engineering, Minneapolis, MN) in which a blue dye salt water solution is separated to produce pure water. Students measure the separation efficiency and production rate of the membrane system. Students can determine the water and salt permeability coefficients and generate data that is useful in scale-up. The overall system including ancillary feed tanks and process modifications (pressure gauges) costs under $3000.



Breadmaker

Another experiment used at our NSF Novel Process Workshop was an automated bread maker. This experiment showed workshop participants how to teach heat transfer and data acquisition to a students, at the same time they are making something fun. The aroma of the bread baking in the lab also added to the interest. This cost-effective experiment consisted of faculty participants weighing out all of the raw materials and then "batching" them in an automated bread machine. The off-the-shelf unit was modified to accommodate thermocouples that measured the bread baking at different points. Additionally, power measurements were made on the unit. After the participants analyzed the profiles of the bread baking over time via the computer, they ate their product. Low end bread makers can now be obtained for approximately $50. The cost of the wattmeter and data acquisition system is about $2,000 (excluding computer).

Fluidized Bed Polymer Coating

Another cost-effective experiment that can be easily integrated into the curriculum is a "Fluidized Bed Polymer Coating Process." This experiment was utilized at our NSF Novel Process Workshop to show both the process engineering aspects of flow in packed and fluidized beds and a unique process of polymer coating. The experiment uses a small bench-scale packed bed with a polymer powder as the packing. Air flow through the bed and resulting pressure drops can be measured. Because the experiment uses a Plexiglas column with colored polymer powder as packing, participants can readily see the bed of solids become fluidized. The experiment is made even more interactive by the participants heating a substrate (metal washer) to be coated. The hot metal part is dipped into the fluidized bed and within seconds the object has a uniform polymer coating. The cost of fabricating the equipment for this experiment is about $830.

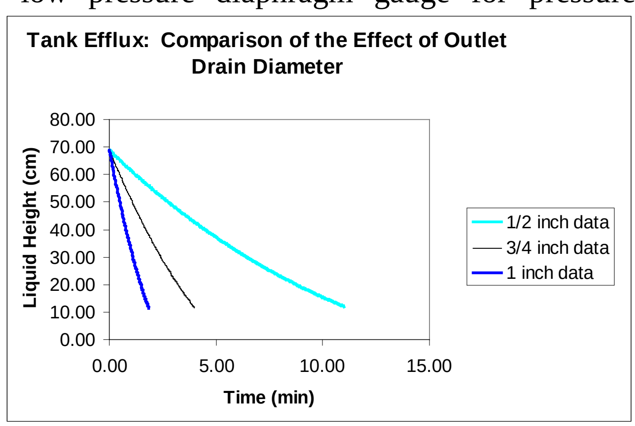
Catalytic Oxidation of VOC's

Our NSF Novel Process Workshop also featured the experiment "Catalytic Oxidation of Volatile Organic Compounds (VOCs)". This experiment used a tube furnace with a palladium catalyst similar to the catalytic converter in an automobile. The objectives of the experiment were to determine the reaction kinetics of propane oxidation by varying the propane concentration and reaction temperature. Process streams were analyzed on-line with an FTIR.

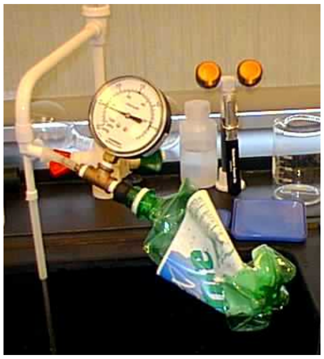
A major advantage of this experiment is that it does not have costly product and reactant disposal problems. The reactants are propane and air and the products are primarily carbon dioxide and water. These gases are easily disposed of using a common vent system. This experiment is also cost effective. It is inexpensive to run, since the primary reactant is propane and air and the energy source is electricity. The construction of the experiment is relatively simple. The reactor is a stainless steel tube with a section of a honeycomb monolith placed inside the reactor. The tube is heated using an electric furnace. The most expensive item is the gas analysis system starting with a relatively low cost on-line FID detector to a more expensive gas chromatograph or FTIR system. The cost of this experiment is about $5,000 which includes the cost of a nearly $3,000 furnace. The cost not included in this figure is the analytical measurement device. If an NDIR analyzer for hydrocarbons is used the cost can be as low as $7,000. Details of this experiment are given in a companion paper in the ASEE 1999 conference [Hes99].

Tank Efflux or Pressure Measurement Devices

The tank efflux experiment introduced by Perna [Per96] was modified to have students investigate pressure measurement devices. In this experiment experiment, students calibrate and use a pressure transducer, sight gauge and low pressure diaphragm gauge for pressure measurements. Using a data acquisition system students measure the pressure of water within a 30 gallon tank. As students fill the tank they calibrate the pressure transducer using a sight gauge mounted on the side of the tank. Next students perform three experiments using a 1/2, 3/4 and 1" outlet drain. In this experiment the slope of height as a function of time, obtained from a mass balance $\frac{dm_{tank}}{dt} = \frac{d(\rho A_{tank} h)}{dt} = -\dot{m}_{out}$



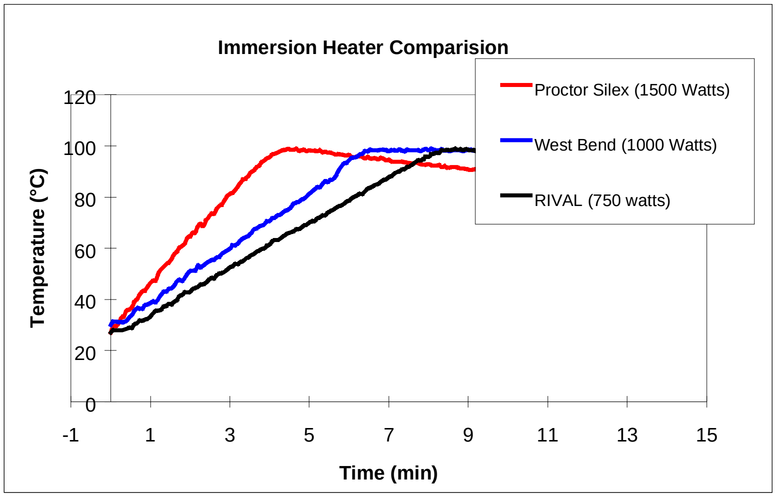
The students transform their data to fit an approximate solution of the above equation assuming that there are no pressure losses in the system. A typical plot generated through this experiment is shown here. This assumption results in the solution of the above equation to be a function of the square root of the height of liquid in the tank. Students examine the error in pressure measurement devices by comparing readings from the sight gauge, diaphragm pressure gauge and pressure transducer. The Nalgene tank costs $103 and the pressure gauge is $57 and the transducer is $138.



To complete the series of pressure measurement experiments a 2-L soda bottle implosion experiment is used to graphically show the effect of vacuum. The equipment consists of a sink-mounted vacuum aspirator, a standard 2-L PTFE, (polyethylene terephthalate) bottle and a vacuum gauge. The students observe the pressure and convert vacuum pressures to gauge and absolute pressures. The experiment is also fun! Students love destroying objects and the sound effects are great. The Nalgene aspirator cost is $8 and the vacuum gauge can be obtained for $32.

Simple Heat Transfer Experiments: Temperature Measurement

In the immersion heater experiment, students measure the temperature of water in an electric kettle heater and the power supplied to this heater. This experiment can be used to introduce students to both heat transfer and temperature measurement. A data acquisition system is used to measure temperature and the power is measured using a Digital Wattmeter. An energy balance on this system, assuming the heat losses from the water are negligible is given by $mC_p^{liq}\frac{\mathrm{d}T}{\mathrm{d}t} = Q_{in} - 0$ From the results of this experiment, students are able to compare the rated power, power delivered to the immersion heater and the power calculated from the regression of the solution of the differential equation with their data. As you can see from the plot the assumption of negligible heat losses is excellent. The students are able to easily integrate this expression and obtain an engineering prediction of the time required to heat 1 L of water using an immersion heater. The cost of this experiment includes $20 for the immersion heater and $1,400 for a data acquisition system and thermocouple and interface card. This experiment could also be done by hand using a thermometer and a stop watch.



Mixing Experiments

"Mixing in the Process Industries" was a combined lecture-demonstration presented by Dr. Arthur Etchells of the DuPont Company at our NSF Process Workshop. His presentation focused on the many applications that mixing has for multiphase processing. Dr. Etchells included a demonstration in his seminar which illustrated the minimum speed required for particle suspension and a second demonstration examining reaction time versus mixing time. Several key areas of mixing as applied to the products manufactured by DuPont were discussed. The Lightnin Lab Master mixer can be obtained for approximately $1,500. The tank can normally be fabricated in-house. This makes a great experiment for a fluid mechanics/transport class or process component design course.

Acknowledgements

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Biographical Information

C. Stewart Slater is Professor and Chair of Chemical Engineering at Rowan University. He received his B.S., M.S. and Ph.D. from Rutgers University. Prior to joining Rowan he was Professor of Chemical Engineering at Manhattan College where he was active in chemical engineering curriculum development and established a laboratory for advanced separation processes with the support of the National Science Foundation and industry. Dr. Slater's research and teaching interests are in separation and purification technology, laboratory development, and investigating novel processes for interdisciplinary fields such as biotechnology and environmental engineering. He has authored over 70 papers and several book chapters. Dr. Slater has been active in ASEE, having served as Program Chair and Director of the Chemical Engineering Division and has held every office in the DELOS Division. Dr. Slater has received numerous national awards including the 1999 Chester Carlson Award, 1999 and 1998 Joseph J. Martin Award, 1996 George Westinghouse Award, 1992 John Fluke Award, 1992 DELOS Best Paper Award and 1989 Dow Outstanding Young Faculty Award.

Robert Hesketh is Associate Professor of Chemical Engineering at Rowan University. He received his B.S. in 1982 from the University of Illinois and his Ph.D. from the University of Delaware in 1987. After his Ph.D. he conducted research at the University of Cambridge, England. Prior to joining the faculty at Rowan in 1996 he was a faculty member of the University of Tulsa. Robert's research is in the chemistry of gaseous pollutant formation and destruction related to combustion processes. Nitrogen compounds are of particular environmental concern because they are the principal source of NO_X in exhaust gases from many combustion devices. This research is focused on first deriving reaction pathways for combustion of nitrogen contained in fuel and second to use these pathways to reduce NO_X production. Robert employs cooperative learning techniques in his classes. His teaching experience ranges from graduate level courses to 9th grade students in an Engineering Summer Camp funded by the NSF. Robert's dedication to teaching has been rewarded by receiving several educational awards including the 1999 Ray W. Fahien Award, 1998 Dow Outstanding New Faculty Award, the 1999 and 1998 Joseph J. Martin Award, and four teaching awards.